DESIGN AND DEVELOPMENT OF AN UNMANNED UNDERWATER REMOTELY OPERATED VEHICLE (ROV) FOR UNDERWATER INSPECTION

TEOH YI XIN

BACHELOR OF MECHATRONICS ENGINEERING WITH HONOURS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DESIGN AND DEVELOPMENT OF AN UNMANNED UNDERWATER REMOTELY OPERATED VEHICLE (ROV) FOR UNDERWATER INSPECTION

TEOH YI XIN

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in partial fulfilment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "DESIGN AND DEVELOPMENT OF AN UNMANNED UNDERWATER REMOTELY OPERATED VEHICLE (ROV) FOR UNDERWATER INSPECTION is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : Xin

Name : TEOH YI XIN

Date : 23/6/2024

APPROVAL

I hereby declare that I have checked this report entitled " DESIGN AND DEVELOPMENT OF AN UNMANNED UNDERWATER REMOTELY OPERATED VEHICLE (ROV) FOR UNDERWATER INSPECTION ", and in my opinion, this thesis fulfils the partial requirement to be awarded the degree of Bachelor of Mechatronics Engineering with Honours

Signature	:	
Supervisor Name	:	PROFESOR MADYA DR MOHD SHAHRIEEL BIN MOHD ARAS
Date	:	23/6/2024

DEDICATIONS

To my beloved supervisor, panels, course mates, friends, and family members.

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ABSTRACT

The exploration of the world's oceans has always been a huge interest for scientists, engineers, and enthusiasts. It ranges from the exploration of marine biodiversity and the study of fragile ecosystems to the inspection of submerged infrastructures. However, underwater exploration has always been a very dangerous task and only trained professionals and divers are able to perform such tasks resulting in very slow progress in the exploration of the world's oceans. Because of that, there has been an increasing demand for safe, effective, and cost-efficient methods or systems that allow advancements and improvements regarding underwater exploration. Hence, this project aims for the design and development an Unmanned Underwater Remotely Operated Underwater vehicle (ROV) for underwater inspections. The goal of this project is for the design and development the 4-degree of freedom ROV which able to perform basic underwater tasks by optimizing its equipment and providing data that can be analysed and understood to its user. The designed propulsion system consists of a four-thrusters configuration for better manoeuvrability of ROV. The performance of ROV will be evaluated in terms of factors in terms of stability, buoyancy, velocity, and acceleration. This project, on the other hand, will have an overall prototype created by using Fusion 360. The body frame of ROV is illustrated in Fusion 360 and it will be ready for laser cutting after completing the finite elements analysis. This step is crucial for ensuring the frame designed is able to withstand the underwater pressure until the maximum rate of 5 meters underwater. The project output involves strong aesthetic acrylic based frame underwater ROV with designed negative 90% buoyancy for manoeuvrability, along with sensors, cameras and waterproof electric housing to allow full functionality. Arduino Uno will be used for the Computer Control System to ensure that the ROV can be operated along with sensors and a camera that supports live camera feeds.

ABSTRAK

Penerokaan ke dasar lautan merupakan satu kajian yang agung bagi saintis, jurutera dan orang yang pakar terhadap bidang laut. Penjelajahan lautan merangkumi bidang penerokaan biodiversiti marin, kajian ekosistem yang rapuh sehingga kepada pemeriksaan infrastruktur yang telah tenggelam dalam laut. Walau bagaimanapun, penerokaan ke dasar lautan merupakan suatu tugas yang sangat berbahaya dan hanya profesional dan penyelam yang terlatih dapat melaksanakan tugas. Hal ini telah meningkatkan permintaan terhadap pencarian suatu kaedah atau sistem yang selamat, berkesan lagi menjimatkan kos yang mampu membantu manusia dalam melaksanakan penyelidikan bawah lautan. Keadaan ini telah menyebabkan penciptaan kenderaan kawalan jauh bawah air (ROV) yang menyumbang besar terhadap industri marin terutamanya dalam melaksanakan kerja pemerhatian dan penerokaan bawah air. Matlamat projek ini adalah untuk mereka bentuk dan pembangunan ROV yang mempunyai 4 darjah kebebasan yang dapat melaksanakan tugas dalam air dengan peralatannya dan mampu mengumpulkan data untuk tujuan analisis dan tafsiran. Sistem pendorong yang direka bentuk terdiri daripada konfigurasi empat pendorong untuk kebolehgerakan ROV yang berprestasi tinggi. Prestasi ROV akan dinilai dari segi faktor kestabilan, daya apungan, halaju dan pecutan. Projek ini, sebaliknya, akan mempunyai prototaip keseluruhan yang direka dengan menggunakan Fusion 360. Rangka bentuk ROV yang direka dalam Fusion 360 akan dihasilkan melalui teknik pemotongan laser selepas berjaya dianalisis dengan Fusion 360 . Langkah ini penting untuk memastikan rangka yang direka mampu menahan tekanan bawah air sehingga kadar maksimum 5 meter di bawah air. Hasilan projek melibatkan rangka ROV bawah air berasaskan akrilik estetik yang kukuh dengan daya apungan yang direka bentuk negatif 90% keapungan untuk kebolehgerakan, bersama-sama dengan penderia, kamera dan perumah elektrik yang kalis air untuk menyempurnakan fungsi ROV. Arduino Uno akan digunakan untuk Sistem Kawalan Komputer bagi memastikan ROV boleh dikendalikan bersama dengan penderia dan kamera yang berfungsi siaran secara langsung.

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LIST OF SYMBOLS AND ABBREVIATIONS

ROV	-	Remotely Operated Vehicles
UTeM	-	Universiti Teknikal Malaysia Melaka
DOF	-	Degree of Freedom
L	-	Length
W	-	Width
H	-	Height
FEA	-	Finite Element Analysis
FYP	-	Final Year Project
PVC	-	Polyvinyl Chloride
TMS	-	Tether Management System

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CHAPTER 1

INTRODUCTION

1.1 Background

Underwater ROVs are submersible robotic systems, used to observe the depths of large bodies of water by operators from shore, or by divers in the water [1]. They allow us to explore the ocean without being in the ocean while being controlled by a person with a group of cables or tether, allowing electrical signals to be sent back and forth between the operator and the vehicle. At most cases, ROV operations are simpler and safer to conducting diving operations because operators can stay safe on ship decks while still allowing investigation of areas that are too deep for humans to safely dive themselves, and ROVs can stay underwater much longer than a human diver, expanding the time available for exploration. Although in practicality, the oil and gas industry use the majority of ROVs, many other departments can still ROV to be useful in various applications including science, military, and salvaging [2].

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ROV's are typically built using light and sturdy materials such as aluminium for their chassis with a large flotation pack attached on top of it in order achieve and maintain a certain level of buoyancy for underwater manoeuvrability. Occasionally, synthetic foam is also used as a floatation material. Most ROV's are designed with heavier components to be closer to the bottom of the structure in order to maintain stability of the ROV. However, different ROV's are designed ever so slightly different from each other in order to fulfil different tasks for different users and companies.

Figure 1.1: Work Class ROV with an Open Box Frame ROV design. **[3]**

Generally, Underwater ROVs are equipped with cameras, light, manipulators, thrusters, and robotic arms to perform basic underwater tasks [3] while also having some outer structure as protection against collision. Whereas important electrical components can be stored in compartments that are filled with oil or atmosphere compartments to prevent any sort of damage by seawater corrosion or the pressure from exposure underwater.

Figure 1.2: Torpedo Shaped ROV [5]

Aside from modifications and equipment attached on the ROV, they typically come in two types of different configurations with their own pros and cons to be chosen by the users based on how they are meant to be used. With Figure 1.1 showing an example of an open box frame ROV which only has important components such as sensors and thrusters enclosed for a lower budget and simpler design that is able to handle basic underwater tasks, the downside however is that box frame ROVs are not suitable for towed applications due to their very poor hydrodynamic design. Which led to the design of the other configuration, which is the Torpedo shaped ROV (Shown in Figure 1.2) that offers extremely low hydrodynamic resistance with the cost of control limitations and difficulty to control. The Torpedo Shaped ROV needs to be moving at high speeds in order to remain positionally and attitudinally stable, but by doing so also makes it very vulnerable to collisions and accidents. Therefore, the user might require a certain level of experience with operating Torpedo shaped ROVs in order to make full use of its features.

Figure 1.3: Observation Class ROV (Seaeye Falcon) [4]

Observation-class ROVs are generally designed with a lighter usage in mind that is equipped with propulsion systems to deliver a camera and sensor package to achieve a balance between budget and simplicity but also to provide a meaningful picture or gather data. Nowadays, observation-class ROVs enable these systems to do more than just providing live camera feedback and photos. With its tooling package and many accessories, the observation-class ROV is able to deliver payload packages of instrumentation, intervention equipment, and underwater navigational aids, enabling them to perform as a full-function underwater vehicle [5]. Making it ideal for casual and basic underwater operations.

1.2 Motivation

Underwater operations are extremely dangerous especially under the harsh conditions of deep seas. With plenty of factors and causes that can directly and indirectly cause injuries or even deaths. Including poor gas management by human divers, human error, poor buoyancy control, equipment misuse, entrapment, rough water conditions and diver's health problems. In some cases, unforeseeable occurrences like underwater turbulences, earthquakes can result in the situation escalating out of control [5].

One of the most notable cases of underwater operation accidents would be the Byford Dolphin accident that occurred in 1983, where a mistake by one of the divers resulted in instant decompression of an underwater chamber resulting in the death of four divers [6] to remind the risks of having human operators performing tasks underwater.

Manned vehicles in comparison to unmanned vehicles like underwater ROVs are also quite dangerous, although the human operator is not directly exposed to the harsh conditions underwater. Mechanical failures of the vehicle can definitely put the operator in a risky situation. A notable example would be the Ocean gate Titan submersible implosion incident that happened in June 2023, where the pressure hull failure of a submarine caused it to implode and kill five of its passengers instantly. Of which an ROV was deployed later after the incident to discover the debris of the submarine to determine the cause of the accident and retrieve photos.

These incidents are the motivations behind the design of an observation ROV, in hopes to replace human operators with unmanned vehicles to eliminate the risk of losing lives while conducting dangerous operations. As long as manned vehicles are still being used, there is a risk for deadly accidents to occur again in just a matter of time. And only the use of underwater ROVs can avoid such fatalities from happening again.

1.3 Problem Statement

The rapid growth of demand from these energy and petrol industries directly translates to more projects involving harvesting natural energy and resources such as fossil fuels. Which include oil rigs and mines. However, a lot of tasks from these oil rigs are underwater operations that requires the workers to be exposed underwater [7]. Where there has been a lot of recorded cases for injuries and fatalities from preventable accidents such as the incidents that are mentioned above.

Besides hazardous environments that threatens the life of the divers. The costing of a company for paying the salary to the divers can be higher depending on types of tasks. Mostly company cannot afford to paying the workers for a long period especially when they are involved in inspection and monitoring task that might take longer time to complete their job. Therefore, proper ROVs and unmanned vehicles have been created over the years to replace humans to remove them from the risks of these tasks. However, some underwater robots are extremely high cost and having multifunction more than necessary for some research company that just aimed for inspection purpose. Hence, it is important to design and develop a low cost unmanned underwater remotely operated vehicle (ROV) for inspection purposes. This can extremely help the small business company, educational organizations, research group able to access to underwater inspection technology with limited budgets.

Due to the unpredictability of the underwater conditions, the ROV must be able to handle itself in terrible working conditions underwater. However, The ROV is hard to perform tasks such as inspections and data collection at specific depths [8]. Therefore, underwater ROVs must have the ability to maintain its depth and not be swayed by the underwater currents and waves easily. ROVs are also meant for monitoring operations in place of humans, by being able to maintain its level of depth can allow for proper monitoring without disruptions.

An underwater ROV must also be stable and buoyant in order to allow optimum manoeuvrability underwater, so that it can perform its desired tasks efficiently. Besides, the well-functionality of ROV is mainly affected by its waterproof characteristics and materials of frame body. All while not sacrificing its ability to accelerate and maintain its velocity to move around underwater. The stability, velocity and acceleration of ROV is important to make sure a ROV is able to carry out underwater tasks effectively and successfully [9].

1.4 Objectives

1) To design and develop a well functionality of negativity 90% buoyancy ROV with a strong, aesthetic acrylic frame and perfectly waterproof electric housing.

2) To study and evaluate the performance of 4-degree manoeuvrability of ROV in in terms of stability, buoyancy, velocity and acceleration for monitoring application.

1.5 Project Scopes

1) This ROV prototype created only be used to undergoes surveillances until the sea deep of 5 meters.
2) The ROV prototype is tethered controlled.
3) The length of the neutrally buoyancy cable used is 15 meters.
4) The ROV propulsion system is consists of 4 thrusters.
5) The ROV will be equipped with simple accessories such as simple control system to monitoring its movement underwater and surveillances application for observing the underwater situations.
6) The place selected for testing the performance of ROV is controllable environment which is control environment at laboratory pool and swimming pool.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to the Marine Society, there are two key figures that played a significant role in the creation and design of modern ROVs. The very first underwater vehicle created with similar ideas like the ROV was developed by as Austrian named Luppis-Whitehead Automobile, who have developed the first Programmed Underwater Vehicle (PUV) that has been recorded to be able to propel itself in water. Whereas the creation of modern underwater ROVs dates back to 1953 where the very first modern tethered ROV named POODLE was developed by Dimitri Rebikoff, inspired by the PUV created by Luppis-Whitehead Automobile from back then [10].

ROV technology started to take off in the 1960s when the US Navy developed an interest in deep sea exploration. The first ROVs were created for search and rescue operations in deep or dangerous waters. An example would be the exploration of wreckage such as the R.M.S Titanic that sank more than a century ago, which humans are not able to inspect or perform any discoveries about it up close until the creation and use of modern ROVs [11].

In just a few decades into the 1980s, ROV technology starts to get commercialized for companies and private use, where it has found itself to be a valuable asset for the oil and gas industries. And in the past 40 years since its invention, there are more and more companies and government departments that have started using ROV technology for their own advantages.

2.2 Explanation of Manned Vehicles & Unmanned Vehicles

Submersible vehicles cover a very broad range of vehicles ranging from manned vehicles such as submarines to unmanned vehicles like ROVs and Autonomous Underwater Vehicles (AUVs). While the difference between ROVs and AUVs with manned vehicles is obvious, being that ROVs and AUVs do not need the operator to be directly in the vehicle while operating the vehicle. It makes the advantages and desirability of unmanned vehicles like the ROV extremely transparent, which is to ensure the operator's safety during underwater missions. Unmanned vehicles are also generally smaller in size compared to manned vehicles as they are only designed for optimum underwater exploration, and there is no need to make space to fit human operators within the vehicle. Due to the smaller size, it makes it more efficient and nimbler under the seawater during exploration missions.

While the difference between unmanned vehicles, the ROV and the AUV is that ROVs are tethered and directly connected to the surface for communications and power whereas AUVs are untethered, making it cable free as it runs on a pre-programmed or login-driven course [12].

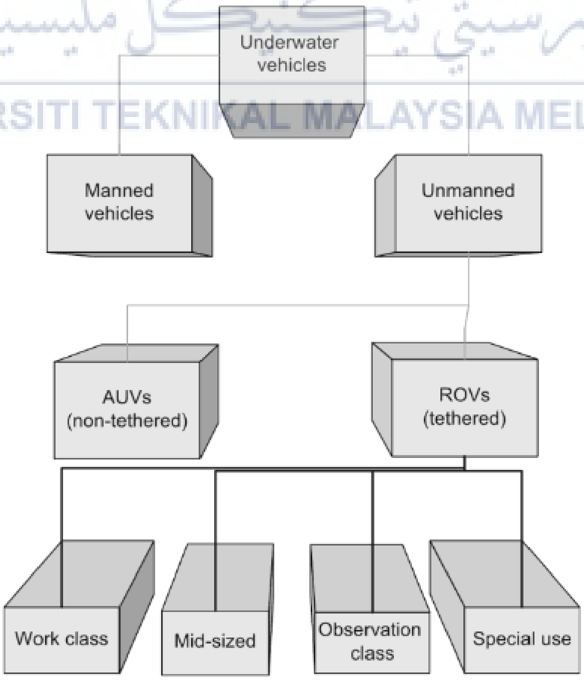


Figure 2.1: Manned Vehicles and Unmanned Vehicles [12]

2.3 Common Classification of ROVs

Generally, submersible ROVs are categorized into several different classes depending on their weight, size, capabilities, and horsepower. Some common classes of underwater ROVs are:

1. Class I: Observation ROVs
2. Class II: Observation ROVs with Payload Option
3. Class III: Work Class Vehicles
4. Class IV: Towed and bottom-crawling vehicles.
5. Class V: Prototypes or development vehicles.

CLASS I: Observation ROVs

Involves small sized submersible vehicles that are fitted with basic equipment such as cameras, lights, thrusters, and sonar. It is mainly used for observation purposes only, hence the name. Due to their small size and simple design, these types of ROV are usually limited to depth ratings as deeper parts of the seawater may have underwater turbulence or extreme pressures that could damage the components of the ROV. These ROVs are also usually hand launched.

Figure 2.2: A small sized Observation ROV [13]

Class II: Observation ROV with Payload Option

Involves submersible vehicles that are slightly larger than normal Observation ROVs, it can fit up to two cameras simultaneously, sonar, and is capable of handling additional sensors without disruption or compromising any of its functionality. It is also generally equipped with more durable pressure holdings. Because of this, ROVs in this class are usually better equipped for a higher depth rating as they have sufficient strength and manoeuvrability to operate under deeper parts in the sea for longer periods of time. Due to the weight of these ROVs, a launch and recovery system and a tether system will be required [13].

Figure 2.3: Observation ROV with Payload Option [13]

Class III: Work Class Vehicles

Involves large vehicles that can carry additional sensors and manipulators. It is noticeably larger, heavier, and more powerful than the previous two classes of Observation ROVs. These ROVs are usually running on high voltage (>3000V) AC circuits from the surface to the vehicle where the power delivered are changed to hydraulic powers immediately for locomotion functions.

Figure 2.4: A Work Class ROV (WCROV) [13]

Class IV: Towed vehicles and bottom-crawling vehicles

Involves vehicles that navigate by being pulled through the water by a surface craft or winch, and bottom-crawling vehicles that utilize wheel systems to move across the seafloor. They are larger in size than average Work Class Vehicles, and they are most suitable for complicated tasks such as dredging, excavation, and other construction works [14].

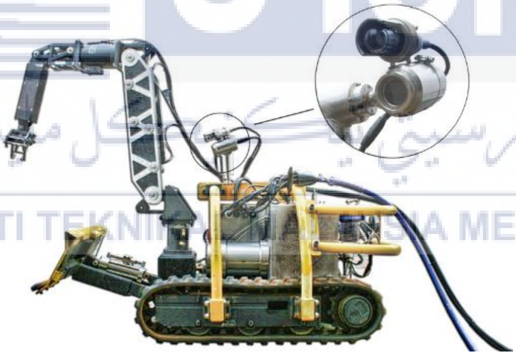


Figure 2.5: A bottom-crawling vehicle [13]

Class V: Prototype Vehicles and Development Vehicles

Involves vehicles that are not officially released as ready to use products, they are usually submersible vehicles that are not market ready or have designs that are way too niche to be viable for the majority of the users.

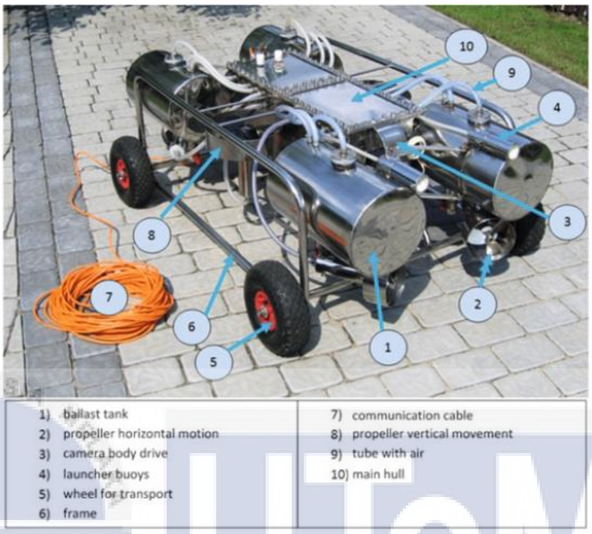


Figure 2.6: An example of a prototype vehicle **[13]**

2.4 Decision on categorizing designed ROV

With reference to all the different classes of ROV shown above, for this project, Class V: Prototype Vehicles and Development Vehicles from the explanation 2.3 will be chosen and designed to fulfil the task of exploring shallow parts of the sea. The criteria of prototype ROV that will be designed required the characteristics shown as table below.

Table 2.1: Characteristics of Prototype of ROV that will be designed in this project.

Characteristics	**Explanation**
Size Category	Prototype Vehicles & Development Vehicles
Vehicle Power	Low voltage DC
Telemetry Type	Neutral buoyancy tether
Depth rating	5 meters underwater
Launch method	Hand deployed
TMS (Tether Management System)	No
Thruster	Electric
Tooling Fluid Flow	Electric only

2.5 Designation of Submersible ROV

There are several factors that need to be considered while constructing an OCROV. Aside from its structural design, it is necessary to consider the choice and design of:

a. Material (Frame Body)

b. Pressure Hulls (Electric Housing)

c. Buoyancy and stability

d. Thrusters

e. Tether

2.5.1 Material (Frame Body) Options

The frame is the structural skeleton of the ROV, which can be created in various shapes and designs using different materials that can determine how the vehicle will be manoeuvring underwater as well as many of its characteristics, whether how heavy it will be, how well it floats and moves around underwater, are all heavily reliant on the type of frame body. Therefore, it is very important to consider a suitable material and design for the ROV frame.

For the project, materials that are easy to manufacture into a suitable shape and design will be highly desired to be used for ROV. As there is a very high probability that the materials will be designed and created within our university areas. Not only that, the material chosen must also be highly durable in order to handle the weights of the electrical components and devices attached to it, so that it doesn't get deformed from its own weight. It should also be able to sustain minor bumps from rocks and sands so that it doesn't break easily while being operated underwater. Lastly, the material should not be too heavy for it to move and float freely underwater.

The most common materials used for underwater ROVs are aluminium, titanium, stainless steel, and plastics. Anodized aluminium offers great durability and corrosion resistance for a relatively low weight. Making it suitable for use in marine environments as it can withstand corrosion caused by saline seawater and it being lightweight helps with the ROV's ability to move freely underwater. However, anodized coatings on the aluminium might wear off under abrasive conditions, making it less durable against impacts during an operation [15].

On the other hand, Titanium is exceptionally strong, lightweight, and corrosion-resistant, even in deep-sea environments. Making it a better option that aluminium in almost every part, except for its price. As titanium is far more expensive than aluminium, and also harder to modify into the desired shapes and designs due to its exceptional strength.

Stainless steel is corrosion-resistant and offers good strength. It's suitable for components that require high strength and resistance to corrosion, such as fasteners, connectors, and certain structural parts. By using stainless steel, the ROV's durability in general can be enhanced. However, stainless steel is heavier than aluminium and titanium, which might affect the buoyancy and ROV's ability to move nimbly underwater. Stainless steel might also be expensive, as it requires extra surface treatments such as electroplating for optimal corrosion resistance [15].

Plastics on the other hand, offer a good balance of strength, weight, and corrosion resistance. They also act as great water insulators to make sure that electrical components and other critical parts in the ROV are safe from the corrosive seawater. However, building an ROV on just plastic might have limitations in terms of depth capability, as it is still nowhere as strong as metals.

As both aluminium and plastic offer great strength and corrosion resistance for a fair budget. While also having corrosion resistant properties, these two material options are highly preferred for the design of ROV in this project.

Another material that is suitable for underwater ROVs is acrylic, which is advantageous and desired due to it being extremely lightweight. Making it easy to install and also fulfils the weight requirements for the material choice of the ROV. Not only that, but it is also very durable as they are rated to be robust, shatter-resistant and is able withstand regular wear and tear and accidents. Acrylic is also resistant to UV rays and moisture, making it ideal for submerging underwater where it will be exposed to sunlight and moisture. The weakness of acrylic is its low heat resistance, they can crack or break if exposed to extreme temperatures and it gets brittle overtime when exposed to high temperatures [16]. But it does not matter for underwater ROVs because while its underwater there is rarely any situation where the temperature is too hot for the acrylic to face any degradation. Making it a very ideal option as the material used for the underwater ROV.

A comparison has been made between aluminium, HDPE, a type of plastic and acrylic to determine the pros and cons of building an ROV with it.

Table 2.2: Comparison of Frame Materials [14] **[16]**

Types of materials	Pros	Cons
Aluminium	• High strength • Rigid designation • Relatively cheap	• Heavy • Corrosion possibilities • Waterproof wields are tricky
HDPE	• Very light • Easily to collapse down for transportation • Easy to machine	• Not so strong • Expensive
Acrylic	• Lightweight • Durable • Resistant to UR rays and moisture	• Low heat resistant

2.5.1.1 Decision on Choosing Frame Body Material

As a result, the acrylic is the most suitable frame among all choices. This is due to the acrylic is the lighter materials which aiding in keeping the ROV's overall weight down, increasing the effectiveness of controllability and manoeuvrability of underwater ROV. Besides, acrylic frame is strong and durable enough for absorbing shocks when there might be happening collisions under sea environment. Furthermore, the ROV is corrosion and moisture resistance which make it longer lifespan when staying in saltwater environment. These characteristics make acrylic as a best choice for ROV frame especially in underwater inspection application where durability and resistance to harsh environments are critical factors.

2.5.2 Pressure Hulls (Electric Housing)

Pressure Hull is a structure that is responsible for maintaining the atmospheric pressure inside the ROV so that the components of the ROV will not get damaged, it also acts as a coating structure with good hydrodynamic efficiency. Generally, pressure hulls are designed to be cylindrical or spherical in shape [17] because unlike a flat surface, spherical shapes can allow the distribution of stress on the surface to be homogeneous while also reducing the hydrodynamic drag [18].

The hull material is another fundamental aspect that is widely considered, as picking a wrong poor or unsuitable material for pressure hull design is proven to introduce non-negligible peculiarities [19] [20]. In which case PolyMethyl MethAcrylate (PMMA) is one of the more desired materials as it allows for an appropriate balance between a fair budget, optical properties, and mechanical strength. On the other hand, a poorly designed pressure hull in terms of design or material choice can be problematic. As analyzed upon the pressure hull of an AUV model designed by FeelHippo, the structural choice of the pressure hull being a cylindrical shell crossed with equidistant rings and end caps have been found to be accountable for the uncertainties, and unmanageable details with appropriate safety coefficients. And in Figure 2.7 shows the three common ways that generic ductile resistant hulls can be damaged as a result of external pressure.

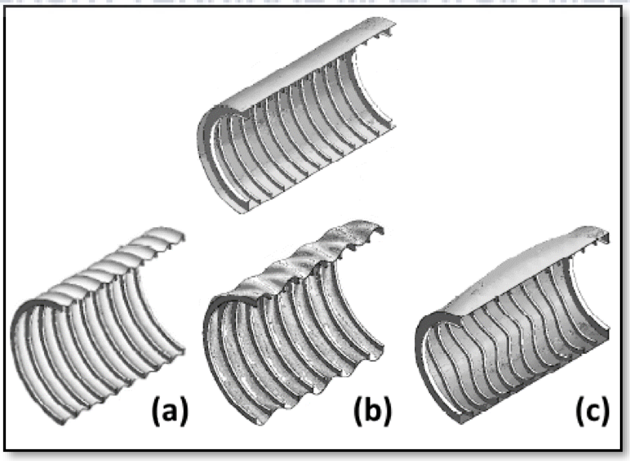


Figure 2.1: A cylindrical structure with non-deformed internal rings (on top), subjected to yielding (a), local instability (b), and general instability (c) **[18]**

However, in some ROV, the control system and electrical circuit is stored in pressure hull which is also known as electrical housing. The electrical components are stored inside the pressure hull for the sake of protecting it from high-pressure environment found underwater. Hence, the materials that chosen to be the electric housing must be robust and well-sealed to prevent the happening of water leakage which may damage the electronic parts.

Table 2.3: Comparison of Electric Housing Materials

Materials	Advantages	Disadvantages
Carbon Fiber	• Strong • Lightweight • Corrosion Resistance	• Expensive • Require specialized tools for fabrication • Brittle when there is collision
Aluminium	• High strength to weight ratio • Good thermal conductor	• More expensive • Require specialized tools for fabrication • May corrode if not do precaution properly
PVC (Polyvinyl Chloride)	• Low cost • Easy to fabricate • Corrosion and moisture resistance • Lightweight • Good electrical insulator	• Lower strength and durability under high pressure
Stainless Steel	• Very strong and durable • Excellent corrosion resistance	• Heavy • Expensive • Difficult to be shaped and welded

2.5.2.1 Decision on Choosing Electric Housing Material

In a conclusion, the PVC is chosen for the materials of electric housing. This is due to the reason of designed ROV is budget-constrained projects. PVC is relatively inexpensive among other materials such as stainless steel and aluminium. Besides, the ease of fabrication will make the custom designing of ROV become easier.

In the other hand, the ROV designed is for underwater inspection, Hence, the materials that been chosen must be fulfil the requirements of corrosion, moisture and chemical resistance. These characteristics making the ROV have long term durability when exposed to saltwater. Furthermore, the PVC is an excellent electrical insulator which is vital for protectimg the electronic components from any potential electrical shorts or interference.

Last but not least, although the PVC is not as strong as other materials such as titanium, but the PVC still provides sufficient strength for underwater inspection with the withstand able pressure, particularly at the depth of 5m underwater.

2.5.3 Buoyancy and Stability

2.5.3.1 Explanation of Stability

According to [21],buoyancy is known as upward force which determines whether an object will experience in floating or sinking state. There are three types of buoyancy which are positive buoyancy, negative buoyancy, and neutral buoyancy.

Positive buoyancy:

The buoyant force (volume of water displaced) is greater than the weight of the object. The object will float.

Negative buoyancy

The weight of the object is greater than the buoyant force (volume of water displaced). The object will sink.

Neutral buoyancy

The weight of the object is equal to the volume of fluid it displaces.

The object neither sinks nor rises but remains suspended at a specific depth in the fluid.

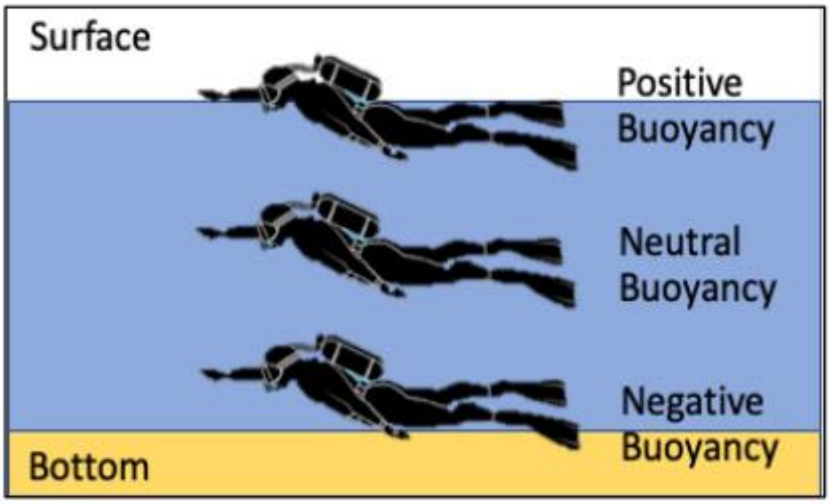


Figure 2.2:Three Types of Buoyancy **[21]**

A comparison for three types of buoyancy is shown in the table below.

Table 2.4: Comparison between three types of buoyancy.

Comparison	Positive Buoyancy	Neutral Buoyancy	Negative Buoyancy
Stability	Low, the ROV will continuously ascend and hard to going deep down to the sea unless counteracted by downwards forces.	Moderate, able to maintain good stability but still can be influenced by horizontal sea currents.	High stability, the sinking tendency of ROV able to maintain their position in the water column especially in turbulent condition.
Resistance to currents	Low resistance to currents.	Moderate resistance to currents.	High resistance to currents.
Energy efficiency	Low efficiency, high energy consumption to counteract the natural buoyant force of ROV.	High efficiency, energy is primarily used for horizontal movement and minor energy used un vertical movement.	Varied efficiency, energy consumption is needed to counteract the sinking force and manage the buoyancy of ROV effectively.

According to [22], it is stated that the aircraft carrier which is shown in below figure having the configuration of 300 m long and is heavily manufactured to carry about 70 airplanes and 4000 sailors.

Figure 2.3: Aircraft Carrier USS Enterprise **[22]**

However, that huge aircraft carrier is possible to float because of the theory of Archimedes' Principle. The situation can be more clarify with the illustration below.

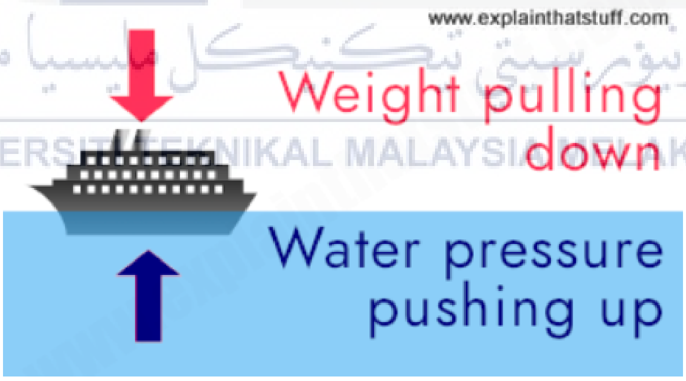


Figure 2.4: Illustration about upthrust force **[22]**.

When an aircraft carrier is placed in water, there is a net force which is known as upthrust supporting the boat from underneath. In the other hand, the boat sinks into the water, the aircraft carrier is pulled down by its own weight and simultaneously pushed up by the upthrust. The aircraft carrier will displace a certain volume of water equal to its own volume. The weight of the water displaced is equal to the weight of the aircraft carrier. Hence, the aircraft carrier will float due to the weight of the boat is less than the weight of the water it displaces.

2.5.3.2 Decision on Designed Buoyancy State of ROV

As a conclusion, the negative buoyancy is the best option for my designed ROV that aimed for underwater inspection. The negative buoyancy provides the best undersea stability which easier for ROV to maintain its position during inspection tasks. The risk of ROV being pushed upward by underwater currents will be reduced too. Furthermore, the ROV able to navigate safely around underwater environment with the minimized effect of vertical and horizontal drift.

2.5.3.3 Archimedes' Principle

The object that can float in water is based on the theory of Archimedes' Principle. According to [23], Archimedes' principle states that an object immersed in a fluid experiences a buoyant force that is equal in magnitude to the force of gravity on the displaced fluid."

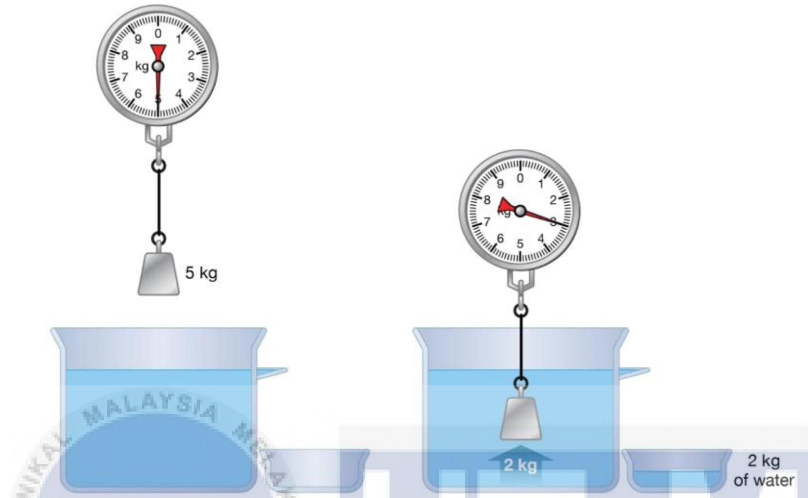


Figure 2.5:The Archimedes Principle **[23]**.

The formula related to buoyancy is based Archimedes' principle and can be expressed mathematically shown as below:

$$F_{\text{buoyant}} = \rho_{\text{fluid}} \cdot V_{\text{displaced}} \cdot g$$ [24]

$F_{buoyant}$ = buoyant force (in Newtons)

ρ_{fluid} = The density of the fluid (kg/m^3)

$V_{displaced}$ = Volume of the fluid displaced by the immersed object (m^3)

g = Acceleration due to gravity (approximately to 9.8m/s^2)

2.5.3.4 Ballast Tank (Optional Choices in ROV)

Static diving technology is the technique commonly used in submarines and other underwater vehicles. The static diving technology able to make an underwater vehicle maintain itself at a specific depth without actively controlling their buoyancy. Ballast tanks are integral to static diving. [25]

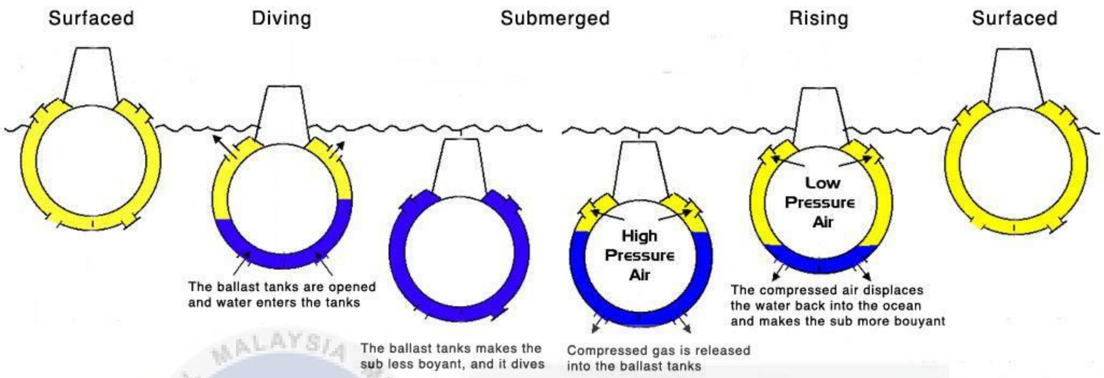


Figure 2.6: Depth controlling technique by using ballast tank **[25]**.

Ballast tank is functioned to control its depth when submerge into the water. When a ROV wants to submerge, the ballast tanks will be opened and filled with water. This can increase its density and causing the ROV to submerge. When the ROV is aimed to resurface, the ROV will pump air into the ballast tanks, causing the water to be displaced and the density of ROV will be reduced.

There are a few types of ballast tank that shown as below: [26]

1. Vented Ballast Tank

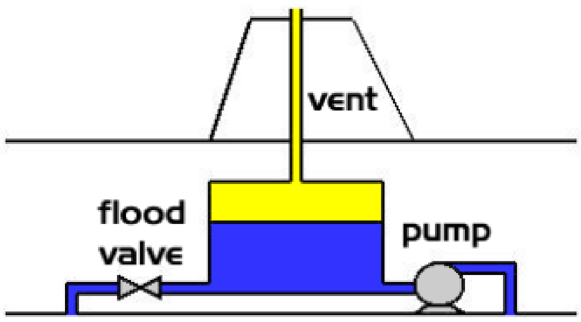


Figure 2.7: Vented Ballast Tank **[26]**

The buoyancy of the boat can be controlled from positive buoyancy to slightly positive (decks awash) with the help of vented tank. The air will escape through the vent and water will fill in the tank when the flood valve is opened. The tank will be emptied again by pumping water out of the tank when there is the air has been sucked back into the tank through the vent. There is requirement needed to be followed which is the top of the vent line must be above the water level.

2. Flexible Ballast Tank

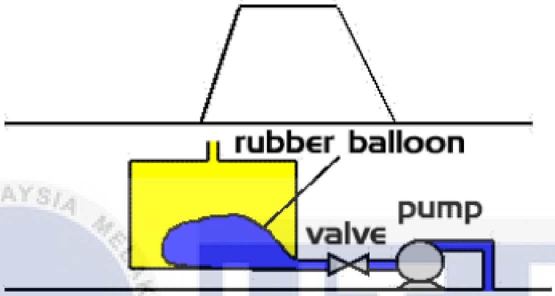


Figure 2.8: Flexible Ballast Tank **[26]**

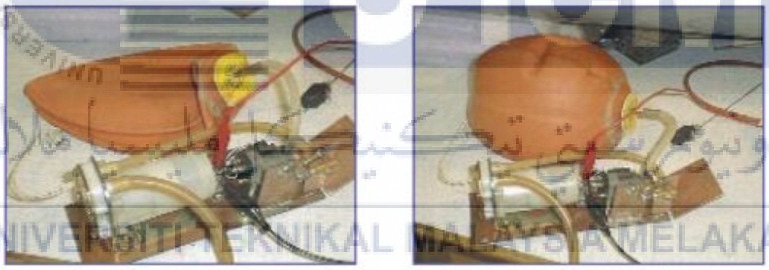


Figure 2.9: Conditions of Empty and Full Flexible Ballast Tank **[26]**

There is a rubber balloon placed inside a rigid tank in the flexible ballast tank. The valve will be opened, and water is pumped into the tank in order to flood the tank. After the tank is flooded with water, the valve is closed to prevent the water is outflow from the rubber balloon. Originally, the air located in the rigid tank is vented into the pressure hull of the boat. Hence, the pressure inside the pressure hull will be increased.

3. Pressure Ballast Tank

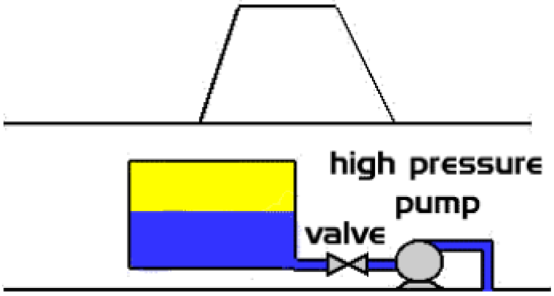


Figure 2.10: Pressure Ballast Tank **[26]**

The pressure ballast tank consists of a well-sealed ballast tank which has the ability to withstand a significant increasing pressure about to (5 bars or so). The water will be pumped into the tank with a high-pressure water pump to flood the tank. The air inside the ballast tank does not have the space to escape, hence the air is compressed inside the ballast tank. The water will be pumped out again by using the water pump in order to empty the tank. Assuming if there is a maximum pressure of 5 bars of the inner tank, there is about 80 percent of the volume of the ballast tank can be used.

However, the usage of ballast tank in not a compulsory element in some simple ROV prototype. The buoyancy control of ROV can be alternatively using the thrusters. The thruster is used in ROV to make it achieve slightly negative buoyancy for the purpose of depth controlling of the vehicle. [27]

Hence, there are some examples of prototype not using the ballast tank for their buoyancy control purpose. For instance, Arduino Sub- A Low Cost ROV Kit for Ocean Engineering Education is the prototype not using the ballast tank system. [28]

There are a few reasons some simple prototype of ROV not using ballast tank system:

- Simplicity of Design
- Shallow Water Operation
- Cost Consideration
- Reduced weight

2.5.4 Thrusters

2.5.4.1 Types of Thrusters

Thrusters are a crucial component in Remotely Operated Vehicles (ROVs) as they responsible for providing the necessary propulsion and manoeuvrability that allow ROV to perform underwater inspection.

When selecting thrusters for an ROV, several factors need to be considered, including weight, thrust, power consumption, efficiency, and overall compatibility with the ROV design.

Here, there is the comparison made among the thrusters of Blue Robotics T100 Thrusters, Blue Robotics T200 Thrusters, and Lixada Thrusters. These thrusters are brushless DC electric motor (BLDC) which provides a lot of advantageous of higher efficiency, greater durability, better performance, lower maintenance and lightweight.

Table 2.5: A comparison between different models of thrusters **[29] [30] [31]**

Features	**Types of Thrusters**		
	Blue Robotics T100 Thrusters	**Blue Robotics T200 Thrusters**	**Lixada Y22763 Thrusters**
Max Thrust	50 N	113 N	50 N
Voltage Range	6 -16 V	6 - 20 V	12 - 24 V
Max Power	250 W	400 W	200 W
Weight	330 g	365 g	162 g
Max Current	12 A	25 A	20 A
Propeller Diameter	60 mm	76 mm	60 mm
Materials	Polycarbonate, Aluminium	Polycarbonate, Aluminium	Stainless Steel, Aluminium Alloy, Nylon

From the table, the T200 thrusters from Blue Robotics stood out as a greater option with greater maximum thrust, current, and power. And despite being more powerful than the T100 it only weighs 45g more than the T100 thrusters. Making it a good trade off and the chosen thruster to be used for the ROV.

Lixada Y22763 thrusters are also compared with the other thrusters, such as the T200. But it falls short due to the shortcomings such as its weaker thrust and power compared to the T200 thrusters. Not only that, but the thrusters are also not suitable for long periods of time in seawater and the propellers only support clockwise rotations.

The T200 thruster is made of high-strength, UV resistant polycarbonate injection moulded plastic. The core of the motor is sealed and protected with an epoxy coating, and it uses high-performance plastic bearings that can withstand in seawater. It also uses aluminium and stainless steel that doesn't corrode under seawater.

The T200 thruster has a specially designed propeller and nozzle which provides efficient, powerful thrust while active water-cooling keeps the motor cool. Unlike other thrusters, water can flow freely through all parts of the motor while it's running, and it can handle extreme pressures under the sea. Not only that, but it also comes with clockwise and counterclockwise propellers to counter torque. [32]

2.5.4.2 Degree of freedom of ROV

The ROV designed can only have maximum 6 degree of freedom. The designed 6-DOF ROV has the capability to move independently in six possible orientations in three-dimensional space. The list of direction that 6-DOF ROV can be moved is shown as below:

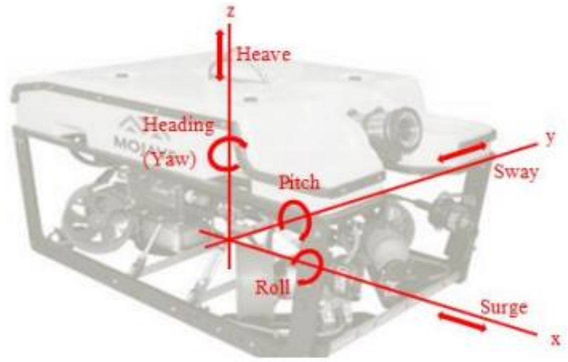


Figure 2.11: The 6-DOF ROV **[33]**

Table 2.6: The table of possible orientation for 6-D0F ROV **[33]**

No	Orientation	Movement	Description
1	Surge	Forward/reverse movement	Longitudinal movement along the horizontal plane. Forward movement is positive.
2	Sway	Sideways movement (left/right lateral motion)	Lateral movement along horizontal plane. Left lateral motion is positive.
3	Heave	Vertical up/down movement	Vertical movement along horizontal plane. Vertical up movement is positive.
4	Yaw	Rotation around vertical axis.	Rotation around vertical axis (z-axis).
5	Pitch	Rotation around lateral axis.	Rotation around lateral axis (y-axis).
6	Roll	Rotation around longitudinal axis.	Rotation around lateral axis (x-axis).

Application of 4-DOF of ROV:

1. The Teledyne SeaBotix LBV150-4

Figure 2.12: The Teledyne SeaBotix LBV150-4 **[34]**

2. ECA H300

Figure 2.13: ECA H300 **[35]**

These 2 ROVs having the 4-thruster configuration which are: one vertical thruster responsible in heave authority, one lateral thruster responsible in sway authority and two horizontal thrusters responsible for surge and heading control.

2.5.4.3 Torque Steer Problem

- One problem will arise from multiple horizontal thrusters aligned along the same axis is torque steer problem.
- As this torque steer problem also faced in the operation of helicopter. Hence, the propeller of a helicopter must be countered by the tail rotor or a counter-rotating main rotor. [36]
- As helicopter, ROV must have counter-rotating thruster propellers for the sake to avoid the torque of the thrusters rolling the vehicle counter to the direction of propeller rotation.
- If this roll does happen, the situation of torque steering will happen because of the asymmetrical thrust and drag loading.

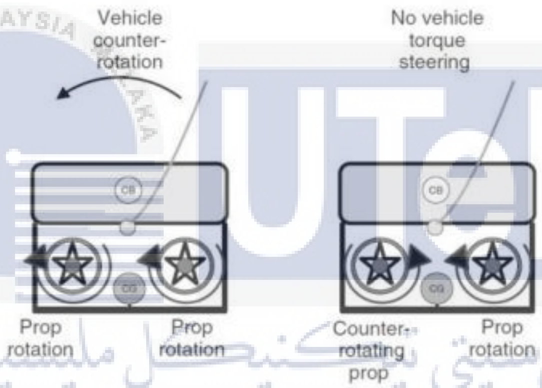
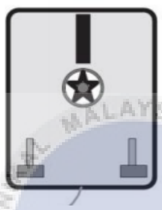
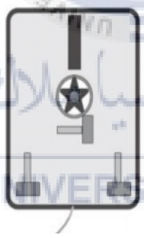
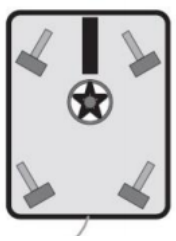


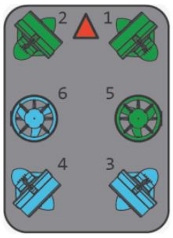
Figure 2.14: Vehicle counter rotation and No vehicle torque steering **[36]**

2.5.4.4 Configurations of Thrusters

The configuration of thrusters on a remotely operated vehicle (ROV) has a significant impact on the s functionality of designed ROV. Different types of configurations of thrusters provide different degrees of manoeuvrability, stability, and control on the designed ROV.

Table 2.7: The available movement for regarding degree of freedom of ROV. **[36]**

No.	Configuration Pattern of Thrusters	Available Movement
1	 Figure 2.15: 3-DOF ROV	• Surge (Forward/backward movement) • Sway (Sideways movement) • Heave (Up/down movement)
2	 Figure 2.16: 4-DOF ROV	• Surge (Forward/backward movement) • Sway (Sideways movement) • Heave (Up/down movement) • Yaw (Rotation around Vertical Axis)
3	 Figure 2.17: 5-DOF ROV	• Surge (Forward/backward movement) • Sway (Sideways movement) • Heave (Up/down movement) • Yaw (Rotation around Vertical Axis) • Pitch (Rotation around Lateral Axis)

4	 Figure 2.18: 6-DOF ROV	• Surge (Forward/backward movement) • Sway (Sideways movement) • Heave (Up/down movement) • Yaw (Rotation around Vertical Axis) • Pitch (Rotation around Lateral Axis) • Roll (Rotation around Longitudinal Axis):

2.5.4.5 Functionality of Thrusters on ROV

Working Principle of Thrusters on 3-DOF ROV

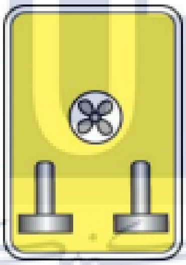


Figure 2.19: 3-DOF ROV

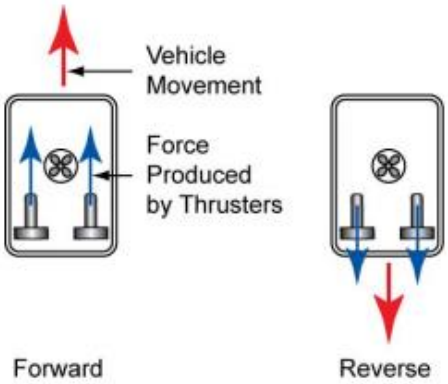


Figure 2.20: Forward and Reverse Movements.

Both horizontal thrusters must generate equal thrust to move straight either in forward or reverse directions.

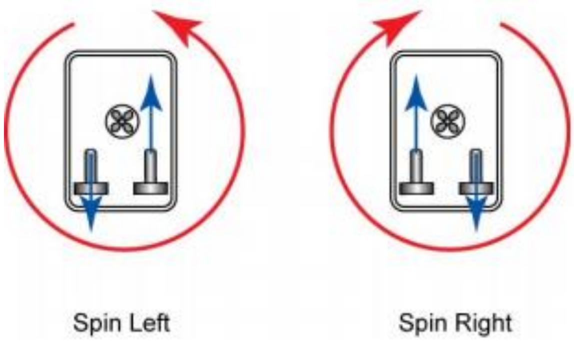


Figure 2.21: Spin left and spin right.

In order to spin the ROV in place, both horizontal thrusters have to act equally but in opposite directions. The forward and reverse thrusts produced will be cancelled but the two thrusters will produce a force couple which spins the ROV either in left or right in place.

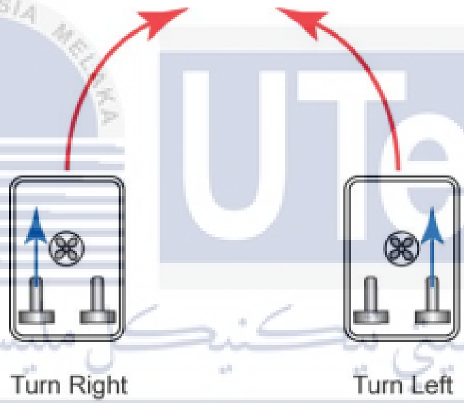


Figure 2.22: Turn right and turn left.

In order to make a ROV to move forward but not in a straight line, only one thruster can be acted. For instance, the ROV will turn to the right if only the port thruster is activated. This is due to the reason that the force that created by thruster and drag which is located around the centre of the vehicle produce a force couple that turns the vehicle.

Introduction on 4-DOF ROV

Four thruster arrangement is created by adding another vertical thruster to 3-DOF ROV for creating larger vertical thrust.

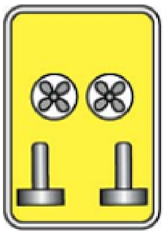


Figure 2.23: 4-thruster arrangement

Another option to locate the 4th thruster is put it for lateral movement. This option aided so much when the ROV is working with payload tools because it can shift laterally without making any other movements.

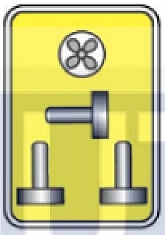


Figure 2.24: 4-thruster arrangement

The configurations pattern of thrusters selected must suit to the specific requirements that ROV needed to be operated at. The factors that needed to be considered are operational conditions such as depth rating, payload capacity, and the complexity of tasks that the ROV will undergo.

2.5.4.6 Comparison of Horizontal Thrusters Configuration

In order to produce a ROV with more accurate controllability of surge, sway and heading, 4-thrusters vectored configuration is widely utilised. This is aimed to increases the controllability of ROV in all horizontal directions.

Hence, there is comparison over Figure 2.31(a): a marked improvement over the non-vectored configuration Figure 2.31(b) in terms of surge and sway thrust capability. [34]

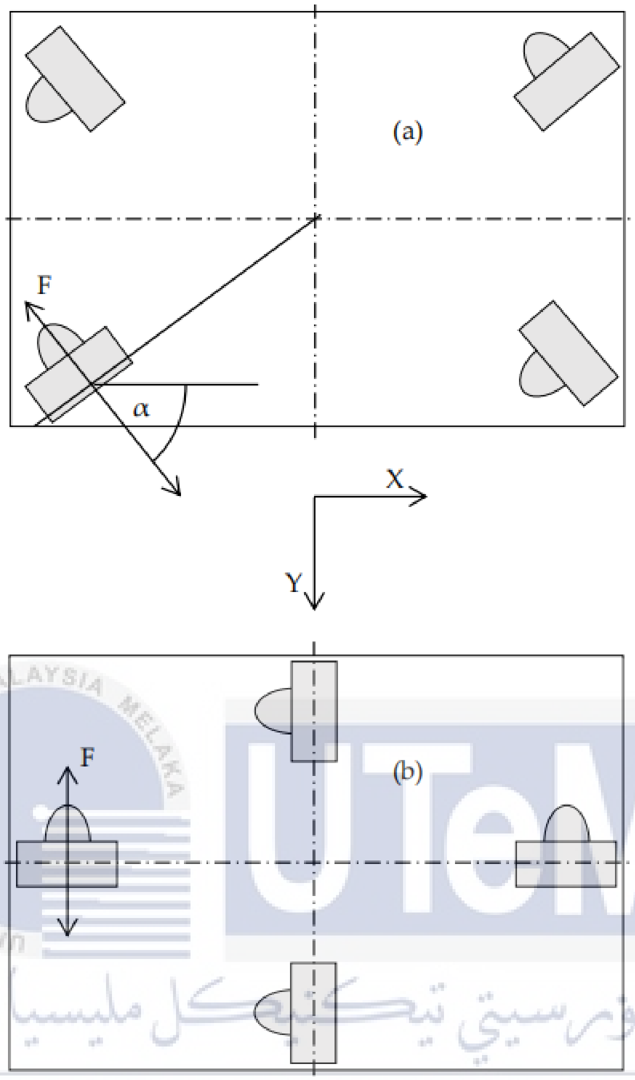


Figure 2.25: Comparison of horizontal thruster configuration **[34]**

Figure 2.31 (a) Vectored orientation thruster configuration can be calculated by:
Tx = 4F.cosα, Ty = 4F.sinα, where F =force.

Figure 2.31 (b) Other two forward, two lateral orientation's thrust can be calculated as:
Tx = Ty = 2F.

If the vectored thrusters were orientated at 45° the thrust would be calculated by using the formula of: Tx = Ty = 2√2F, which shows the greater thrust capabilities [37].This vectored thruster configuration also have advantages on a higher level of fault tolerance [38].

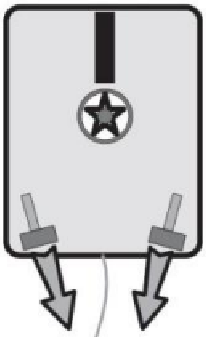


Figure 2.26: Vectored-Thrusters Alignment

The two-vectored thrusters aligned along the longitudinal axis giving the advantage of better turning moment, while providing the ROV with strong longitudinal stability.

2.5.4.7 Working Principle of Thrusters on 4-DOF ROV

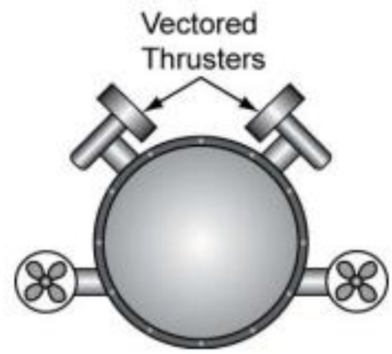


Figure 2.27: 4-thruster configuration (two-vectored & two lateral)

1. The figure below shows the 4 motions of ROV is generated when the two vertical thrusters produce equal thrust.

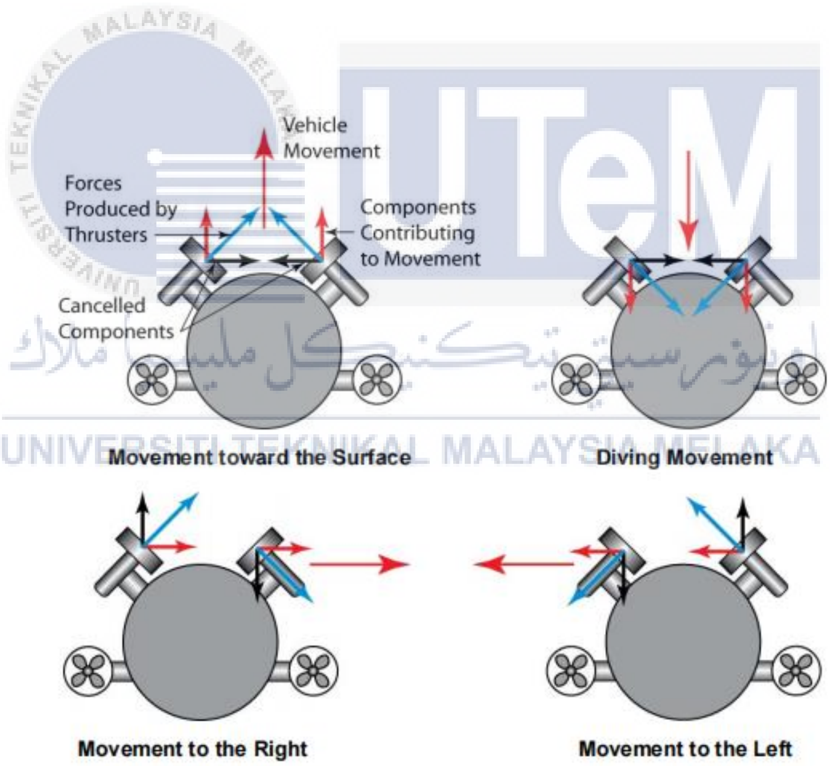


Figure 2.28: 4-Vehicle Movements from the Vectored Thrusters Illustrated

2. If each thruster controls their speed independently, the ROV able to move in any direction in the vector thruster plane. The figure has illustrated the related motion.

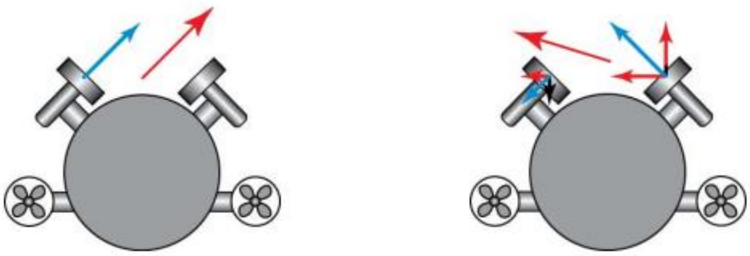


Figure 2.29: A Couple of Possible Movements if Thrusters Speeds Are Independently Controlled

2.5.4.8 Decision on Thrusters Designed

The criteria of propulsion system of ROV are constructed as below:

i. Types of Thrusters: T200 Thrusters

- Provides significantly higher thrust, suitable for ROV to operate in strong currents which more power is the must for manoeuvrability and station-keeping.
- Robust materials built, ensuring its longevity and reliability.
- Energy efficiency.

ii. 4 -degree of freedom

- A 4-degree freedom of thruster configuration for ROV is chosen. A 4-DOF thruster configuration is generally more energy efficient than configuration with higher degree of freedom. This efficiency helps ROV to prolong its operational time and reduce the frequency of recharging or replacing the power source.

- Most underwater inspection ROV do not require more than 4-DOF. This is because of the 4-DOF is sufficient to provide the movement of forward, backward, turning left and right, raising and submerging which enable the ROV to undergo underwater inspection.

iii. 90-Degrees Thruster Configuration

- A 90-degrees configuration allows for straightforward control algorithm which is simplicity in control. The precise manoeuvrability can be achieved due to the thrusters are aligned with the primary axes.

- The unwanted drift can be reduced by placing the trusters aligned to the main axes compared to 45-degrees configuration. The stability of the ROV can be improved during the operations.

2.5.5 Pressure Sensor

Pressure sensor is important for the well functionality of ROV. Pressure sensors is primarily used to measure the depth at which the ROV is undergoing underwater inspections. Knowing the exact depth of ROV is crucial for avoiding obstacles and ensuring the ROV is within a safe operating range.

Besides, the pressure sensor functioned to provide essential data on temperature, depth and pressure which contribute significantly to the success and reliability of underwater missions, whether for scientific research or industrial applications.

The Bar02 Ultra-High Resolution Pressure Sensor is a low-pressure and high-resolution pressure sensor that is capable of measuring up to 10-meter depth under water. It has been rated to be highly accurate compared to its retired predecessor, the Bar30 sensor. This sensor includes a temperature sensor accurate to ±2°C, giving it extra features to provide more information to the user. The details for Bar02 pressure sensor are as follows:

Table 2.8: Detailed features of the Bar02 pressure sensor **[39]**

Features	**Specification**
Pressure Range	0 – 10 bar (0 – 1000 kPa)
Resolution	0.16 mbar
Accuracy	±0.5% FS
Supply Voltage	3.3V or 5V
Interface	I2C
Operating Temperature	-40 to 85°C
Material	Stainless Steel
Dimensions	24 mm diameter, 16 mm height
Weight	9 g

2.5.6 Tether

Tethers are responsible for the connection of the surface console with the ROV for communication purposes, such as information gathered from sensors and live cameras back to the surface. Power is not required for transmission from tethers because ROVs usually have batteries built in. Therefore, the priority during the design and choosing of ROV tethers doesn't need necessarily include power transmission, but instead other important characteristics such as low drag, light weight, and buoyant so that it doesn't affect the ROV's performance.

Neutrally buoyant tether, fibre-optic tethers, copper tethers, and CAT5e tethers are all popular options as tethers for a submersible ROV as they offer their own pros and cons as shown in Table 2-6.

Table 2.9: Comparison between tethers **[40] [41]**

No.	**Types of tethers**	**Pros**	**Cons**
1	**Fiber Optic**	• Thin • Fast Transmission • Low weight	• Expensive • More fragile • Difficult to terminate.
2	**Copper**	• Neutrally buoyant • More durable • Easy to terminate.	• Thicker • Expensive
3	**Copper** **(no buoyancy)**	• More durable • Cheaper	• Thicker
4	**CAT5 Ethernet Cable**	• Less drag • Noise immunity • Low weight	• No protective jacket • Not neutrally buoyant

		• High-speed data transfer • Low cost • Low latency	
5	**Neutrally Buoyant Tether**	• Less drag • Neutrally buoyant • Good stability	• Expensive

That being said, a proper tether management system is also important while designing tethers, as extended tethers can cause extreme cable to drag which can disrupt the operation of the ROV while underwater. It also allows for a less hazardous launch and recovery of the ROV.

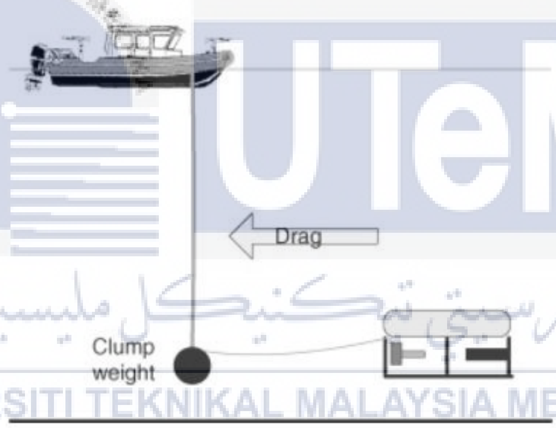


Figure 2.30: An example of how drag can affect the ROV.

2.5.6.1 Decision on Choosing Type of Tethers

Cat 5 Ethernet cable was chosen for ROV tethers due to its combination of high-speed data transmission capabilities. Cat 5 cables are able to support data transmission speed up to 100 Mbps and even up to 1 Gbps in some cases. This is sufficient for the transmission of video feeds, sensor data and the control algorithm between RIV and surface control box. The low latency of Cat 5 cables enables the real-time control and monitoring of ROV which is crucial for precise manoeuvrability and data collection during underwater inspection.

Besides, the Cat 5 cables are cheaper and affordable. This makes them an economical choice for ROV tether. This is due to the ease of replacement if it is damaged, cutting down the maintenance costs. Furthermore, the cables are designed with noise immunity which ensures stable and reliable data can be transmitted.

Moreover, the Cat 5 cables are low in weight which reduces the load on ROV, allowing for the ease of manoeuvrability. With less weight of tether to be counteract, the propulsion system of thruster able to operate at maximum efficiency.

In the other hand, Cat 5 cables have a relatively small diameter compared to ither thicker cables. This small diameter reduces the hydrodynamic drag, allowing the ROV to move more smoothly and efficiently through the water. The ROV with the characteristics of less drag is able to maintain its position more effectively especially in currents or turbulent water. This advantage is very crucial for ROV which is specially customized for underwater inspection.

2.6 Related Works

2.6.1 Related Journal Research

Model 1:

Development of ROV for Underground Power Transmission Equipment Inspection in Submerged Manhole (2020) [42]

1.0 Objective:

To design a ROV with the characteristics of high mobility, wide visibility, and sufficient operating time, to inspect underwater objectives and above-water objectives inside the manhole.

2.0 Main required specifications of ROV

Table 2.10: Main required specification for ROV Underground Inspection **[42]**

No.	Parameters	Description
1	Dimension	• Must be in mini size. • Can be inserted into the manhole through the Φ750 mm ground opening. • Can pass through the ladder frame (300mm x 300mm)
2	Mobility	• Moving Forward, Reverse, Ascent, Descent, Right turn, Left turn
3	Visibility	• Can grasp the crack of inspection objectives. • Can inspect underwater and above-water objectives
4	Maximum Depth	• 20m
5	Operating Time	• 1 hour or more

3.0 Overall mechanical design of ROV

Figure 2.31: Components of Prototype System **[42]**

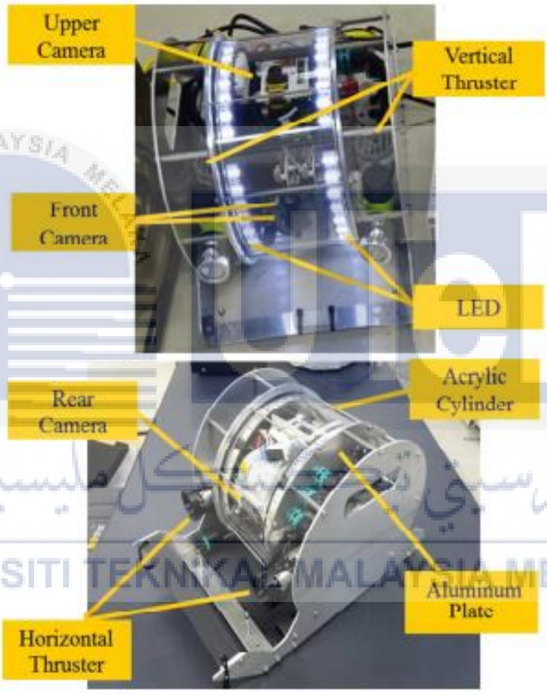
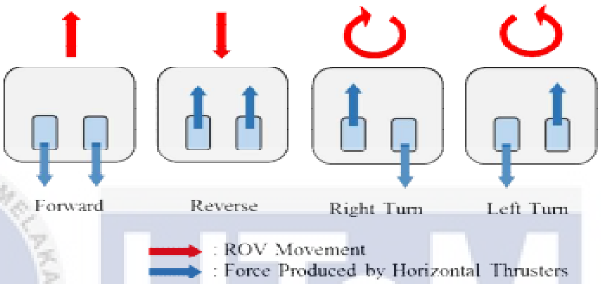


Figure 2.32: Structure of Main Body **[42]**

4.0 Components attached to ROV.

Table 2.11: List and descriptions of components attached to ROV Underground Inspection

No.	Items	Descriptions
1	4 Cameras	• two in front, one in upper part, and one in rear • Front camera: Inspect underwater inspection objectives. • Upper camera: Inspect above-water inspection objectives. • Rear camera: Check the tether.
2	4 Thrusters	• two for horizontal movement • two for vertical movement  Figure 2.33: Horizontal Thrusters Operation and ROV Movement
3	Power supply	• Voltage of the main circuit needs to be 14.4V or more than that. • Main body is equipped with an auxiliary battery to ensure stable operation of the system

Model 2:

Design of a Low-Cost Prototype Underwater Vehicle (2022) [43]

1.0 Objective:

To design a small, inexpensive ROV that can navigate in shallow water for the purpose of monitoring water quality and demonstrating vehicle control algorithms.

2.0 Main required specifications of ROV

Table 2.12: Main required specifications for Low-Cost ROV **[43]**

No.	Parameters	Description
1	Dimension	• 0.35 x 0.26 x 0.23 meters
2	Mobility	• 3 Degree of freedom • Yaw, Heave, Surge
3	Weight (in air)	• 1.6 kg
4	Operating Depth	• Up to 20m
5	Operating speed	• 0.2 m/s to 0.4 m/s
6	Actuators	• Three 12-V DC motors
7	On-board computer	• Arduino Nano
8	Sensor kit	• MPU-9250, MS5083-05ba, Gravity Turbidity Sensor
9	Power and data transmission mechanism	• DC wire (for power), CAT5 Ethernet cable (for data)

3.0 Overall mechanical design of ROV

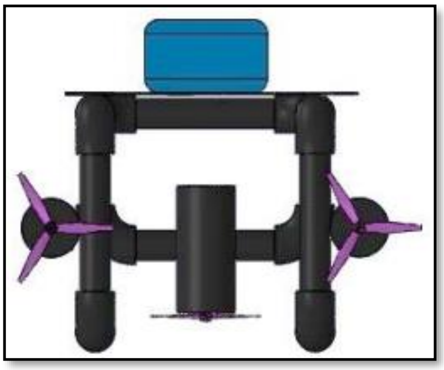


Figure 2.34: Front View of the Low-Cost ROV CAD Model **[43]**.

- Open-frame ROV
- ROV frame: Polyvinyl chloride tubes
- Single hull alongside a 0.35-meter-long frame
- A blue plastic container hull fixed at the top of ROV (consists of all electrical components)

4.0 Components attached to ROV.

Table 2.13: Components attached to Low-Cost ROV **[43]**.

No.	Items	Descriptions
1	Three 12V DC thrusters	• Two thrusters positioned on either side: • Independent surge and yaw motion control • Top thruster: Diving control
2	A depth transducer	• Monitor the ROV's depth based on the sensor.
3	9 DOF IMU (accelerometer, gyroscope, magnetic compass)	• To guarantee proper orientation of the ROV, crucial for precise navigation and control
4	Turbidity detector	• Function as spewing a laser beam into water and measures its transmittance and scattering rate.
5	Arduino Nano micro-controller	• Act as the controller of ROV

Model 3:

Design and Development of a Robotic Vehicle for Shallow-Water Marine Inspections (2020) [44]

1.0 Objective:

To design a ROV for the purpose of underwater marine inspections for ship hull or marine debris.

2.0 Main required specifications of ROV

Table 2.14: Specific Requirements for ROV Shallow-Water Marine Inspections. **[44]**

No.	Parameters	Descriptions
1	Material of Frame	• Black anodized aluminium alloy
2	Weight	• 8.6 Kg (without Foam) • 9.24 Kg (With Foam)
3	Dimensions	• 0.54 m x 0.34 m x 0.31 m
4	Diving Depth	• Up to 10 m
5	Average Speed	• 1.92 Knots (0.99 m/s)
6	Buoyancy	• Subsea polyurethane foam (0.68 Kg) • Slightly positively buoyant in water
7	Power	• 14.8 VDC, 0.182 kW
8	Thrusters	• Six Blue Robotics T-100 thrusters
9	Cable	• 2 wire Cable of 90 m
10	Data Telemetry	• Normal two-wire cable
11	Hardware	• Raspberry pi 3B, Arduino Uno
12	Software	• Qground Control, Putty
13	Camera	• Raspberry pi camera
14	Lights	• 2 lumen subsea lights
15	Navigation Sensors	• LS20031 GPS receiver, 30 bar pressure/ depth, • Current and Voltage Sensing and inertial MPU-9250 (3-DOF Gyroscope, 3-DOF Accelerometer, 3-DOF Magnetometer) sensor

3.0 Overall mechanical design of ROV

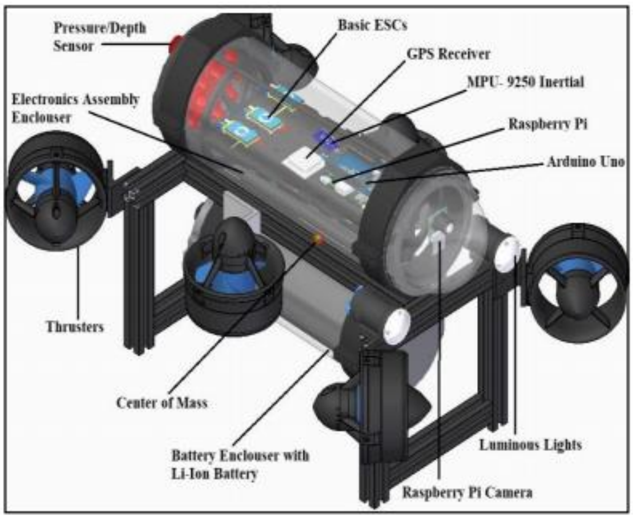
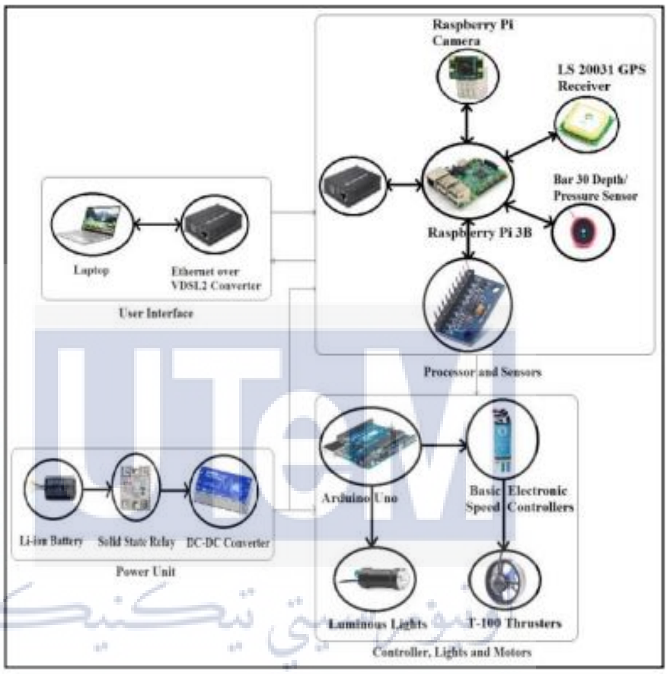


Figure 2.35: Design of Shallow-Water Marine Inspections ROV **[44]**.

Figure 2.36: Real view of the developed Shallow-Water Marine Inspection ROV **[44]**.

4.0 Components attached to ROV.

Table 2.15: Components attached to Shallow-Water Marine Inspection ROV. **[44]**

No.	Items	Descriptions
1	Two watertight enclosures	• First enclosure: control system and camera • Second enclosure: battery
2	Two high intensity luminous lights	• Provide clearer visual observations
3	Electronic System	 Figure 2.37: ROV System Diagram
4	Six thrusters	• 2 Thrusters: Vertical motion • 4 Thrusters: positioned 45 degrees from each other, responsible for horizontal motion. • Six degrees of freedom: Heave, Surge, Sway, Roll, Pitch, Heading

Model 4:

Development and Experiments of a Novel Deep-sea Resident ROV (2021) [45]

1.0 Objective:

1. To reduce the complexity of the conventional Tether Management System (TMS) meanwhile ensure there is sufficient energy for the Rover ROV.
2. To design a ROV with combined energy supply scheme based on floating charging technology is proposed.
3. To innovative a ROV different from the traditional power supply solution that ROV is powered by surface vessel through umbilical cable.
4. To design a ROV which can be operated at the deep-sea with higher reliability and longer working time capability.

2.0 Main required specifications of ROV

Table 2.16: Main Specifications of Novel Deep-Sea Resident ROV **[45]**

No.	Parameters	Description
1	4 system is proposed.	• **First System:** A garaging system consisting of TMS and docking station. • **Second System:** A submerged power supply system • **Third System:** Communication with the shore or surface vessel. • **Forth System:** A deployed ROV body
2	Size (L × H × W)	• 1.2×0.7×0.4 m
3	Mass	• 138 kg (in air)
4	Power	• 4kW
5	Degree-of-freedom	• 6
6	Speed	• 2 knots

7	Tether cable	• 120m
8	Thrusters	• Supply voltage :48VDC • Max power: 500 W per thruster • Quantity: 8
9	Diving Depth	• 3000m

3.0 Overall mechanical design of ROV

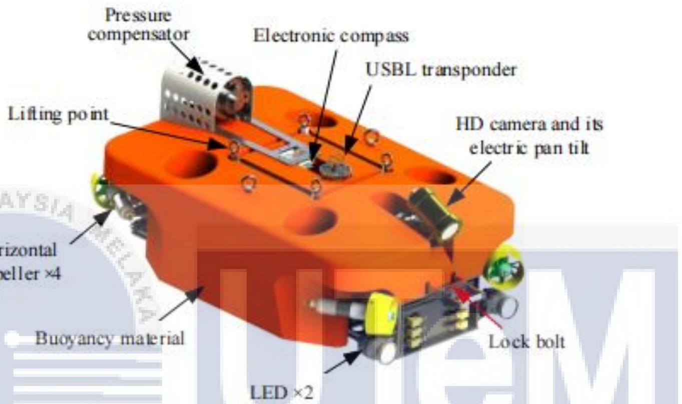


Figure 2.38: The overall design of Rover ROV body **[45]**.

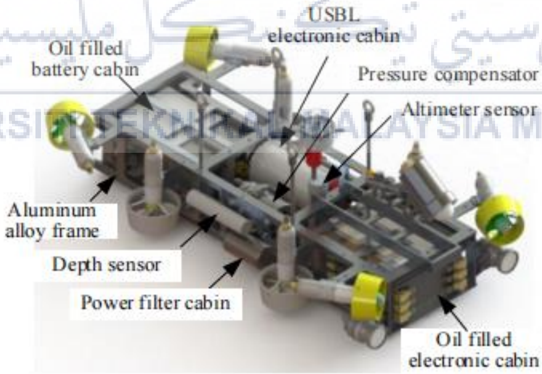
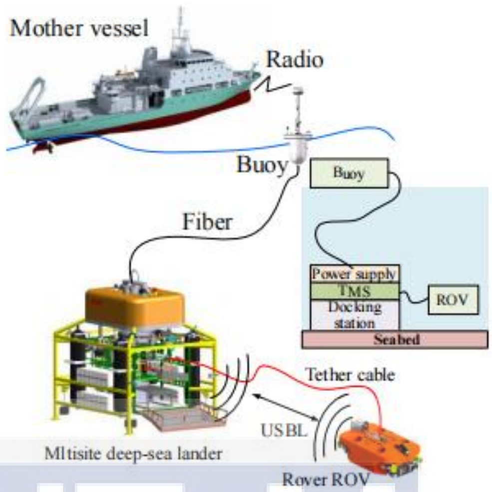
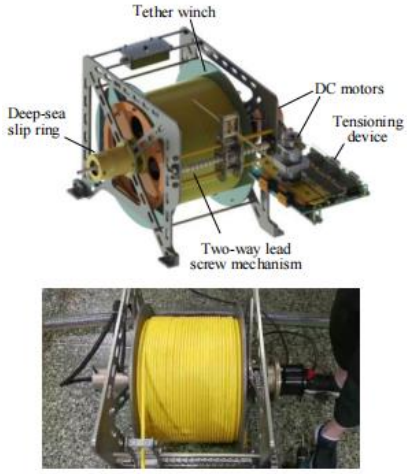
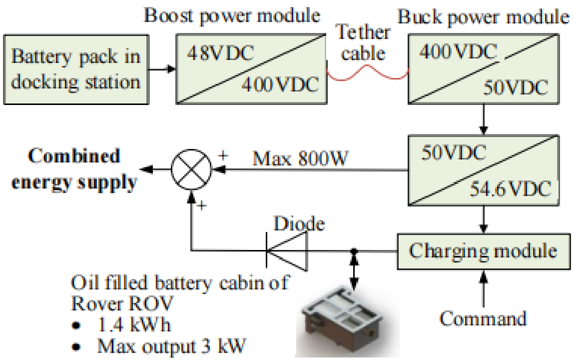
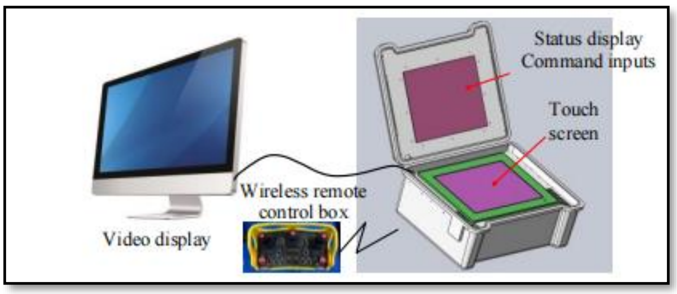


Figure 2.39: Layout scheme of internal modules of Rover ROV **[45]**.

4.0 Development of Rover ROV.

Table 2.17:The table of development of the Deep-Sea Rover ROV System **[45]**.

No.	Items	Descriptions
1	Rover ROV System Design	 Figure 2.40: Benthic working scenario of the Rover ROV.
2	Tether Management System	• To accommodate 120 m of a 10 mm diameter neutral buoyancy tether • TMS designed in aluminium alloy and having the weighs about 65 kg in air. • The breaking strength of the tether cable is 600kg.  Figure 2.41: The small-scale TMS

3	Combined Energy Supply Scheme	• Power source of Rover ROV is provided by the submerged docking station. • Floating charging technology is introduced.  Figure 2.42: Structure of the combined energy strategy of the Rover ROV.
4	Control System Design	• Dividing into the surface part and the underwater part. • The two parts communicate with each other through an optical fibre. • The surface control unit can follow up the underwater video and • vehicle status data display. • The operator can use the surface operation box to operate the Rover ROV for completing the tasks. • The equipment of the surface control unit is installed in the surface portable operation box.  Figure 2.43: The configuration of the surface portable operation box for the Rover ROV.

Model 5:

ArduinoSub –A Low-Cost ROV Kit for Ocean Engineering Education (2019) [28]

1.0 Objective:

1. To design a low cost ROV kit with the function of path following, heading to waypoint, depth holding and video recording.
2. To develop a low cost ROV kit to improve marine technical education.

Table 2.18: Main Specifications of ArduinoSub **[28].**

No.	Parameters	Descriptions
1	Material of Frame	• Polyethylene pipe
2	Weight	• 5.8 kg in the air
3	Dimensions	• 36 x 33 x 25cm
4	Diving Depth	• 40 meters
5	Average Speed	• (max 1 m/s)
6	Buoyancy	• 200 grams positive buoyancy in the water
7	Thrusters	• Two vertical thrusters & two vertical thrusters • Each provide more than 40 N
8	Camera	• HD camera
9	Lights	• 2 underwater lights

3.0 Overall mechanical design of ROV

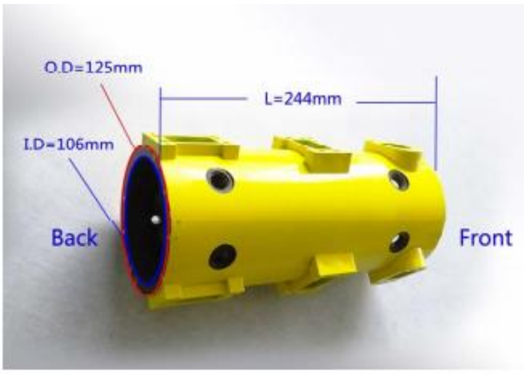
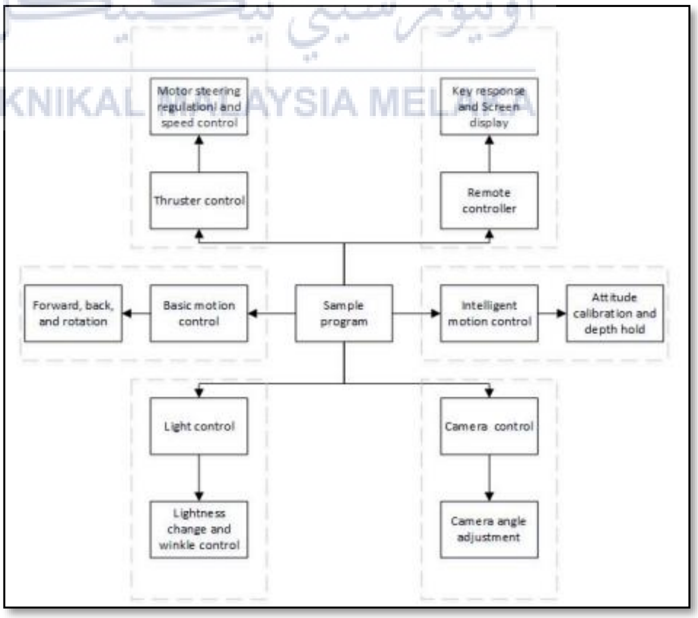


Figure 2.44: The pressure housing of ROV **[28]**.

Figure 2.45: The overall structure of ROV. **[28]**

4.0 Development of the system ROV

No.	Items	Descriptions
1	Power System	• Use eight 21700 lithium-ion rechargeable batteries. • has a 4S2P. • 8Ah (amp-hours) capacity and 40A (amps) maximum continuous discharge rating • enough power ROV for continuous usage up to 2 hours
2	Control Unit	• Arduino Mega 2560 microcontroller • neutrally buoyant tether cable was used. • power management board and controller board.  Figure 2.46: The ROV control unit **[28]**.

3	Surface Unit	 Figure 2.47: The surface unit of ROV **[28]**. • The topside gamepad controller shown is used to communicates with the main controller board. • The built-in LCD screen responsible for displaying robot status such as voltage, depth, operating mode, and battery level of ROV. • A DVR is associated with the LCD display. The DVR is functioned to record 1080p high-definition videos which is transmitted from the ROV camera via the tether.
4	Software	 Figure 2.48: Sample program structure of ROV **[28]**.

2.6.2 Comparison on Different Designation of ROV

After details analysis on each journal, a table is made for the clear comparison between the journals taken based on certain parameters. This step can be advantageous in benchmarking purpose, justifications of choices and decision-making process.

Table 2.19: Comparison of Different Designation ROV

Parameter	Model 1	Model 2	Model 3
	Manhole Inspection ROV (2020)	**Low Cost ROV (2022)**	**Shallow-Water Inspection ROV (2020)**
Size (L×W×H)	700 mm × 250 mm × 250 mm	350 mm × 260 mm × 230 mm	540 mm × 340 mm × 310 mm
Mass (in air)	Less than 3 kg	1.6 kg	9.24 kg
Materials of frame body	Acrylic	Polyvinyl chloride	Black anodized aluminium alloy
Stability	Neutral buoyancy tether reduce drag	Additional foam	• Subsea polyurethane foam (0.68 Kg) • Slightly positive buoyancy in water
Ballast Tank	Nope	Nope	Nope
Propulsion System	4 thrusters (2 horizontal 90°, 2 vertical 90°)	3 thrusters (2 horizontal 90°, 1 vertical 90°)	6 thrusters (4 horizontal 45°, 2 vertical 90°)
Computer Control System	PC & LAN hub	Arduino Nano	Arduino Uno & Raspberry Pi 3B
Tether length	25 meters	22 meters	12 meters
Max depth	20 meters	20 meters	10 meters
Camera	1 waterproof camera	Nope	1 Raspberry pi camera

Sensors	4 waterproof cameras	MPU-9250, MS5083-05ba, Gravity Turbidity Sensor	GPS receiver, pressure & depth sensor, 3-DOF Gyroscope sensor, 3-DOF Accelerometer sensor, 3-DOF Magnetometer sensor
Monitoring & Surveillance System	Live video streaming through PC	Nope	Live video streaming through PC

Table 2.20: (Continued) Comparison of Different Designation ROV

Parameter	Model 4 Deep-sea ROV (2021)	Model 5 Arduino Sub ROV (2019)	My Design Inspection ROV
Size (L×W×H)	1200 mm × 700 mm × 400 mm	360 mm × 330 mm × 250 mm	500 mm × 300 mm × 350 mm
Mass (in air)	138 kg	5.8 kg	7.7 kg
Materials of frame body	Aluminium alloy	Polyethylene pipe	Acrylic
Stability	Neutral buoyancy tether reduce drag	Positive buoyancy in water	• Tubing sponge • 90% negative buoyancy in water • Cat 5 cables to reduce drag
Ballast Tank	Nope	Nope	Nope
Propulsion System	8 thrusters (4 horizontal 90°, 4 vertical 90°)	4 thrusters (2 horizontal 90°, 2 vertical 45°)	4 thrusters (2 horizontal 90°, 2 vertical 90°)
Computer Control System	PC & Ethernet	Arduino Mega 2560 microcontroller	Arduino Uno
Tether length	120 meters	42 meters	15 meters
Max depth	3000 meters	40 meters	5 meters
Camera	One HD camera	One HD camera	1 waterproof endoscope camera
Sensors	Depth sensor & Altimeter sensor	MPU-9250, Depth sensor, Leak detection sensor	Leakage sensor, Depth, Pressure and Temperature sensor
Monitoring & Surveillance System	• Surface Operation Unit • Surface Operation Box	Nope	Live video streaming through a laptop screen (Associated with waterproof endoscope camera)

With references to the journal collected, my design is proposed and is listed in the table above for the comparison purpose. My design is focused on the usage of inspection purpose and the maximum depth rating is till 5 meters, thus there is some changes in the specifications.

The material of frame body of my design is made of acrylic with reference to model 1 because of its advantageous being extremely lightweight. This characteristic making it easy to install and fulfils the weight requirements for the material choice of the ROV. Besides, it is able withstand regular wear and tear and accidents. Acrylic is also resistant to UV rays and moisture, making it ideal for submerging underwater.

The stability of my designed ROV is consists of all the method used in model referred which are added subsea polyurethane foam, 90% negative buoyancy in water and using Cat 5 cable as tether for reducing the drag.

Due to the ROV designed is just for the inspection purpose and not go for too deep-sea level, hence the ballast tank is an optional choice for ROV. In my designation, ballast tank which responsible for submerging and rising of ROV is substituted by the usage of thrusters.

After comparing the propulsion system designed of the referred models, the ROV designed is wished to have 4 thrusters' configuration which are 2 horizontal thrusters is aligned at 90 degrees and other 2 vertical thrusters are aligned at 90 degrees. The 90-degrees configuration is used due to its simplicity in control and precise in manoeuvrability. The thrusters are designed to be operated at their maximum efficiency in their aligned directions which ensuring there is no vectoring thrust at angles that will result losses and reduced efficiency.

Moreover, the Arduino Uno is used in computer control system. The Arduino Uno is act as a microcontroller which is responsible for controllers, light, camera, sensors and motors. There is also leakage sensor, depth sensor and pressure sensor fixed in the ROV. The ROV designed will have the function of live video streaming through the laptop which is associated with camera used.

2.6.3 K-Chart on designing the ROV.

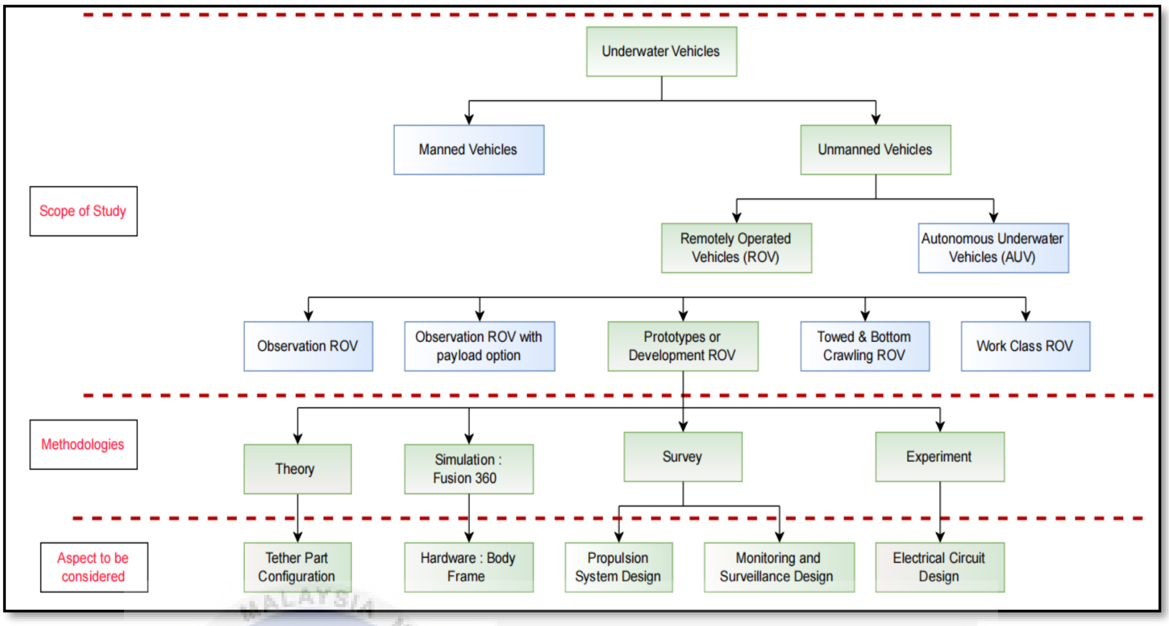


Figure 2.49: K Chart of the project.

2.6.4 Pair Wise Comparison & Weighted Objectively Method

Table 2.21: Table of Requirement and Specification on Designed ROV.

Requirements	**Specification**
Size	500 mm × 300 mm × 350 mm
Material	Acrylic
Stability	• Tubing sponge • 90% negative buoyancy in water • Cat 5 cables to reduce drag
Propulsion System	4 thrusters (2 horizontal 90°,2 vertical 90°)
Computer Control System	Arduino Uno
Tether	15m
Depth	5m

There are too many requirements to be listed out in order to design and develop a ROV. Hence, the pair wise comparison method is used to determine the more important requirements that needed to be prioritized during the designation of ROV.

Table 2.22: Results for Pair Wise Comparison

Requirement		A	B	C	D	E	F	G	Totals	Weights
Size	**A**	1	1/3	4	3	7	8	1/5	23.53	0.16
Material	**B**	3	1	9	8	8	10	9	48.00	0.33
Stability	**C**	1/4	1/9	1	1/8	6	5	5	17.49	0.12
Propulsion System	**D**	1/3	1/8	8	1	8	5	7	29.46	0.20
Computer Control System	**E**	1/7	1/8	1/6	1/8	1	3	9	13.56	0.09
Tether	**F**	1/8	0	1/5	1/5	1/3	1	6	7.96	0.05
Depth	**G**	5	1/9	1/5	1/7	1/9	1/6	1	6.73	0.05
									146.73	1.00

There is the conclusion can be made based on the score obtained for each requirement according to pair wise comparison method. In a conclusion, material of body frame is the most important considered factors, followed by the requirements of propulsion system and size of desired ROV.

The material is the most crucial factor because a good materials with the right buoyancy properties provides stability to the ROV. The materials of body frame must able withstand the high pressure underwater and resist to corrosion due to saltwater for ensuring its longevity and reliability. The factor of size is important to the objective and the function of ROV to be used. Besides, the propulsion system is important for providing the ROV manoeuvrability.

In short, in designing process, the three criteria that described as above have to be put on higher priority.

The scale 1 to 5 is used in the Weighted Objectively Method table below. The scale of 1 = poor; scale of 5 =excellent state.

Table 2.23: Weighted Objective Method

Requirement	**Weights**	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**		**My Design**	
		Manhole Inspection ROV (2020)		Low Cost ROV (2022)		Shallow-Water Inspection ROV (2020)		Deep-sea ROV (2021)		Arduino Sub ROV (2019)		Inspection ROV (2024)	
Size	0.16	3	700 mm × 250 mm × 250 mm	4	350 mm × 260 mm × 230 mm	4	540 mm × 340 mm × 310 mm	3	1200 mm × 700 mm × 400 mm	4	360 mm × 330 mm × 250 mm	5	500 mm × 300 mm × 350 mm
Material	0.33	5	Acrylic	3	Polyvinyl chloride	2	Black anodized aluminium alloy	2	Aluminium alloy	3	Polyethylene pipe	5	Acrylic
Stability	0.12	3	Neutral buoyancy tether reduce drag	2	Additional foam	4	Subsea polyurethane foam, slightly positive buoyancy	3	Neutral buoyancy tether reduce drag	2	Positive buoyancy in water	5	Tubing sponge, 90% negative buoyancy, Cat 5 cable to reduce drag
Propulsion System	0.20	4	4 thrusters (2 horizontal 90°, 2 vertical 90°)	3	3 thrusters (2 horizontal 90°, 1 vertical 90°)	5	6 thrusters (4 horizontal 45°, 2 vertical 90°)	3	8 thrusters (4 horizontal 90°, 4 vertical 90°)	3	4 thrusters (2 horizontal 90°, 2 vertical 45°)	4	4 thrusters (2 horizontal 90°, 2 vertical 90°)
Computer Control System	0.09	3	PC & LAN hub	4	Arduino Nano	5	Arduino Uno & Raspberry Pi 3B	3	PC & Ethernet	4	Arduino Uno	5	Arduino Uno
Tether	0.05	3	25 meters	3	22 meters	3	12 meters	4	90m	4	30m	5	15 meters
Depth	0.05	2	20 meters	2	20 meters	3	10 meters	3	10m	3	15m	4	5 meters
Total Score	**1.00**	**3.8902**		**3.0877**		**3.5388**		**2.7271**		**3.1879**			**4.7534**

From the table shown above, my design (Inspection ROV) obtained the highest total score which is 4.7534 out of 5.0 indicate that it is the best designation of ROV for the unmanned remotely operated vehicles for inspection purpose.

2.7 Summary

In a summary, the selection and design of an ROV require consideration of various factors including material of frame body, material of electric housing, buoyancy and stability, thrusters, tethers and sensors.

After doing the related journal research and comparison, the best decision is made to design dan develop an Inspection ROV. For the frame body material, the acrylic is chosen because of its characteristics of light in weight, strong and durable enough for absorbing shocks, corrosion and moisture resistance. For electric housing, PVS is chosen due to its inexpensive price, ease of fabrication, excellent electric insulator and long-term durability when exposed to saltwater.

On the other hand, a target of the ROV to achieve a negativity 90% buoyancy is desired for my project. This is because this buoyancy level will effectively minimize the influence of underwater currents and improve the ROV's ability to maintain its position, increasing its stability during inspection tasks.

Besides, there is not using any ballast tank system in this designed ROV because of few reasons which are shallow water operation, which its maximum diving depth is only 5 meters, cost consideration and reduced weight. However, the usage of ballast tank is not a compulsory element for their buoyancy control purpose. The buoyancy control of ROV can be alternatively using the thrusters.

For the thruster configuration, types of thrusters chosen is T200 thrusters. This is because of its significantly higher thrust, robust materials built and energy efficiency. A 4-degree freedom of thruster configuration for ROV is chosen. This is due to the reason of 4-DOF is sufficient to provide the movement of forward, backward, turning left and right, raising and submerging which enable the ROV to undergo underwater inspection. There are 90-degrees thruster configuration for both vertical and horizontal thrusters’ arrangement. This arrangement has lot advantageous which allow for precise manoeuvrability, reducing in unwanted drift and simplicity in control.

For the tether part, Cat 5 Ethernet cable was chosen for ROV tethers. This is because of its combination of high-speed data transmission capabilities, low latency, low in weight and reducing of hydrodynamic drag.

In order to enhance functionality of ROV, the accessories such as pressure sensor and waterproof endoscope camera is added. The pressure sensor provides crucial data such as the measurements on temperature, depth and pressure. The surveillance camera system gives the live visual feedback to operator to visually inspect underwater structures, marine life or search areas. This integration enabling more precise navigation, accurate inspections, and better decision-making during underwater operations.

As a conclusion, the selecting and integrating of the components has been carefully considered from different aspects to achieve superior performance and reliability in ROV intended inspection tasks.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this methodology chapter, the overall process regarding the main ideas and research methodology will be discussed. Hence, the project flowchart, prototype design, experimental set-up and experiment list will be written clearly. The proper planning of the ROV project needs to be done to ensure there is a clear framework for project development, outlining the steps and distributed tasks within the time. This can help the project development will be done in time with successfully achieving the objectives effectively.

The design and development of ROV involves 3 parts which are mechanical part, electrical part and software part. In order to design the overall prototype of ROV, the body frame of ROV must be drawn by using the software which is called Fusion 360. To test the durability underwater of prototype designed, the finite element analysis is done to avoid the failure points and improve overall structural robustness of ROV. After the finite analysis is completed upon the prototype drawn, the next steps which is fabrication will be carried out.

Once the prototype of the ROV is completed, the focus shifts to finalizing the electrical circuit consists of integrating the controller and configuring the software part. The software part including of Arduino Software and Processing Software. These steps are critical to ensure that the ROV operates efficiently and meets the project's objectives.

After the prototype is done, the testing of the ROV for the evaluation of certain parameters such as stability, buoyancy, acceleration, and velocity is evaluated on its performance. To successfully achieve the objectives, procedures of list of experiments is listed out in this chapter.

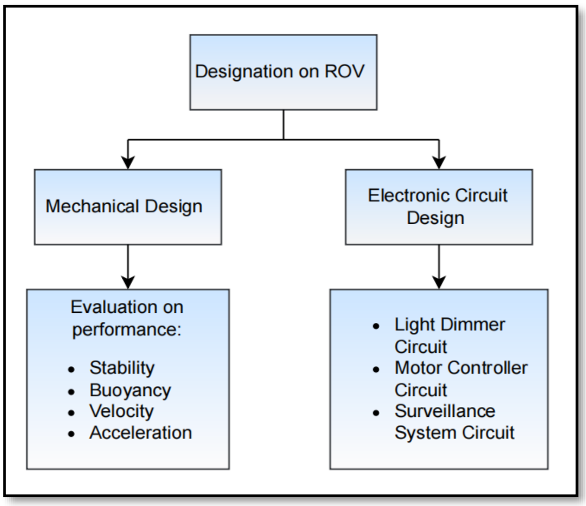


Figure 3.1: Main Ideas of Designation of ROV

3.2 Project Flow Chart

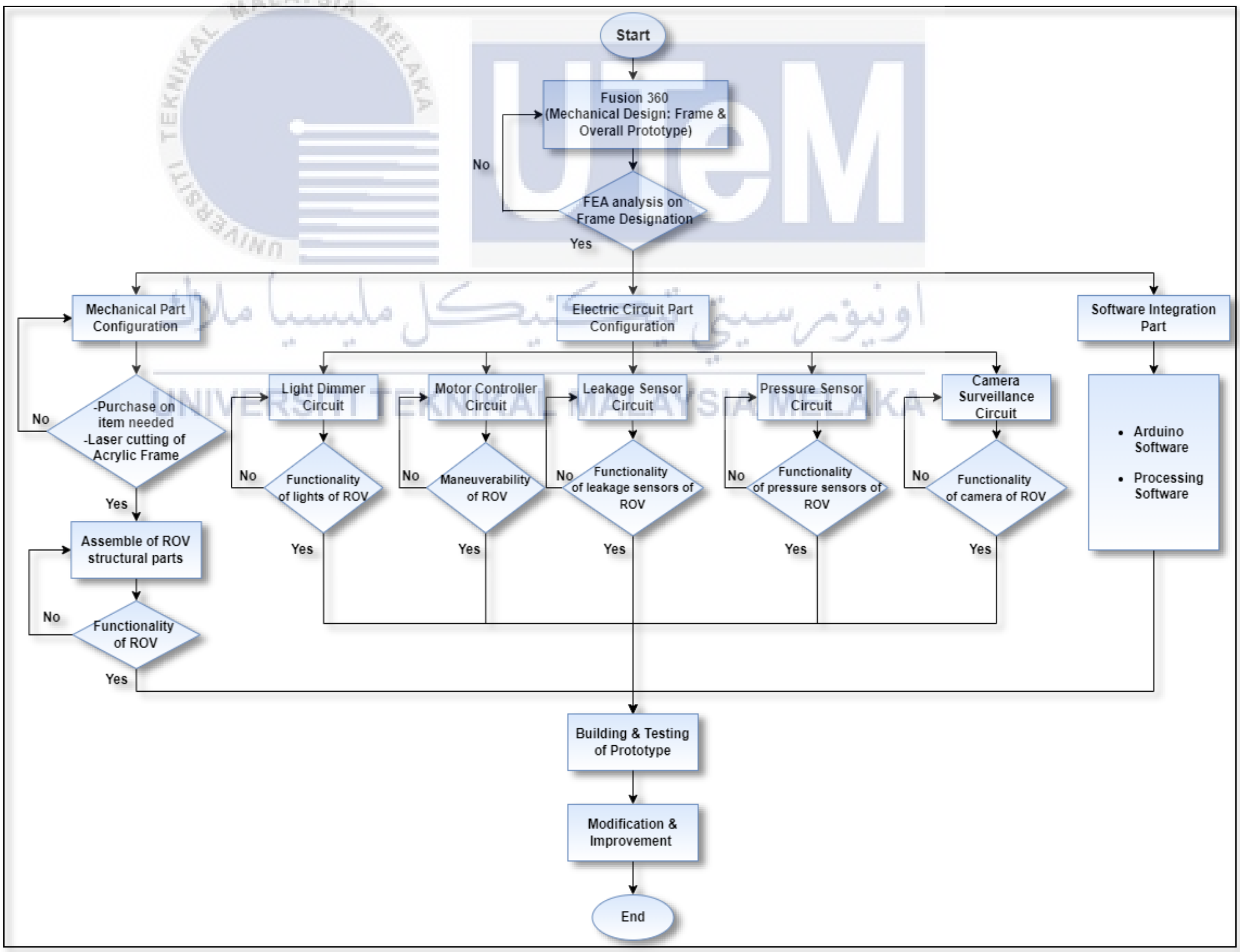


Figure 3.2: PSM Flow Chart

3.3 Mechanical Part Configuration

3.3.1 Specifications of ROV

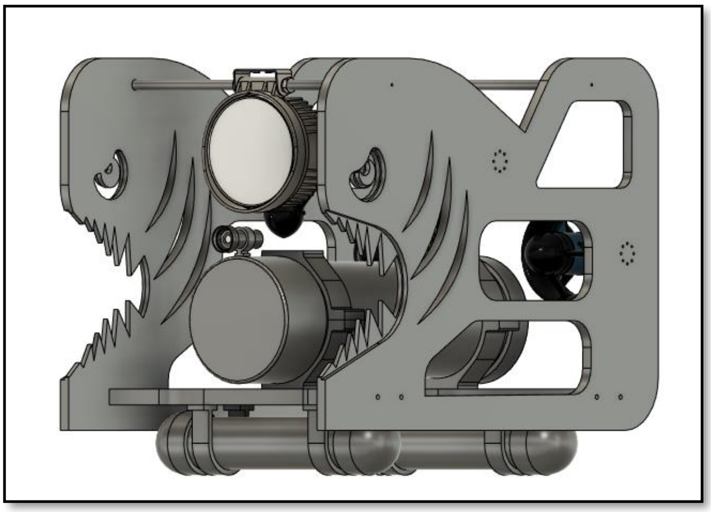


Figure 3.3: Overall Prototype Design

Table 3.1: Specification of ROV Designed

No.	Specifications	Description
1	Material of frame body	Acrylic
2	Structural Materials	PVC pipe
3	Weight	7.7 kg
4	Dimension	500 mm × 300 mm × 350 mm
5	Diving Depth	5 meters
6	Buoyancy	• Tubing Sponge • 90% negative buoyancy in water • Cat 5 cables to reduce drag
7	Thrusters	T200 Thruster
8	Propulsion System	4 thrusters (2 horizontal 90°,2 vertical 90°)
9	Full Throttle FWD/REV Thrust @ 12 V	3.71 / 2.92 kg f
	Full Throttle FWD/REV Thrust @ 16 V	5.25 / 4.1 kg f

	Full Throttle FWD/REV Thrust @ 20 V	6.7 / 5.05 kg f
10	Cables	Neutrally Buoyancy Tether
11	Computer control system	Arduino Uno as the microcontroller of controller, light, sensors & motor
12	Camera	1 endoscope camera (associated with laptop screen to have live video streaming function)
13	Lights	1 waterproof light
14	Sensors	Leakage sensor, Depth sensor, Pressure sensor and Temperature sensor
15	Mission	Underwater Inspection
16	Controlling method	Remote Control from surface

3.3.2 Designation of ROV prototype by using Fusion 360

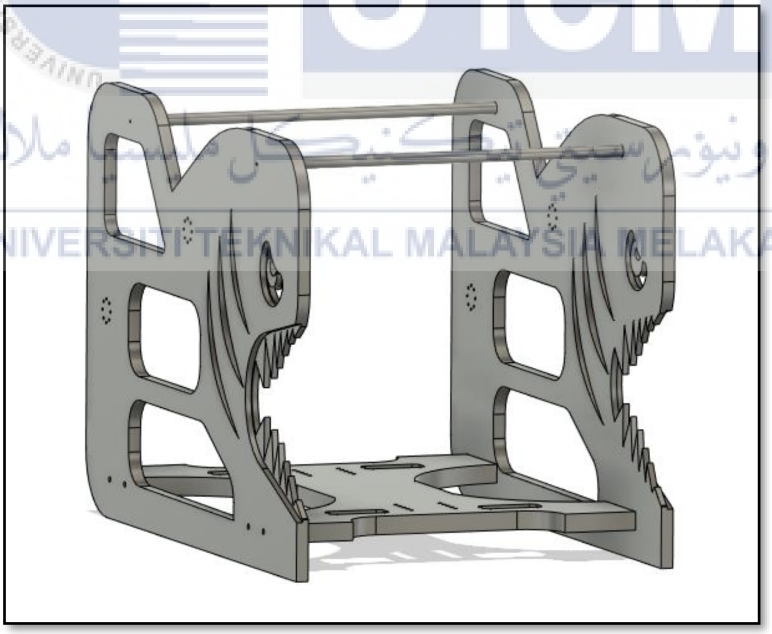


Figure 3.4: Frame of ROV

The material of frame body is made of acrylic because its advantageous in lightweight properties, durable as it can withstand regular wear and tear when undergoes underwater tasks. Acrylic also resistant to UV rays and moisture which make it as a suitable material of submerged materials where it may be exposed to sunlight and moisture.

There are some spaces designed within the ROV frame because of the factors of buoyancy. The space between the frame is for the purpose of allowing water to flow through. This will reducing the overall weight of ROV thus increasing the buoyancy. Besides, the existence of space between ROV frame is aimed to improve the hydrodynamics of the ROV. This will reduce the drag and resistance as the ROV moves through the water.

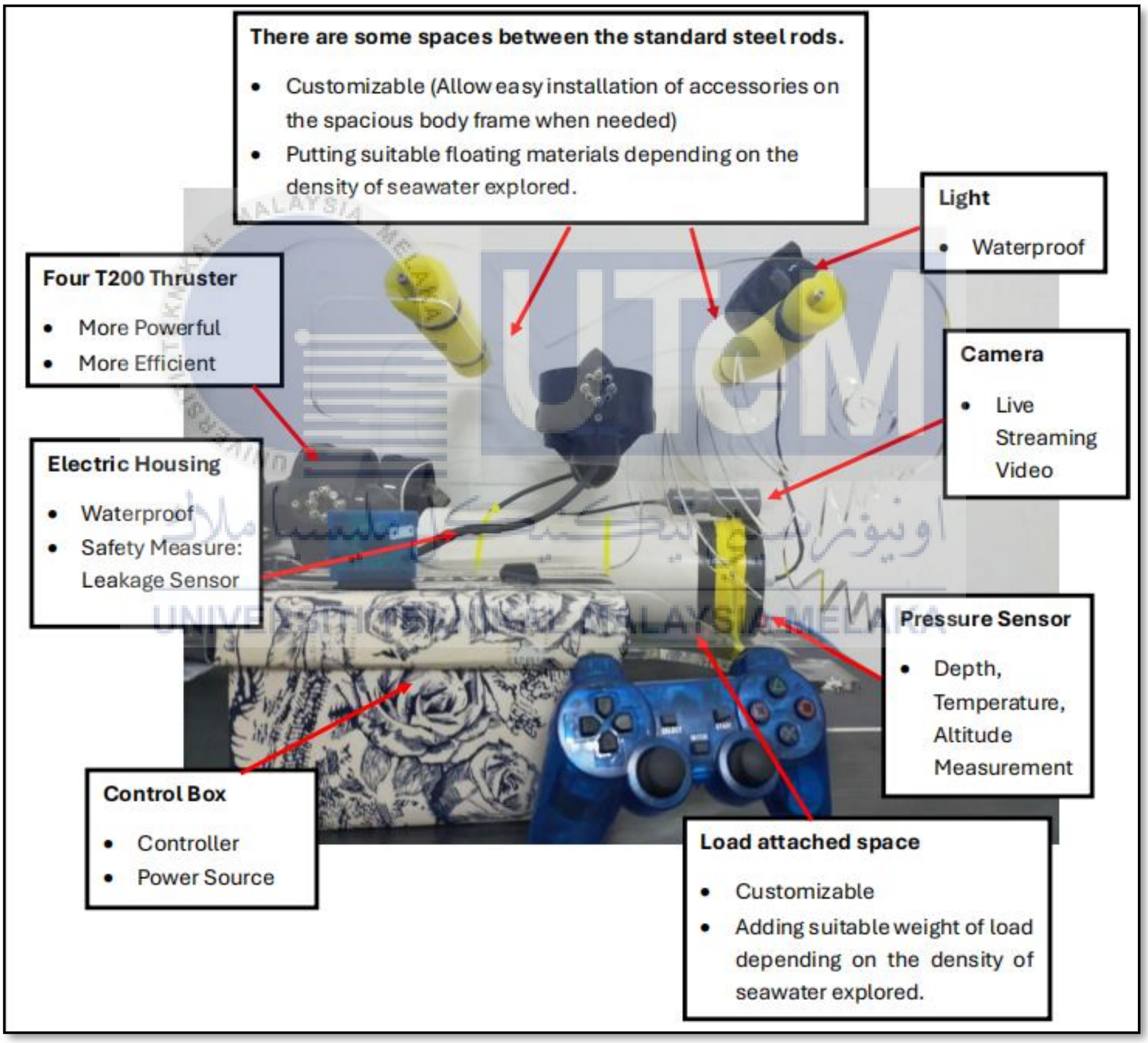


Figure 3.5: Components of Designation ROV

There are 4 thrusters' configuration for the propulsion system designation. There are 2 vertical thrusters located at 90 degrees at the top side of the ROV. The 90 degrees thruster giving a straight-forward motion, easier in controlling rising and submerging motion of ROV also known as depth controlling technique. There is other 2 horizontal thruster aligned at the 90 degrees at the back side of the ROV. The 90 degrees of thrusters having beneficial in more precise manoeuvrability, reducing the unintended drift which may occur in 45 degrees configuration.

Besides, the pressure hull is made of PVC. This is because PVC have the weight reduction properties, corrosion resistant characteristics and good electrical insulators. These benefits make the PVC as the materials of pressure hull which is aimed to store and protect the sensitive electronic components underwater.

Moreover, there are two PVC tubes which is hollow will be fixed at the bottom of ROV. The dense substances such as pebbles will be added into the PVC tube for adding the weight of overall ROV. This is due to the reason of adjusting the buoyant force acting on the ROV to make it achieve the desired depth in different density layers of sea. This make our ROV can be controlled when deployed at different types of water environment such as ocean and lake which may have different density of water.

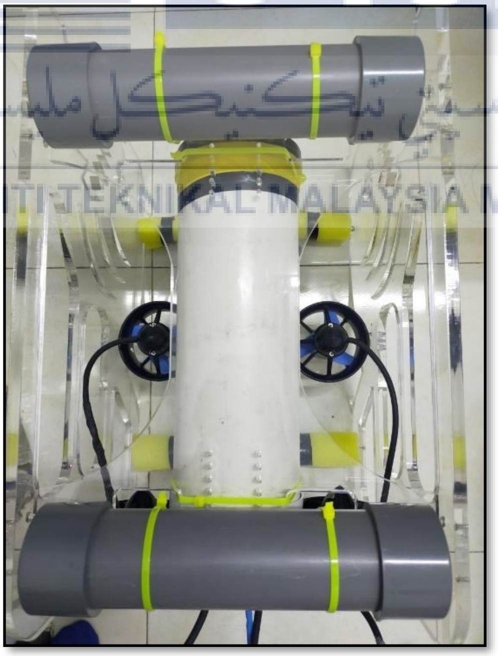


Figure 3.6: PVC tubes fixed at the bottom of ROV.

However, the two PVC underneath can be replaced also by stainless steel which can be directly attached to the below of ROV depend on user convenient.

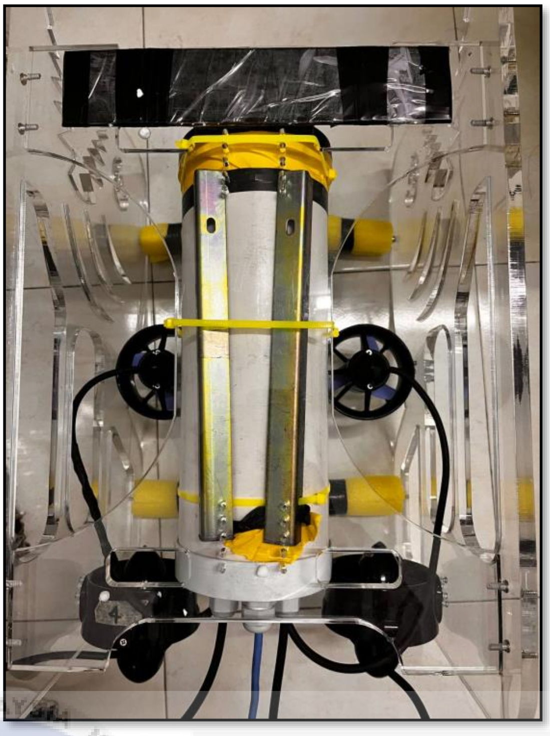


Figure 3.7: Stainless steel is directly attached to the below of ROV.

This ease of attachable different load is due to the bottom part of the ROV which is designed to have some hollow part to let it more flexible when handling different loads.

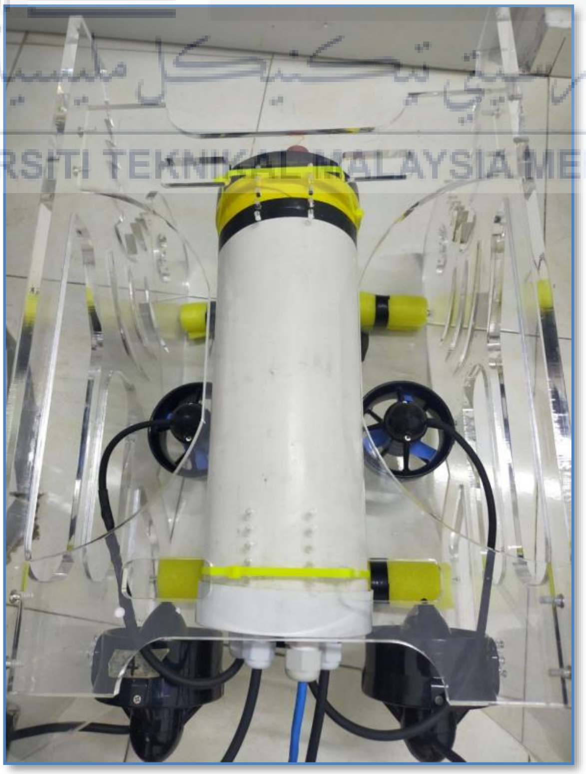


Figure 3.8: Hollow part at the bottom frame.

In addition, there is the integrations of components such as lights, sensor and camera that enhances the functionality of ROV. Generally, the underwater environments are lack of natural lights. Hence, there is the needs of lights for providing clear visibility for the onboard camera. Moreover, the sensor for pressure, depth and temperature are critical components in ROV for providing essential data in enhancing safe operations, precise navigation and supporting scientific research. Besides, the camera is important for the inspection purpose for underwater tasking. There will be a laptop screen associated with camera to provide live streaming video.

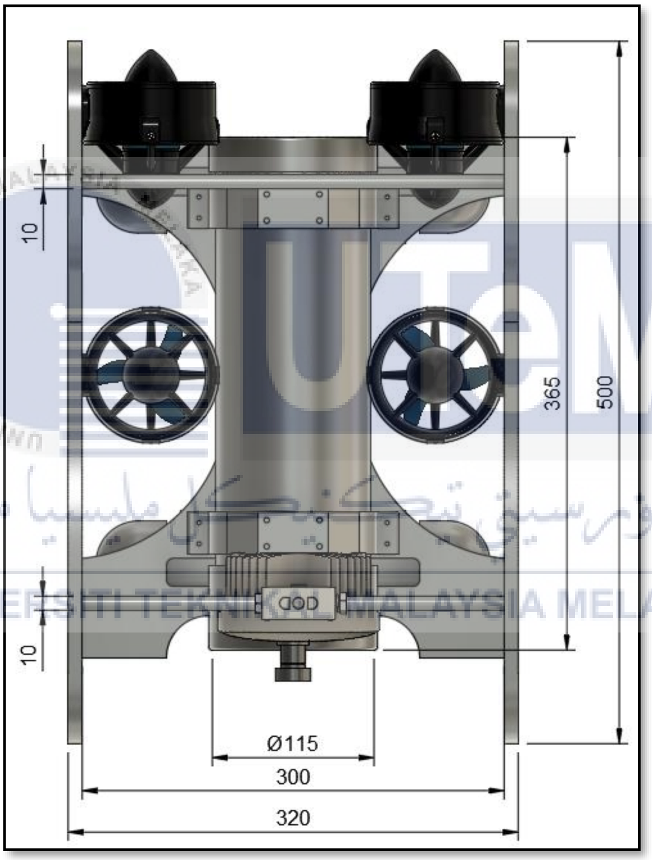


Figure 3.9: Top view of ROV

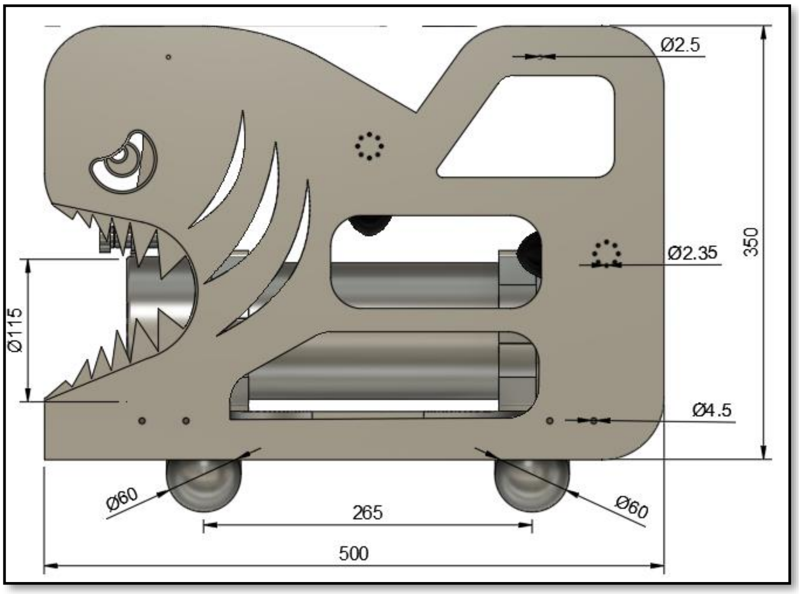


Figure 3.10: Side view of ROV

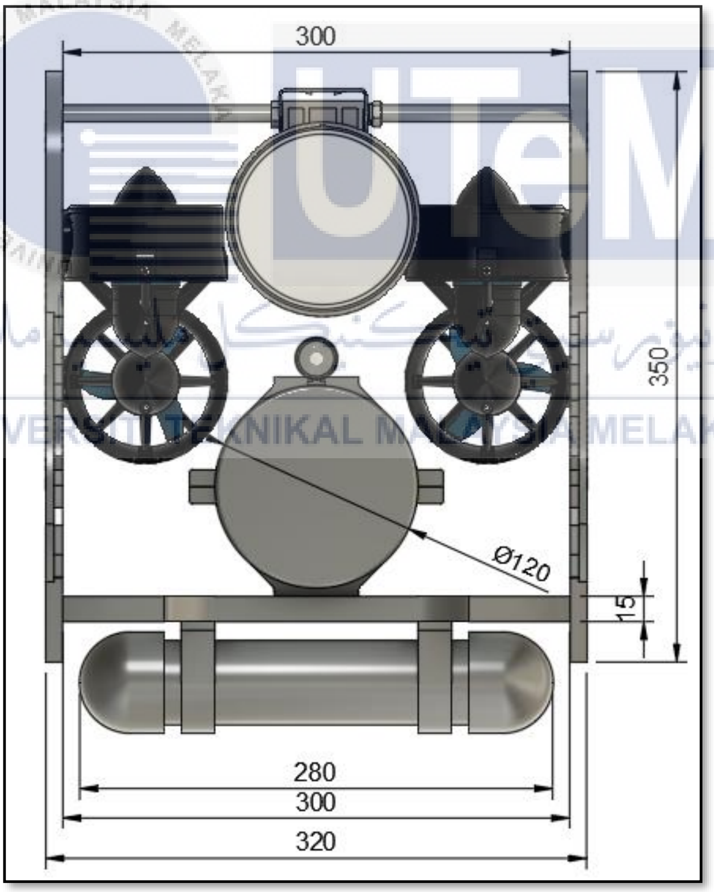


Figure 3.11: Front view of ROV

3.4 Centre of Gravity of ROV

The centre of gravity of ROV is important to be figured out for effective operations, and better manoeuvrability of ROV. The known centre coordinates of ROV helps in the navigation and control of ROV. Besides, it also helps in positioning the thrusters and other tools such as camera and light accurately.

The centre of gravity of ROV in coordination form can be found by using Fusion 360.
The centre of gravity is shown as below:
X: 235.031 mm
Y: 634.153 mm
Z: 137.70 mm

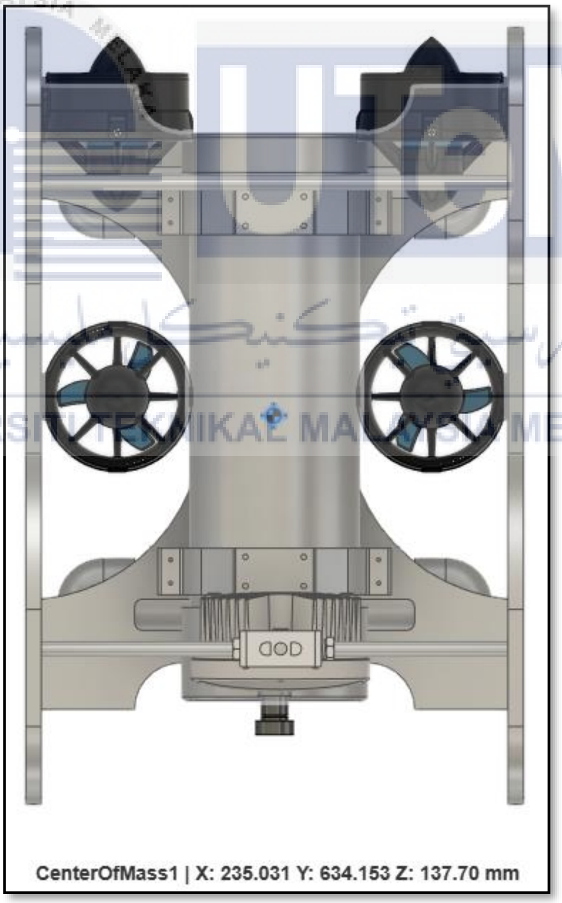


Figure 3.12: Centre of gravity of ROV.

3.5 Electrical Part Configuration

Electric circuits are crucial to well functionality and performance of ROV. They serve as the backbones for power distribution, control systems, sensor integration, and effective communication. Well-designed electric circuits contribute significantly to ROV's performance, reliability and adaptability, making the ROV as ideal tools for underwater inspection.

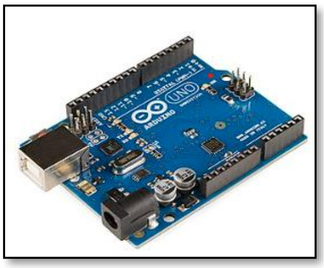
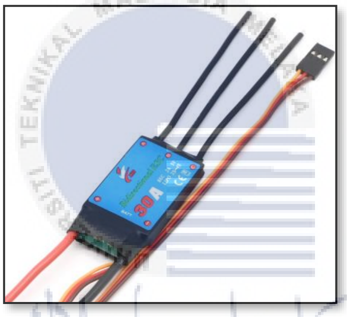
3.5.1 Components of Electric Circuits

There are 5 main circuits which consists of light dimmer circuit, motor controller circuit, leakage sensor circuit, pressure sensor circuit & surveillance camera circuit.

The table below shows the components and their functions respectively.

Table 3.2: Function of each component in electric circuit.

No.	Components	Functions
1	Thrusters T200  Figure 3.13: Thrusters T200	• Provide the necessary propulsion force for the forward, reverse, turn right, turn left, raising & submerging motion of ROV. • Controlled by the Arduino Uno via electronic speed controllers.

2	Arduino Uno  Figure 3.14: Arduino Uno	• Act as a central processing unit, receiving and interpreting signals from the PS2 joystick (controller of ROV). • Control outputs which are lights and thrusters based on joystick inputs. • Reads data from various sensors such as pressure and leakage sensor and provide real-time feedback by sending data to a connected computer.
3	Brushless Directional ESC (30A)  Figure 3.15: Brushless Directional ESC (30A)	• Regulate the power supplied to the thrusters based on the control signals from the Arduino. • Adjusting the speed and direction of thrusters by interpreting the PWM signals from the Arduino. • Connected between Arduino and thrusters, allowing the precise manoeuvrability of ROV.
4	PS2 Joystick  Figure 3.16: Wireless PS2 Joystick Controller	• Provide users input for manual controlling the movement and functions of ROV. • Connected to Arduino which interprets joystick movement to control the thrusters, lights and sensors.

5	Light  Figure 3.17: Light	• Provide visibility for ROV during underwater inspection. • Connected to Arduino's digital output pins. • Controlled by Arduino which can switch the lights on or off based on the signal from the PS2 joystick.
6	Leakage Sensor  Figure 3.18: Leakage Sensors	• Detect the presence of water inside electric housing of ROV. • Connected to one of the Arduino's analogue input pins.
7	Buzzer  Figure 3.19: Buzzer	• Buzzer emits a loud sound, alerting the users about presence of water inside electric housing of ROV. • Connected to one of the Arduino's digital output pins.

8	Pressure Sensor  Figure 3.20: Bar02 Pressure Sensor	• The sensor provides crucial data on pressure, temperature and depth for analysis purpose. • Connecting the pressure sensor to Arduino microcontroller for real-time data processing in ROV.
9	Waterproof Endoscope Camera  Figure 3.21: Waterproof Endoscope Camera	• Provides visual feedback from underwater environments. • Transmit live video feeds to operator through laptop screen, enabling real-time inspection and navigation.

3.5.2 Electronic Wiring

The figure below shows the electric wiring of overall ROV electric circuit.

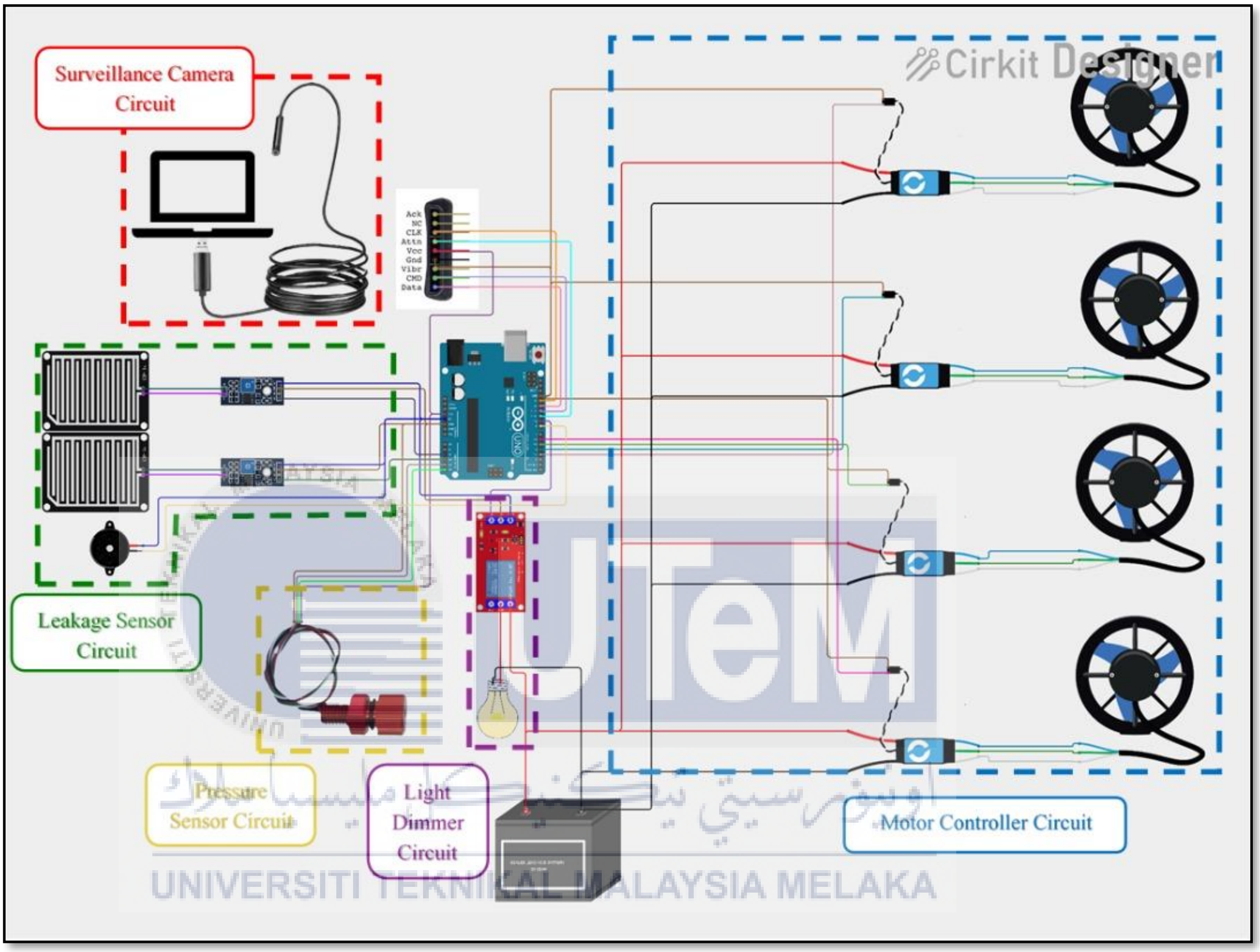


Figure 3.22: Overall electric circuit of ROV.

Each circuit shown in figure 3.19 must be carefully considered from the aspects of safety measures to ensure the system's reliability, safety and optimal performance.

Table 3.3: Safety measures for each type of circuits.

No.	Types of Circuit	Safety Measures
1	Light Dimmer Circuit	• Providing overcurrent protection by using relay module. • Providing electrical isolation between high-power side source (battery and light) and the low-power side source (Arduino). Protecting Arduino from high voltages.
2	Motor Controller Circuit	• Waterproofing techniques is done well to prevent water ingress into the motor controllers and thrusters to avoid short circuits. • Uses fuses to protect against overcurrent that might damage the motors.
3	Leakage Sensor Circuit	• Regular testing the sensor's functionality. • Having multiple sensors in critical areas for redundancy purpose.
4	Pressure Sensor Circuit	• Regularly calibrate the sensor to maintain its accuracy on data obtained.
5	Surveillance Camera Circuit	• Waterproof casing and connectors are used to protect the camera from water ingress. • The cable is protected by strain relief and sheathing to prevent damage.

3.5.3 Controller of ROV

The wireless PS2 joystick is used as a controller to remotely control the ROV's movements and functions with ease. Wireless PS2 joystick is the best option of controllers for its user-friendly and versatile interface for operating the ROV

The buttons on the PS2 joystick can be mapped to various functions such as turning on lights and performing various movement such as moving forward and backward. The Arduino software is integrated to respond to specific button presses.

The figure below shows the picture of a wireless PS2 joystick and the names of its buttons respectively.

Figure 3.23: Name of buttons on PS2 Joystick.

The table below shows the movement of ROV when each of the respective buttons are pressed.

Table 3.4: The movements of ROV when the L3 & R3 are moved with different directions.

Controller Conditions		**Functions**
L3 (Left Joystick)	R3 (Right Joystick)	
↑	↑	Moving Forward
↓	↓	Moving Backward
↑	↓	Turn Right
↓	↑	Turn Left

Table 3.5: The movements of ROV when different buttons of ROV is pressed.

Controller Conditions	**Functions**
L1 Button Pressed	Submerge
R1 Button Pressed	Raise
Square Button Pressed	Lights ON/OFF

3.6 Software Integration

3.6.1 Arduino Software

Arduino IDE is used for the development of complex control algorithms for the software design for controlling the ROV prototype, as it is a solid option for a platform effective for real-time control applications. These core algorithms will be responsible for handling data such as the depth, temperature, and pressure collected from the sensors attached on the ROV, such as the Bar02 pressure/depth sensor.

Figure 3.24: Arduino IDE

The data processing involves several steps, namely:

1. **Filtering:** Further improve the accuracy of sensor readings with noise reduction.
2. **Conversion:** Transforming pressure data into depth measurements and converting these measurements into usable units.
3. **Control Feedback:** Providing critical information about the current state of the ROV’s operation to the control system.

The algorithms developed with the Arduino IDE can also manage the lights and brushless motor thrusters through ZMR 30A bidirectional Electronic Speed Controllers (ESCs), which enables the ROV to move based on real-time inputs from the PS2 controller operated by the user. Offering precise control over the ROV when performing basic movements such as moving forward, backwards, raising, submerging, and turning left and right.

3.6.2 Processing Software

A graphical user interface (GUI) is developed for the ROV using a processing software that is free and open-source platform ideal for creating graphical interfaces.

Figure 3.25: Processing Software

The program acts as an interface for interactions between the microcontroller and the user by processing inputs from the PS2 controller, sending appropriate commands to the microcontroller according to the inputs processed, and receiving data such as water pressure, depth and temperature from the attached sensors to be displayed as a data for the user, allowing real time feedback to the user while observing the ROV prototype's behaviour and its surrounding environment.

An example of the user interface showing the data received from the sensor can be seen on the figure below.

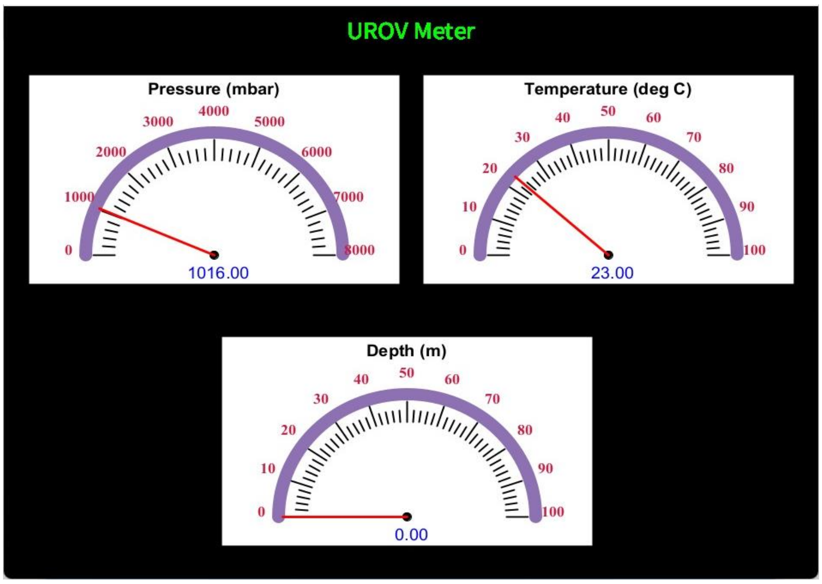


Figure 3.26: UROV Meter (Graphical User Interface)

Where several meters correspond to the live feedback and readings detected by the sensors on the ROV. This allows the user to stay updated and notified of the status of the ROV at all times, which is very useful while performing tasks underwater. In emergency situations, the user will be able to respond immediately if any of the meters show abnormal readings such as extremely high pressure and depth which might damage the ROV.

3.6.3 Surveillance Camera System

The ROV is equipped with a surveillance camera system that improves the efficiency and quality of underwater inspection tasks. The operator will be given live visual feedback to visually inspect underwater structures, marine life, or search areas. The integration of the camera with the control system allows for synchronized movement through the camera with the live visual feedback received, allowing the operator to navigate and perform tasks underwater with ease and they will be able to easily navigate around obstacles and debris. Not only that, but it also helps the operator to quickly understand the situation and condition of the surroundings around the ROV instead of just relying on meter readings and guessing with the data observed.

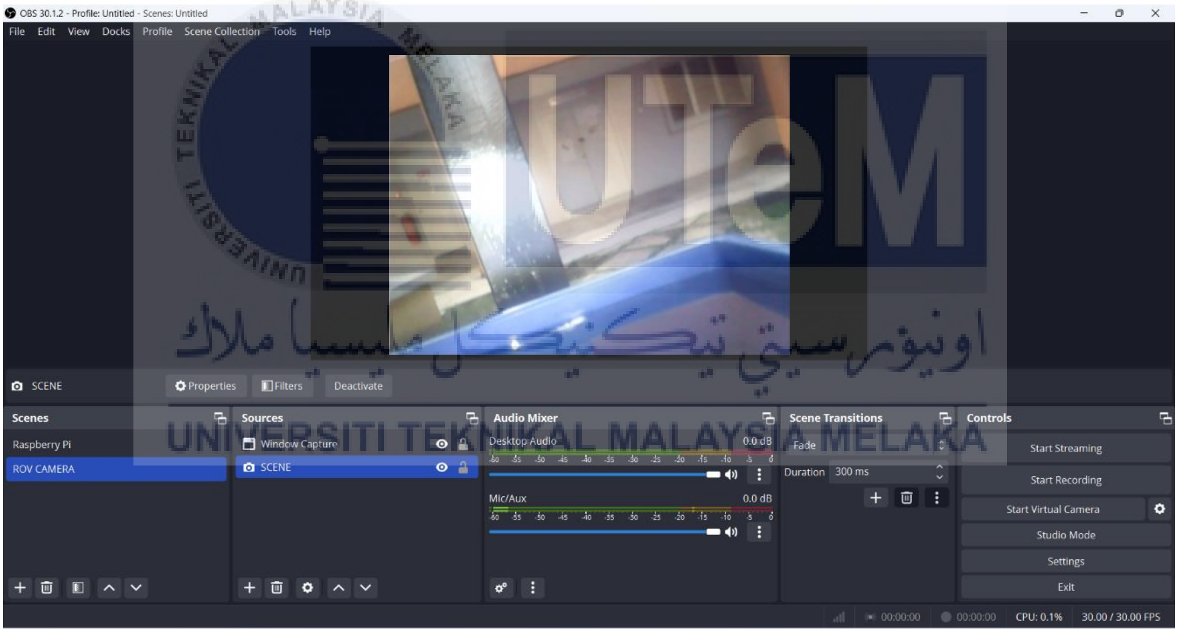


Figure 3.27: The live streaming video through OBS studio software (laptop screen)

3.7 List of Experiments

Table 3.6: List of Experiments

No.	List of Experiments	Objective 1	Objective 2
1	Finite Elements Analysis (Testing on the durability of frame)	✓	
2	Testing on the Waterproof Body Structure	✓	
3	Testing on the Buoyancy of ROV		✓
4	Testing on the manoeuvrability of ROV (Forward & Reverse)		✓
5	Testing on the manoeuvrability of ROV (Turning Left & Right)		✓
6	Testing on the manoeuvrability of ROV (Raising & Submerging)		✓

3.7.1 Experiment 1: Finite Elements Analysis

Objectives:

To evaluate and ensure that the structural frame designed is able to withstand the loads and pressures encountered during underwater operations.

Hypothesis:

a) The stress distribution of ROV will remain within safe limits, ensuring the frame does not experience permanent deformation.

b) The frame designed will demonstrate adequate safety factors.

Apparatus:

a) Fusion 360 (Software)

Procedure:

1) The experiment will start as the flow chart shown below:
2) There are two types of analysis will be carried out:
    a) Stress distribution
    b) Safety Factor

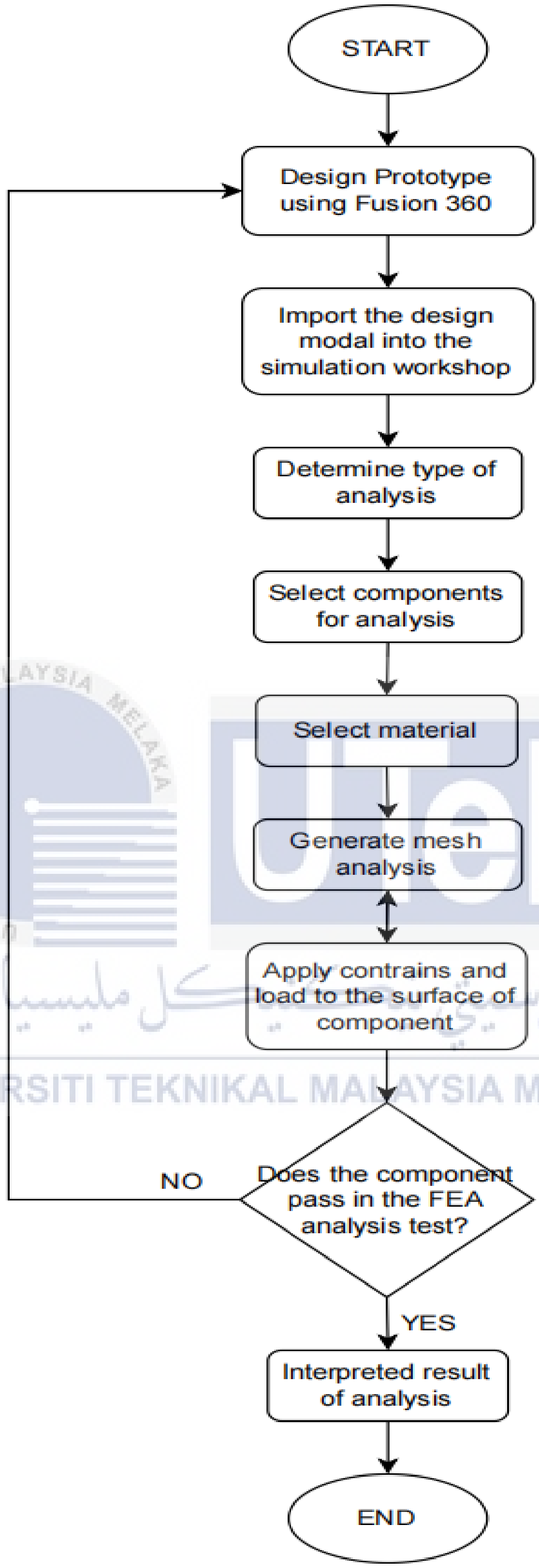


Figure 3.28: Flow Chart of FEA

3.7.2 Experiment 2: Testing on Waterproof Body Structure

Objectives:

To determine and ensure that the sealing condition of electronic housing is perfectly waterproof.

Hypothesis:

The sealing condition of electric housing is in the good condition and able to withstand the underwater pressure for the periods of 3 hours.

Apparatus:

a) Designed ROV
b) Electronic Housing
c) Lab Pool
d) Stopwatch

Procedure:

1) The electronic housing is properly sealed and capped.
2) The electronic housing is soaked in the lab pool for 3 hours.
3) The condition of electronic housing is checked and observed in 30 minutes intervals for 3 hours.
4) The two leakage sensors which are put inside the electronic housing will send the signal to Arduino uno, and the buzzer will sound if there is any water flowing into it.
5) The observation of leakage sensors is recorded in table.
6) The experiment is repeated for several times until the perfectly sealed electronic housing is obtained which means there is no detection of any leakage sensors.

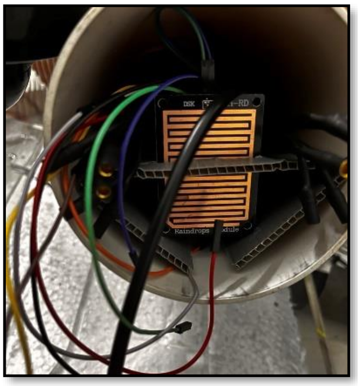


Figure 3.29: Leakage sensors is put inside the electric housing.

3.7.3 Experiment 3: Testing on the Buoyancy of ROV.

Objectives:

To determine the optimal weight that needed to make ROV as ideal slightly positive which is 90% negativity buoyancy.

Hypothesis:

a) When ROV is rises to surface of water, ROV exist as positive buoyancy.
b) When ROV is neither rise nor sink in water, ROV exist as neutral buoyancy.
c) When ROV is sinks into water, ROV exist as negatively buoyancy.

Apparatus:

a) Load (steel or iron plate)
b) Designed ROV
c) Lab Pool
d) Measuring Tape
e) Weighing Machine

Procedure:

1) The overall length of ROV is measured and recorded before putting in the water.
2) The position of ROV in water without attached to any load is measured and tapped to get the mark for calculating buoyancy purpose.
3) Designed ROV is put in the lab pool for 3 minutes. The length of body of ROV in water is measured and tapped for marking.
4) The weight of ROV is increased by using various of weight of the load and the position of negative buoyancy of ROV is observed.
5) The percentage of negativity buoyancy is calculated by using formula below:

Original length of ROV: 350 mm

$$\text{Percentage} = \frac{length\ of\ ROV\ body\ sink\ in\ water}{original\ length\ of\ ROV\ body} \times 100\ \%$$

6) The weight of load is continually attached to ROV until the designed ROV achieve 90% negatively buoyancy.
7) The load's position is adjusted to make the ROV position is in the stable condition.
8) The data is recorded in a table.

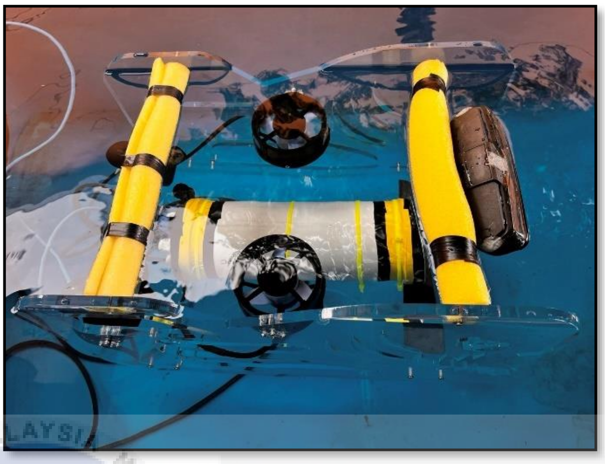


Figure 3.30: ROV achieved negativity 90% buoyancy in lab pool.

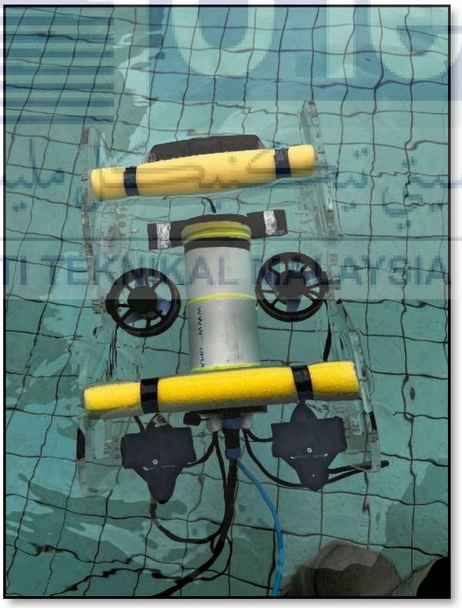


Figure 3.31: ROV achieved negativity 90% buoyancy in swimming pool.

3.7.4 Experiment 4: Testing on the Manoeuvrability of ROV.

This experiment 4 has been divided into 3 sub-experiments which respectively tested on the motion of ROV which are moving forward & reverse, turning right & left and finally is motion of rising and submerging. The data obtained later is analysed to obtain the value of its respectively parameters of velocity and acceleration.

3.7.4.1 Experiment 4.1: Moving Forward & Reverse

Objectives:

To determine the speed, velocity and acceleration of ROV during forward and reverse motion in a controlled environment.

Hypothesis:

ROV will achieve a consistent speed and velocity in both forward and reverse direction with symmetrical acceleration profiles, assuming there is no other external forces and obstacles.

Apparatus:

a) Designed ROV
b) ROV Controller
c) Lab Pool & Swimming Pool
d) Stopwatch
e) Measuring Tape

Procedure:

1) The experiment will be taken place in lab pool and swimming pool.
2) First, the experiment will be taken place in lab pool with a straight path of a known distance (2.4 meters) which is made by using a measuring tape.
3) The condition of ROV is checked for ensuring it is ready for launching.
4) The electric housing is checked for ensuring it is perfectly sealed.
5) The ROV is placed at the starting point in the water.
6) The buoyancy state of ROV is checked.
7) The loads are attached to the frame of ROV to make it become 90% negatively buoyancy.

8) The main switch of ROV is switched ON for ensuring the controller is in ON condition.
9) The ROV horizontal thrusters are controlled by using PS2 joystick controller for the forward movement.
10) The stopwatch is started as the ROV is start moving forward.
11) The distance of ROV moving forward is monitored, and the time taken is recorded at regular intervals of 0.2 meters.
12) The stopwatch is stopped once the ROV reached the end point.
13) The step 9 to 11 is repeated for reverse motion.
14) The position, velocity and acceleration can be calculated by the formula as shown below:

$$Velocity = \frac{Displacement}{Time}$$

$$Acceleration = \frac{Velocity}{Time}$$

15) The experiment is repeated three times to ensure the data obtained is accuracy and consistency.
16) Step 2 to step 14 is repeated by changing the venue to a swimming pool with a straight path of a known distance (6 meters) which is made by using a measuring tape.

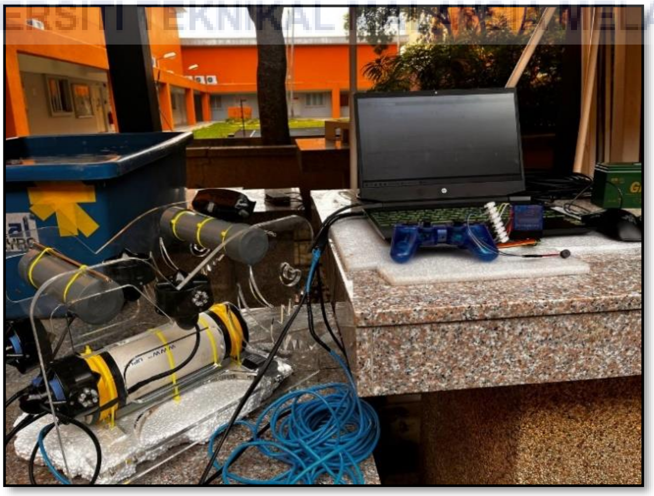


Figure 3.32: Experiment Set up at Lab Pool

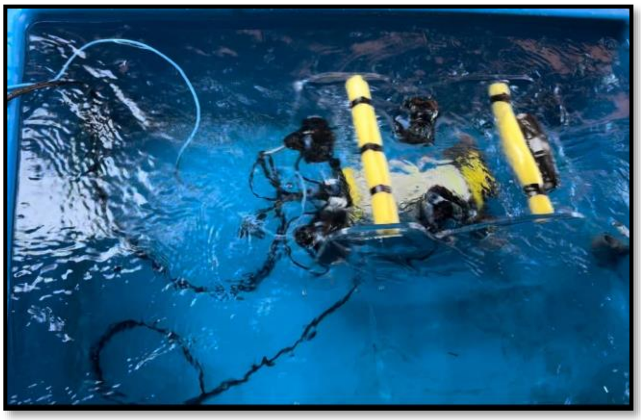


Figure 3.33: ROV is moving forward & backward in lab pool.

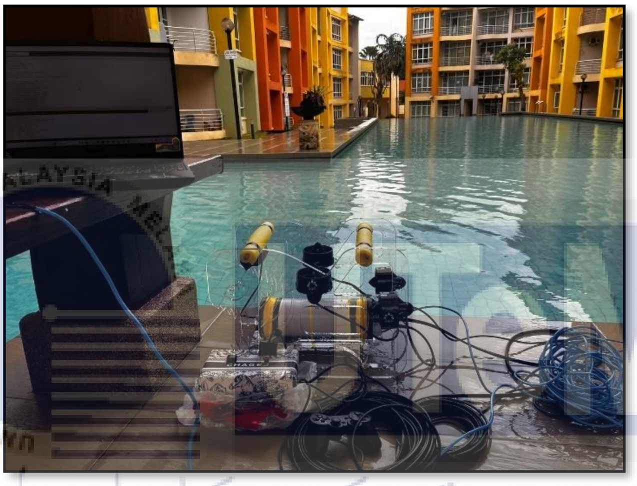


Figure 3.34: Experiment Set Up in Swimming Pool

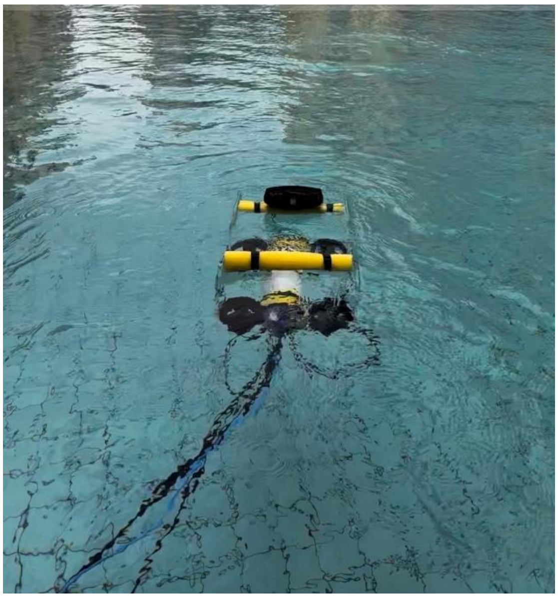


Figure 3.35:ROV is moving forward & backward in swimming pool.

3.7.4.2 Experiment 4.2: Turning Right & Left

Objectives:

To measure the time taken and calculate the angular velocity and angular acceleration of an ROV during a 180-degrees turning to right and 180-degrees turning to left.

Hypothesis

The ROV will exhibit similar angular velocity and symmetrical angular acceleration profile for both 180-degrees turning to right and left, assuming there is symmetrical thrust and torque applied to it.

Apparatus:

a) Designed ROV
b) ROV Controller
c) Swimming Pool
d) Stopwatch

Procedures:

1) The experiment will be taken place in swimming pool.
2) The condition of ROV is checked for ensuring it is ready for launching.
3) The electric housing is checked for ensuring it is perfectly sealed.
4) The ROV is placed at the starting point in the lab pool.
5) The buoyancy state of ROV is checked.
6) The loads are attached to the frame of ROV to make it become 90% negatively buoyancy.
7) The position of ROV is marked before the turn.
8) The main switch of ROV is switched ON for ensuring the controller is in ON condition.
9) The ROV horizontal thrusters are controlled by using PS2 joystick controller to move the ROV.
10) The stopwatch is started as the ROV is started to turn right.
11) The time taken for ROV to reach every 30 degrees interval until 180-degrees turn is recorded.
12) The angular velocity and angular acceleration are calculated by the formulas below:

$$Angular\ velocity = \frac{Angle\ turned}{Time\ taken}$$

$$Angular\ acceleration = \frac{Angular\ velocity}{Time\ taken}$$

13) The step 9 to 11 is repeated for the condition of turning left.
14) The experiment is repeated three times to ensure the data obtained is accuracy and consistency.

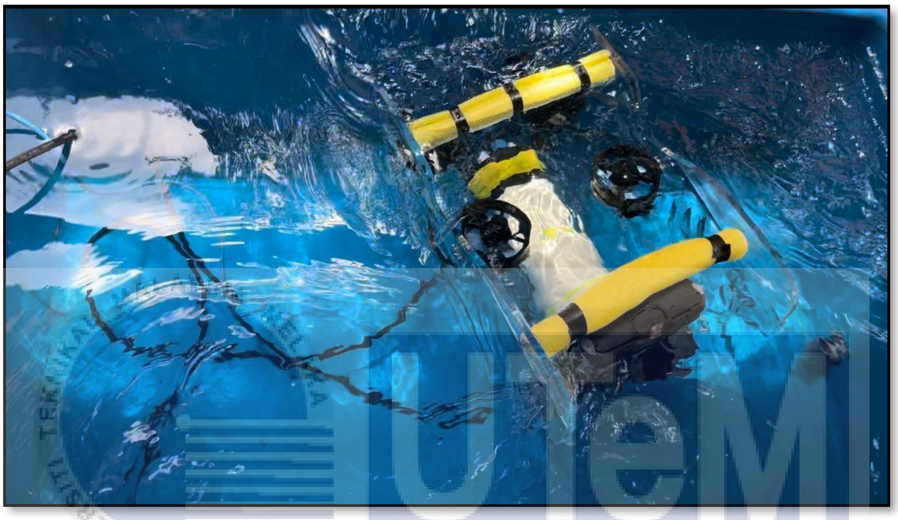


Figure 3.36: ROV is turning right & left in lab pool.

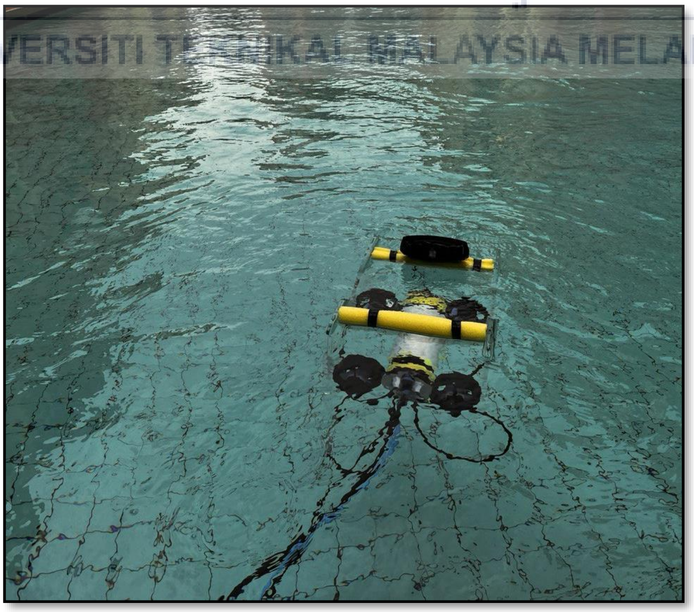


Figure 3.37: ROV is turning right & left in swimming pool.

3.7.4.3 Experiment 4.3: Raising & Submerging

Objectives:

To determine the vertical speed, velocity and acceleration of an ROV for the motion of rising and submerging in water.

Hypothesis:

The ROV will raise and submerge at consistent speed with symmetrical acceleration profile, assuming there are uniform propulsion forces applied to it.

Apparatus

a) Designed ROV

b) ROV Controller

c) Lab Pool & Swimming Pool

d) Stopwatch

Procedures:

1) The experiment will be taken place in lab pool and swimming pool.
2) First, the experiment will be taken place in lab pool with a known depth distance (1.5 meters) which is made by using a measuring tape.
3) The condition of ROV is checked for ensuring it is ready for launching.
4) The electric housing is checked for ensuring it is perfectly sealed.
5) The ROV is placed at the starting depth in the lab pool.
6) The buoyancy state of ROV is checked.
7) The loads are attached to the frame of ROV to make it become 90% negatively buoyancy.
8) The main switch of ROV is switched ON for ensuring the controller is in ON condition.
9) The ROV vertical thrusters are controlled by using PS2 joystick controller to move the ROV.
10) The stopwatch is started as the ROV is started to submerge.
11) The distance of ROV submerging is monitored, and the time taken is recorded at regular intervals of 0.2 meters.
12) The stopwatch is stopped once the ROV reached the end point.
13) The step 10 to 12 is repeated for raising motion.

14) The velocity and acceleration can be calculated by the formula as shown below:

$$Velocity = \frac{Displacement}{Time}$$

$$Acceleration = \frac{Velocity}{Time}$$

15) The experiment is repeated three times to ensure the data obtained is accuracy and consistency.
16) Step 2 to step 15 is repeated by changing the venue to a swimming pool with a known depth distance (9.5 meters) which is made by using a measuring tape.

Figure 3.38: ROV is submerging in lab pool.

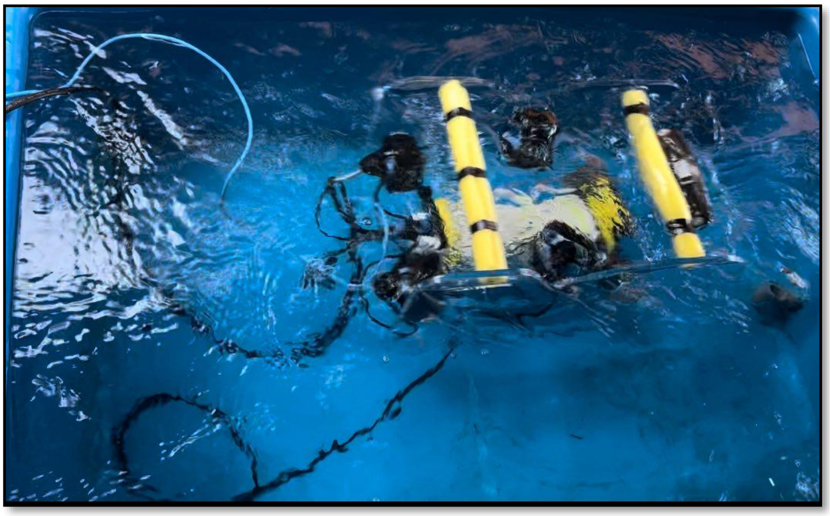


Figure 3.39: ROV is raising in lab pool.

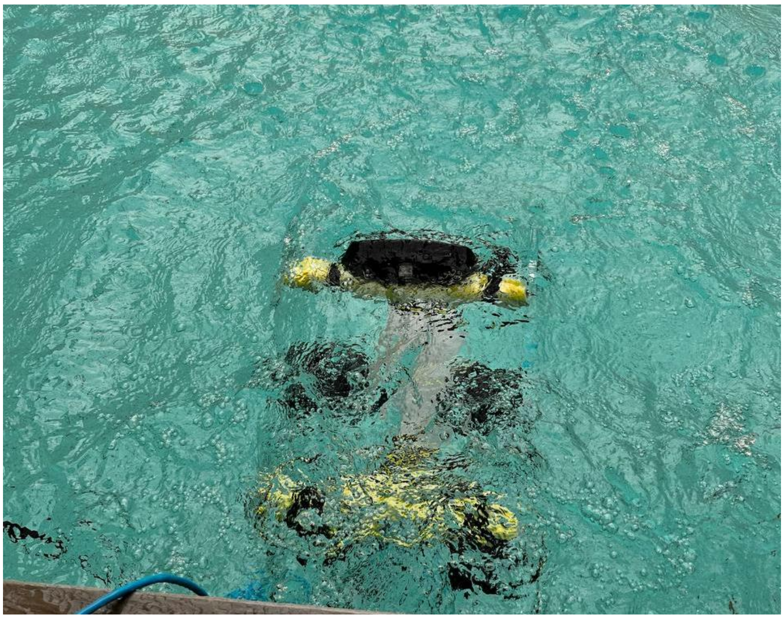


Figure 3.40: ROV is submerging in swimming pool.

Figure 3.41: ROV is raising in swimming pool.

3.8 Summary

In summary, upon to the project flow chart, the mechanical part, electrical part and software part of ROV is done perfectly within the time given. For mechanical part, there is the brief explanation about designation of ROV prototype by using Fusion 360. The explanation covers the aspect of specifications, advantages and uniqueness.

For the electrical parts, there is the secure connection among all electric components. Checking for proper voltage levels, signal integrity and potential short circuits. Protective measure is done to safeguard the electronics against overloads and spikes.

For the Software part, the Arduino is used for doing programming code for manoeuvrability of ROV. The ROV is moved based on the real-time inputs from the PS2 controller operated by the user. Besides, the processing software is used to create a graphical user interface (GUI). This interface is used to show the measurement data on temperature, depth and pressure when ROV is doing underwater inspection. Besides, there is surveillance camera system which associated with OBS studio software to give operator live visual feedback to visually inspect underwater structures, marine life, or search areas.

The specifications of designed ROV will be tested and analysed from different experiments from different parameters such as finite element analysis, waterproof body structure, buoyancy, velocity and acceleration on movement of 4-DOF. Respective experiments are described in a list and the procedures of each experiment are provided with a brief explanation.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the prototype of ROV will be analysed on several experiment to ensure its well functionality from the aspect of strongness, ability to withstand the pressure until maximum diving depth of 5 meters, and safety of factors. This all criteria can be tested on experiment 1: Finite element analysis.

Besides, the ROV will be tested on different aspect such as waterproof body structure, buoyancy and stability. The results obtained will then tabulated in tables and undergo analysis. These experiments are important to ensure that the ROV can perform effectively in underwater environment.

For the precise manoeuvrability of ROV, the ROV has been tested on the movement on moving forward and backward, raising and submerging in term of velocity and acceleration. These experiments have been conducted on two different venues such as lab pool and swimming pool to ensure the accuracy of data obtained. However, the experiments of turning right and left only taken place in lab pool because the swimming pool able to provides controlled and calm environment, ensuring that external factors such as currents and waves do not affect the ROV's turning movements

By conducting a series of targeted experiments, the project aims to verify that the ROV meets all design criteria and can perform effectively in real-world underwater environments for underwater inspection.

4.2 Experiment 1: Preliminary Result of Finite Element Analysis

In this chapter, the static stress of ROV is studied in finite element structural analyses. According to the Fusion 360 website quoted, the following conditions must be true for the validation of static stress analysis [46]:

- The loading only causes small deflection or rotation on the objects. The deformation caused must not have a significant effect on the surface area where the loads are applied, load direction and load magnitude.
- The stiffness and the strength of materials remains not change.
- In loading conditions, the dynamic effects caused are not significant.

In this project, the static stress analysis is used to check for the ROV frame its mechanical parts which consists of base frame with PVC pipe (attachable to load) and electric housing (storage of electric circuit).

The stress analysis of the ROV frame can be observed through the rainbow spectrum which uses the concept of colour gradient to represent the stress levels on a ROV model's surface. The area with high stress concentration is represented by warms colours such as reds and oranges, while the area with low stress concentration is represented by cool colours which are blues and green. Generally, the green colour shows that the materials are experiencing a moderate stress level which means the stresses experienced is within the acceptable limits.

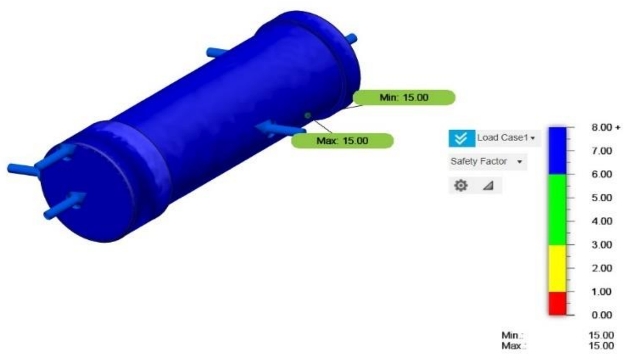
The stress analysis is used to check for the acceptability of underwater pressure that will be withstand by the designed ROV. This will check for the ability of ROV designed to submerge to the deep-sea level about its maximum diving rate of 5 meters underwater.

Table 4.1: Safety Factor Analysis of the Components of ROV

<table>
<tr><th>No.</th><th>Components of ROV</th><th>Safety Factor Analysis</th></tr>
<tr><td>1</td><td>Frame of ROV</td><td>

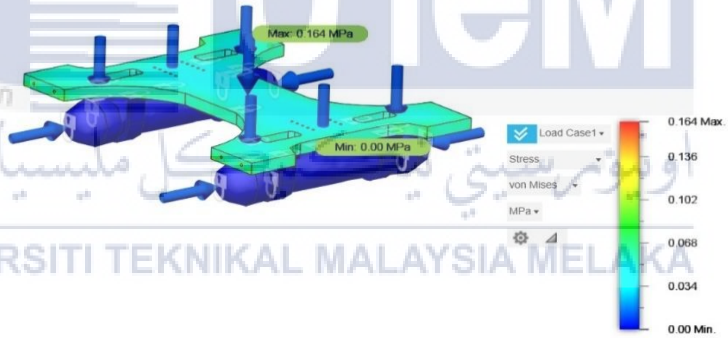
Maximum safety factor: 8.00</td></tr>
<tr><td>2</td><td>Base frame
&
PVC pipe</td><td>

Maximum safety factor: 8.00</td></tr>
<tr><td>3</td><td>Electric Housing

(Storage of Electrical Circuit)</td><td>

Maximum safety factor: 8.00</td></tr>
</table>

Table 4.2: Stress Analysis of the Components of ROV

No.	Components of ROV	Stress Analysis
1	Frame of ROV	 **Maximum stress level: 3.503MPa**
2	Base frame & PVC pipe	 **Maximum stress level: 0.164 MPa**
3	Electric Housing (Storage of Electrical Circuit)	 **Maximum stress level: 0.064 MPa**

Discussion:

In short, the objective of this ROV frame designed to be strong enough to dive at maximum rate of 5 meters underwater is achieved. Hence, FEA analysis is shown that the main components of the ROV is able to withstand the pressure beyond 5 meters underwater which is proved by the formula of hydrostatic pressure shown as below: [47]

Formula of Hydrostatic pressure:

Where,

P = Pressure in Pascals (Pa)

ρ = density of fluids in kilograms per cubic meter (kg/m^3)

g = gravitational acceleration (m/ s^2)

h = depth in meters (m)

As the knowledge of average density of sea water = 1025 kg/ m^3

Depth of diving = 5 meters

P = ρgh

= 1025 (9.81) (5)

= 50.3 kPa

Below show the results obtained from FEA for the maximum stress level for each of the components of ROV:

i. Frame ROV: 3.503 MPa (3503 kPa)
ii. Base frame & PVC pipe: 0.164 MPa (164 kPa)
iii. Electric Housing: 0.064 MPa (64 kPa)

Conclusion:

In conclusion, objective 1 that desire to design an aesthetic ROV frame which strong enough to dive at a maximum rate of 5 meters is achieved. This is due to the FEA analysis that has been done successfully to prove that the components of ROV designed are able to withstand the pressure of more than 50.3 kPa.

Overall, the FEA analysis provides assurance that the designation of components of ROV is robust and the factor of safety analysis of the components of ROV are greater than 1. The positives outcome obtained has proved that designation of ROV is suitable for inspection ROV purpose and ready to be proceed to next step: hardware fabrication.

4.3 Experiment 2: Testing on Waterproof Body Structure

Indicator:

	Buzzer no sound, meaning the leaking sensors are not activated, no leakage of water
	Buzzer is ON, meaning the leaking sensors are activated, water leakage is detected

Results:

Table 4.3: Observation of Waterproof Body Structure

Time (min)	Trial 1	Trial 2	Trial 3
	Leakage Sensors	Leakage Sensors	Leakage Sensors
30			
60			
90			
120			
150			
180			

Discussion:

Table 4.4: Discussion on Experiment of Waterproof Body Structure

No.	Observation	Reason
Trial 1	At 90th minutes, a leakage was detected.	• The tape used was not able to withstand water for long periods of time. • The tape is not sealed properly.
Trial 2	At 120th minutes, a leakage was detected.	• The tape is sealed properly but need improve from the quality of tape used. • This indicates that the tape's adhesive properties degrade over time when exposed to water.
Trial 3	There are no leakages occurred.	• The sealing is done by glue PVC and high durable water-resistance wate tape. • Creating a robust and reliable seal.

Discussion:

The experiment has successfully shown that the objective 1 has achieved by ensuring electronic housing is perfectly sealed and waterproof. The initial trials with tape even with improved sealing method were not entirely successful in preventing leakage. The most effective sealing method is the usage of glue PVC combined with high durable water-resistant tape which providing a reliable and long-lasting waterproof seal.

4.4 Experiment 3: Testing on the Buoyancy of ROV.

Results:

Original length of ROV: 350 mm

$$\text{Percentage} = \frac{length\ of\ ROV\ body\ sink\ in\ water}{original\ length\ of\ ROV\ body} \times 100\ \%$$

Mass of load added (kg)	First Trial (Negative Buoyancy)		Second Trial (Negative Buoyancy)	
	Length of body sink in water (mm)	Percentage (%)	Length of body sink in water(mm)	Percentage (%)
0.3	175	50.00	178	50.86
0.5	210	60.00	212	60.57
0.6	240	68.57	246	70.29
0.7	279	79.71	281	80.29
0.8	320	91.429	321	91.71

Discussion:

The experiment has successfully achieved objective 1 which make the ROV as slightly positive buoyancy (90% negative buoyancy).

The experiment conducted has demonstrated that different weights attached to ROV produce varying degrees of negative buoyancy for the ROV. The weight required for ROV to achieve 90% negative buoyancy is 0.8 kg. At this buoyancy level, the ROV exhibit the best performance with minimal tilt and oscillation, making it the most stable configuration among the tested weights.

4.5 Experiment 3: Moving Forward & Backward

4.5.1 Venue: Lab Pool (Straight path distance: 2.4 meters)

Moving Forward

Table 4.5: Time taken for ROV is recorded at regular intervals of 0.2 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0	0	0	0	0
0.2	0.3	0.2	0.2	0.2333
0.4	0.7	0.6	0.4	0.5667
0.6	1.0	0.9	0.7	0.8667
0.8	1.3	1.2	1.0	1.1667
1.0	1.7	1.6	1.3	1.5333
1.2	2	1.9	1.6	1.8333
1.4	2.2	2.1	1.9	2.0667
1.6	2.7	2.4	2.1	2.4000
1.8	3.0	2.6	2.4	2.6667
2.0	3.4	3.0	2.6	3.000
2.2	3.7	3.3	3.0	3.3333
2.4	4.0	3.8	3.5	3.7667

Table 4.6: Performance of ROV on Forward Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0	0	0	0
0.2	0.2333	0.8573	3.6745
0.4	0.5667	0.7058	1.2455
0.6	0.8667	0.6923	0.7988
0.8	1.1667	0.6857	0.5877
1.0	1.5333	0.6522	0.4253
1.2	1.8333	0.6546	0.3570
1.4	2.0667	0.6774	0.3278
1.6	2.4000	0.6667	0.2778
1.8	2.6667	0.6750	0.2531
2.0	3.0000	0.6667	0.2222
2.2	3.3333	0.6600	0.1980
2.4	3.7667	0.6372	0.1692

Moving Backward

Table 4.7: Time taken for ROV is recorded at regular intervals of 0.2 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0.0	0.0	0.0	0.0	0.0000
0.2	0.2	0.3	0.1	0.2000
0.4	0.5	0.6	0.4	0.5000
0.6	0.9	1.2	0.7	0.9333
0.8	1.3	1.5	1.2	1.3333
1.0	1.6	1.8	1.5	1.6333
1.2	1.9	2.1	1.8	1.9333
1.4	2.3	2.4	2.1	2.2667
1.6	2.6	2.7	2.4	2.5667
1.8	2.8	2.9	2.6	2.7667
2.0	3.0	3.1	2.9	3.000
2.2	3.2	3.3	3.0	3.1667
2.4	3.5	3.6	3.3	3.4667

Table 4.8: Performance of ROV on Backward Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0.00	0.0000	0.0000	0.0000
0.2	0.2000	1.0000	5.0000
0.4	0.5000	0.8000	1.6000
0.6	0.9333	0.6429	0.6888
0.8	1.3333	0.6000	0.4500
1.0	1.6333	0.6123	0.3749
1.2	1.9333	0.6207	0.3211
1.4	2.2667	0.6176	0.2725
1.6	2.5667	0.6234	0.2429
1.8	2.7667	0.6506	0.2352
2.0	3.000	0.6667	0.2222
2.2	3.1667	0.6947	0.2194
2.4	3.4667	0.6923	0.1997

Graph Analysis

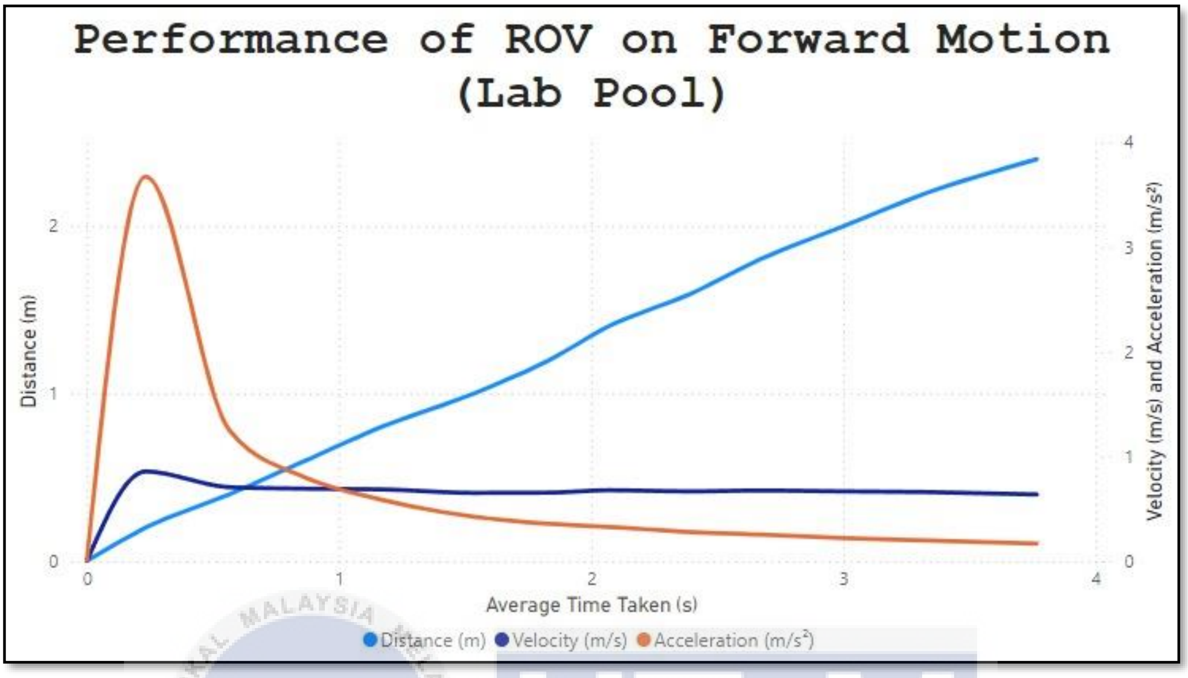


Figure 4.1:Graph of Performance of ROV on Forward Motion (Lab Pool)

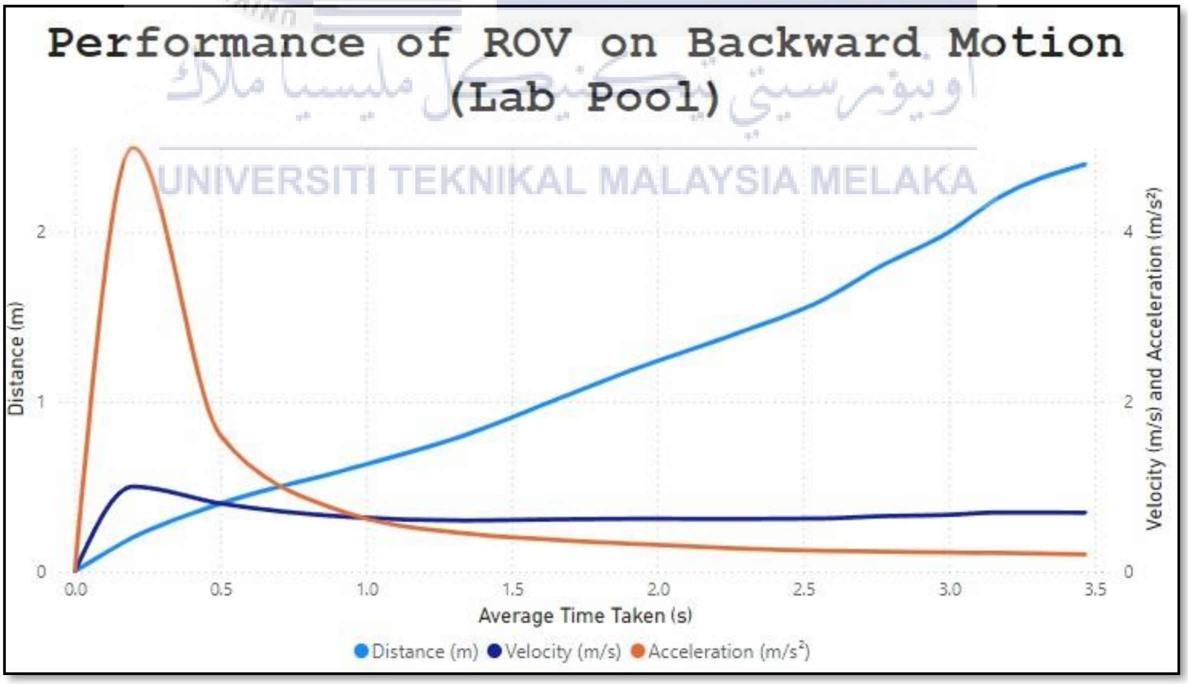


Figure 4.2: Graph of Performance of ROV on Backward Motion (Lab Pool)

4.5.2 Venue: Swimming Pool (Straight path distance: 6.0 meters)

Moving Forward

Table 4.9: Time taken for ROV is recorded at regular intervals of 0.5 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0.00	0.00	0.00	0.00	0.0000
0.50	0.70	0.90	0.60	0.7333
1.00	1.60	1.60	1.30	1.5000
1.50	2.00	2.30	2.10	2.1333
2.00	2.70	2.90	2.80	2.8000
2.50	3.30	3.40	3.60	3.4333
3.00	4.10	4.30	4.30	4.2333
3.50	4.90	5.00	5.00	4.9667
4.00	5.40	6.40	5.70	5.8333
4.50	6.10	6.50	6.40	6.3333
5.00	7.00	7.00	7.00	7.0000
5.50	7.50	7.80	7.50	7.6000
6.00	8.00	8.50	8.30	8.2667

Table 4.10: Performance of ROV on Forward Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s^2)
0.00	0.0000	0.0000	0.0000
0.50	0.7333	0.6818	0.9298
1.00	1.5000	0.6667	0.4444
1.50	2.1333	0.7031	0.3296
2.00	2.8000	0.7143	0.2551
2.50	3.4333	0.7282	0.2121
3.00	4.2333	0.7087	0.1674
3.50	4.9667	0.7047	0.1419
4.00	5.8333	0.6857	0.1176
4.50	6.3333	0.7105	0.1122
5.00	7.0000	0.7143	0.1020
5.50	7.6000	0.7237	0.0952
6.00	8.2667	0.7258	0.0878

Moving Backward

Table 4.11: Time taken for ROV is recorded at regular intervals of 0.5 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0.00	0.00	0.00	0.00	0.0000
0.50	0.80	0.70	0.60	0.7000
1.00	1.70	1.30	1.20	1.4000
1.50	2.20	2.00	1.90	2.0333
2.00	2.90	2.70	2.50	2.7000
2.50	3.60	3.40	3.20	3.4000
3.00	4.10	4.00	3.80	3.9667
3.50	5.00	4.80	4.60	4.8000
4.00	5.50	5.30	5.20	5.3333
4.50	6.40	6.20	5.90	6.1667
5.00	7.10	7.00	6.80	6.9667
5.50	7.60	7.50	7.30	7.4667
6.00	8.40	8.00	7.80	8.0667

Table 4.12: Performance of ROV on Backward Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0.00	0.0000	0.0000	0.0000
0.50	0.7000	0.7143	1.0204
1.00	1.4000	0.7143	0.5102
1.50	2.0333	0.7377	0.3628
2.00	2.7000	0.7407	0.2743
2.50	3.4000	0.7353	0.2163
3.00	3.9667	0.7563	0.1907
3.50	4.8000	0.7292	0.1519
4.00	5.3333	0.7500	0.1406
4.50	6.1667	0.7297	0.1183
5.00	6.9667	0.7177	0.1030
5.50	7.4667	0.7366	0.0987
6.00	8.0667	0.7438	0.0922

Graph Analysis

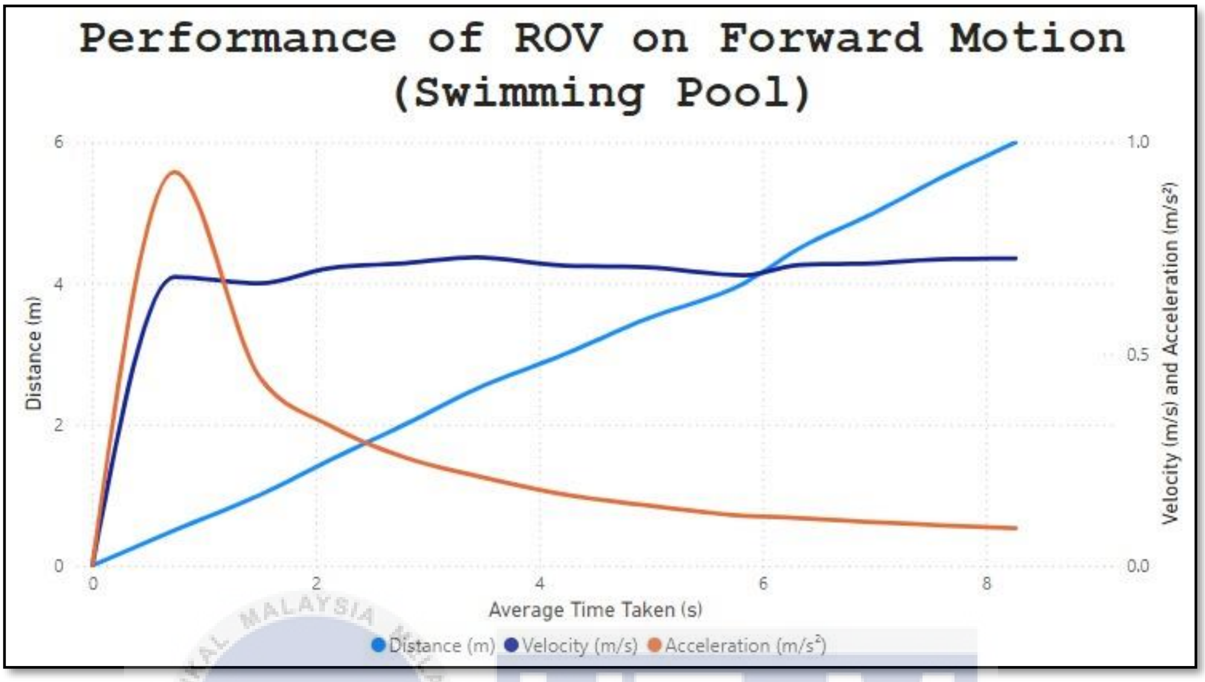


Figure 4.3: Graph of Performance of ROV on Forward Motion (Swimming Pool)

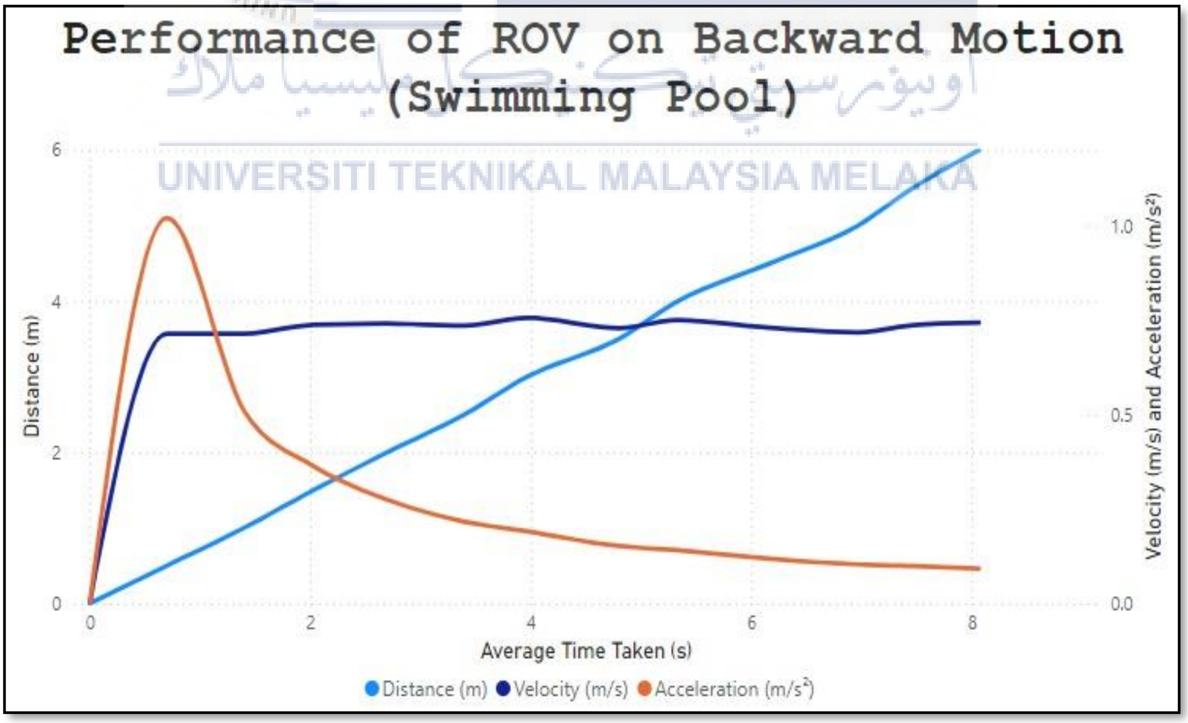


Figure 4.4: Graph of Performance of ROV on Backward Motion (Swimming Pool)

4.5.3 Discussion on Moving Forward & Backward Motion

Discussion:

From the experiment that been done in different venue which are swimming pool and lab pool, refer to figure 4.1, 4.2, 4.3 and 4.4, the graphs have successfully shown that ROV achieved consistent speeds in both forward and backward motions.

Besides, the velocity measurements have confirmed that the ROV able to maintain a stable speed in designated direction about 0.6 to 0.7 m/s. On the other hand, the consistent performance of ROV has been showed in symmetrical pattern of acceleration profiles during both acceleration and deceleration phases.

The hypothesis stated was accepted as the ROV demonstrate similar speed, velocity and acceleration in forward and backward motion. The objective has successfully achieved.

In a conclusion, this has successfully proved that the ROV's propulsion system is balanced and capable of providing consistent performance in both directions whether forward and backward motion, especially important for the task of underwater inspection.

4.6 Experiment 4: Turning Right and Left

Turning Right

Table 4.13: Time taken for ROV is recorded at regular intervals of 45 degrees

Degree (°)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0	0.0	0.0	0.0	0.0000
45	0.8	1.0	0.7	0.8333
90	1.6	1.8	1.3	1.5667
135	2.3	2.5	1.9	2.2333
180	2.8	2.9	2.6	2.7667

Table 4.14: Performance of ROV on Turning Right Motion

Degree (°)	Average Time Taken (s)	Angular Velocity (rad/s)	Angular Acceleration (rad/s²)
0	0.0000	0.0000	0.0000
45	0.8333	0.9425	1.1310
90	1.5667	1.0026	0.6400
135	2.2333	1.0550	0.4724
180	2.7667	1.1355	0.4104

Turning Left

Table 4.15: Time taken for ROV is recorded at regular intervals of 45 degrees

Degree (°)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0	0.0	0.0	0.0	0.0000
45	0.7	0.9	0.6	0.7333
90	1.7	1.5	1.1	1.4333
135	2.4	2.1	1.6	2.0333
180	2.7	2.9	2.4	2.6667

Table 4.16: Performance of ROV on Turning Left Motion

Degree (°)	Average Time Taken (s)	Angular Velocity (rad/s)	Angular Acceleration (rad/s²)
0	0.0000	0.0000	0.0000
45	0.7333	1.0710	1.4605
90	1.4333	1.0960	0.7647
135	2.0333	1.1588	0.5699
180	2.6667	1.1780	0.4418

Graph Analysis

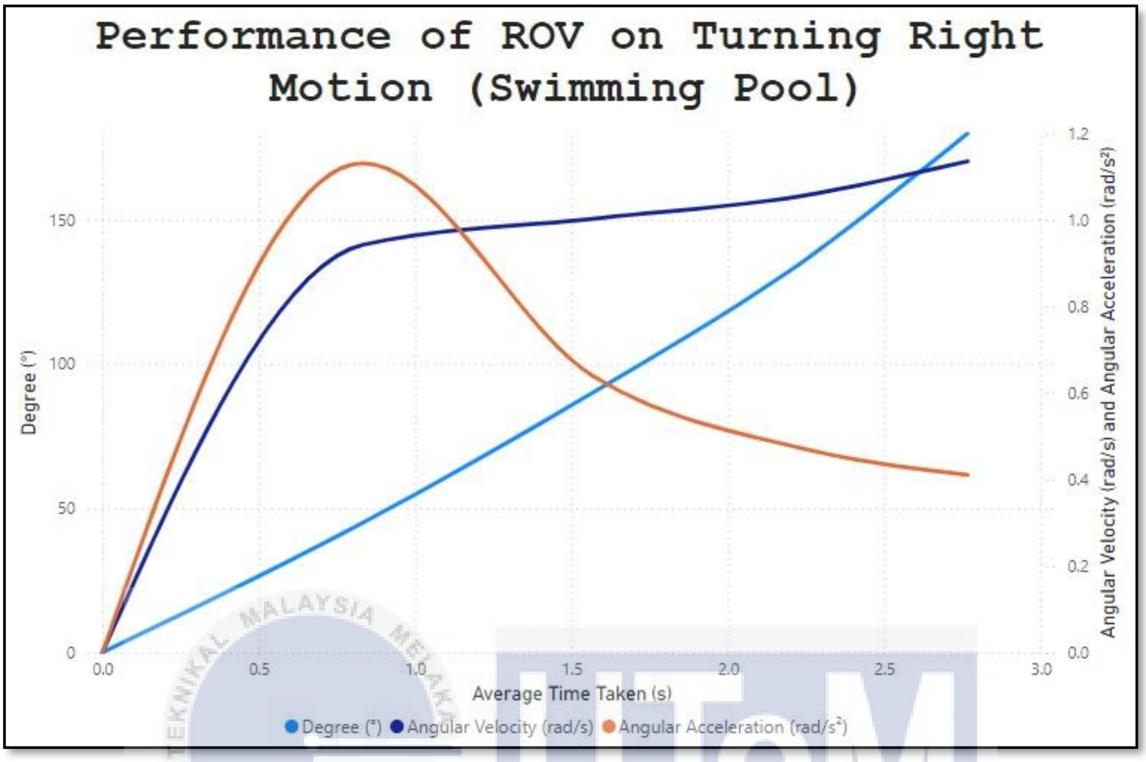


Figure 4.5: Graph of Performance of ROV on Turning Right Motion (Swimming Pool)

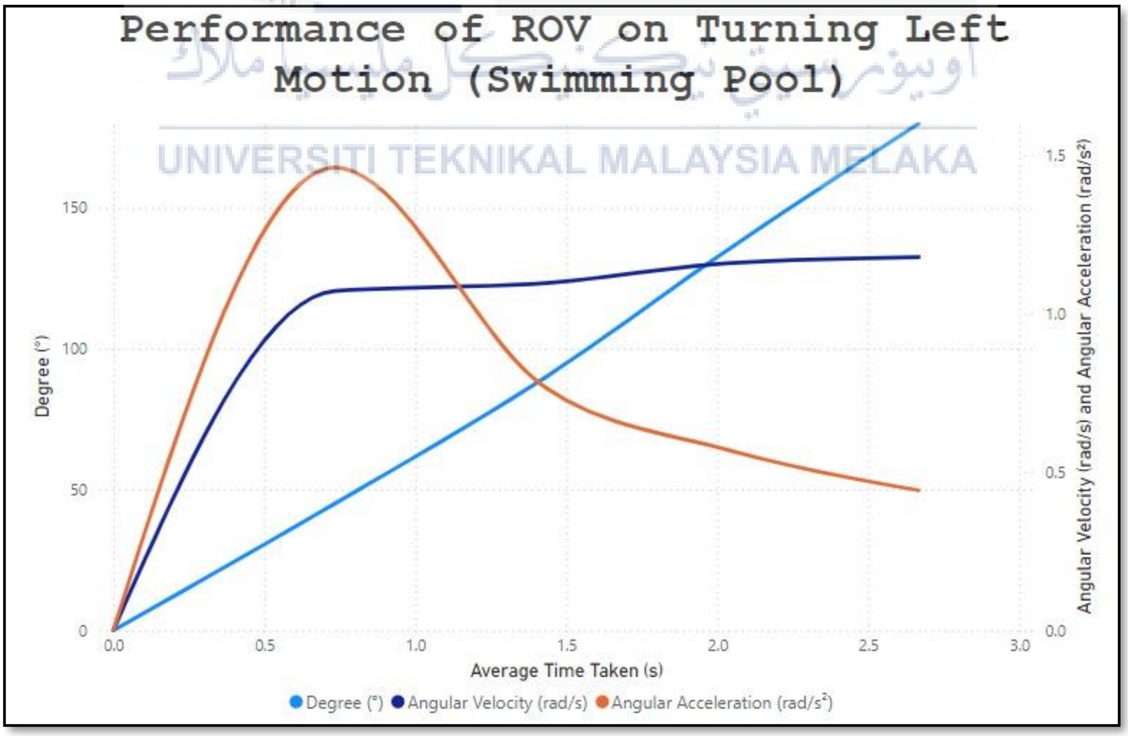


Figure 4.6: Graph of Performance of ROV on Turning Left Motion (Swimming Pool)

4.6.1 Discussion on Turning Right & Left Motion

Discussion:

The experiment of turning right and left only taken place in swimming pool because the swimming pool able to provides controlled and calm environment, ensuring that external factors such as currents and waves do not affect the ROV's turning movements. Besides, the turning movement experiment is not same as forward, backward, raising, and submerging movements which are more fundamental and less sensitive to slight environmental variations.

From the figure 4.5 and 4.6, the time taken to complete the motion of turning right and left in 180-degress was comparable. The angular velocity measurements were consistent for both turning directions, indicating similar rotational performance for ROV. Besides, the acceleration profile obtained were symmetrical pattern as velocity profile, assuming there is uniform thrust and torque applied.

The objective has achieved, and the data obtained are tabulated in table 4.13, 4.14, 4.15 and 4.16. The hypothesis was validated as the ROV exhibited similar angular velocity and similar angular acceleration as the turning times for both 180-degree right and left turns are almost same.

The results obtained has shown that the rotational performance of ROV is symmetry, vital for ensuring that the ROV can effectively manoeuvre in tight spaces and able to maintain directional control. These characteristics are critical for tasks requiring precise orientation adjustments.

4.7 Experiment 5: Raising & Submerging

4.7.1 Venue: Lab Pool (depth: 0.45 meters)

Raising:

Table 4.17: Time taken for ROV is recorded at regular intervals of 0.05 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0.00	0.00	0.00	0.00	0.0000
0.05	0.30	0.20	0.30	0.2667
0.10	0.70	0.40	0.60	0.5667
0.15	0.90	0.70	0.80	0.8000
0.20	1.30	0.90	1.20	1.1333
0.25	1.50	1.10	1.40	1.3333
0.30	1.80	1.30	1.60	1.5667
0.35	2.20	1.50	1.80	1.8333
0.40	2.30	1.80	2.00	2.0333
0.45	2.40	2.00	2.20	2.2000

Table 4.18: Performance of ROV on Raising Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0.00	0.0000	0.0000	0.0000
0.05	0.2667	0.1875	0.7031
0.10	0.5667	0.1765	0.3114
0.15	0.8000	0.1875	0.2344
0.20	1.1333	0.1765	0.1557
0.25	1.3333	0.1875	0.1406
0.30	1.5667	0.1915	0.1222
0.35	1.8333	0.1909	0.1041
0.40	2.0333	0.1967	0.0967
0.45	2.2000	0.2045	0.0930

Submerging:

Table 4.19: Time taken for ROV is recorded at regular intervals of 0.05 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0.00	0.00	0.00	0.00	0.0000
0.05	0.30	0.20	0.20	0.2333
0.10	0.60	0.40	0.40	0.4667
0.15	0.70	0.60	0.60	0.6333
0.20	1.30	0.80	0.90	1.0000
0.25	1.50	1.10	1.20	1.2667
0.30	1.70	1.20	1.40	1.4333
0.35	1.90	1.50	1.60	1.6667
0.40	2.00	1.70	1.80	1.8333
0.45	2.30	2.00	2.00	2.1000

Table 4.20: Performance of ROV on Submerging Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s^2)
0.00	0.0000	0.0000	0.0000
0.05	0.2333	0.2143	0.9184
0.10	0.4667	0.2143	0.4592
0.15	0.6333	0.2368	0.3740
0.20	1.0000	0.2000	0.2000
0.25	1.2667	0.1974	0.1558
0.30	1.4333	0.2093	0.1460
0.35	1.6667	0.2100	0.1260
0.40	1.8333	0.2182	0.1190
0.45	2.1000	0.2143	0.1020

Graph Analysis

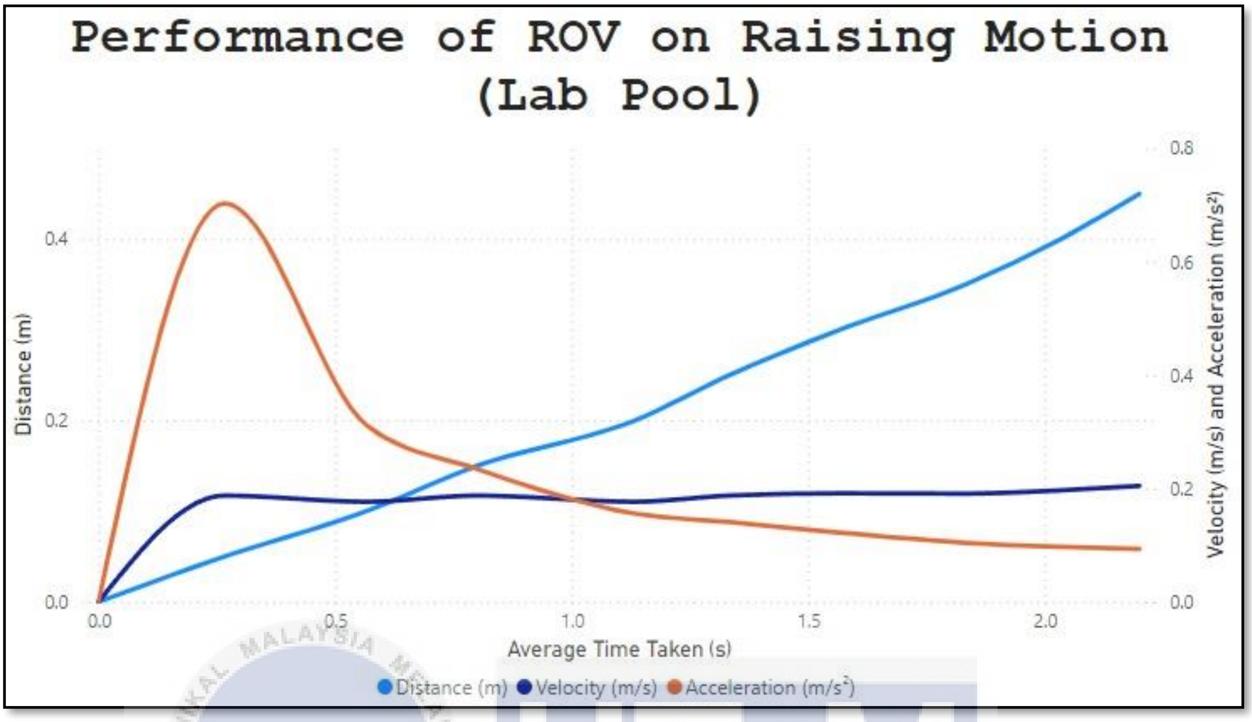


Figure 4.7: Graph of Performance of ROV on Raising Motion (Lab Pool)

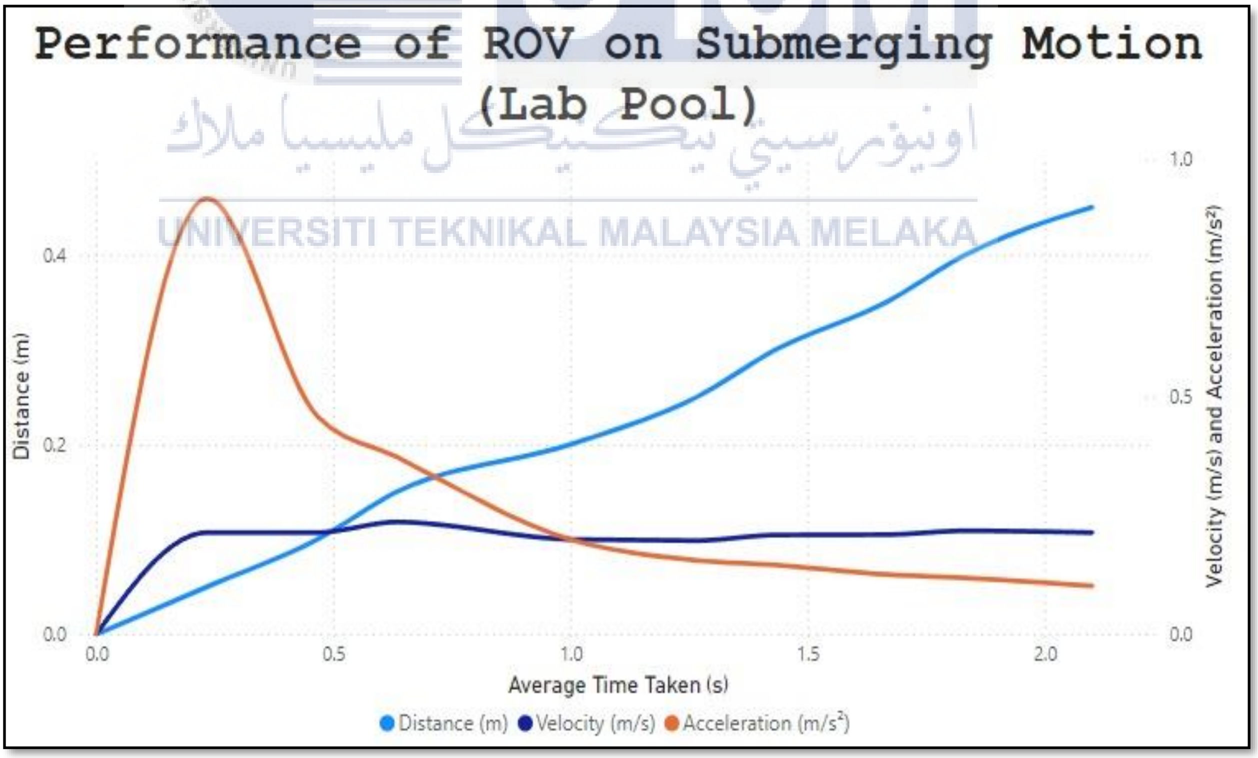


Figure 4.8: Graph of Performance of ROV on Submerging Motion (Lab Pool)

4.7.2 Venue: Swimming Pool (depth: 0.90 meters)

Raising

Table 4.21: Time taken for ROV is recorded at regular intervals of 0.1 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0.00	0.00	0.00	0.00	0.0000
0.10	0.50	0.60	0.50	0.5333
0.20	0.90	1.00	0.80	0.9000
0.30	1.40	1.50	1.30	1.4000
0.40	2.00	2.10	1.80	1.9667
0.50	2.60	2.70	2.50	2.6000
0.60	3.10	3.20	2.90	3.0667
0.70	3.50	3.70	3.30	3.5000
0.80	4.00	4.10	3.80	3.9667
0.90	4.30	4.50	4.00	4.2667

Table 4.22: Performance of ROV on Raising Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0.00	0.0000	0.0000	0.0000
0.10	0.5333	0.1875	0.3516
0.20	0.9000	0.2222	0.2469
0.30	1.4000	0.2143	0.1531
0.40	1.9667	0.2034	0.1034
0.50	2.6000	0.1923	0.0740
0.60	3.0667	0.1957	0.0638
0.70	3.5000	0.2000	0.0571
0.80	3.9667	0.2017	0.0508
0.90	4.2667	0.2109	0.0494

Submerging:

Table 4.23: Time taken for ROV is recorded at regular intervals of 0.1 meters

Distance (m)	Time Taken (s)			
	Test 1	Test 2	Test 3	Average
0.00	0.00	0.00	0.00	0.0000
0.10	0.60	0.50	0.60	0.5667
0.20	1.20	1.00	1.20	1.1333
0.30	1.60	1.50	1.80	1.6333
0.40	2.00	2.10	2.30	2.1333
0.50	2.40	2.60	2.70	2.5667
0.60	2.80	3.10	3.10	3.0000
0.70	3.20	3.60	3.50	3.4333
0.80	3.60	4.10	4.10	3.9333
0.90	4.10	4.50	4.60	4.4000

Table 4.24: Performance of ROV on Submerging Motion

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0.00	0.0000	0.0000	0.0000
0.10	0.5667	0.1765	0.3114
0.20	1.1333	0.1765	0.1557
0.30	1.6333	0.1837	0.1125
0.40	2.1333	0.1875	0.0879
0.50	2.5667	0.1948	0.0759
0.60	3.0000	0.2000	0.0667
0.70	3.4333	0.2039	0.0594
0.80	3.9333	0.2034	0.0517
0.90	4.4000	0.2045	0.0465

Graph Analysis:

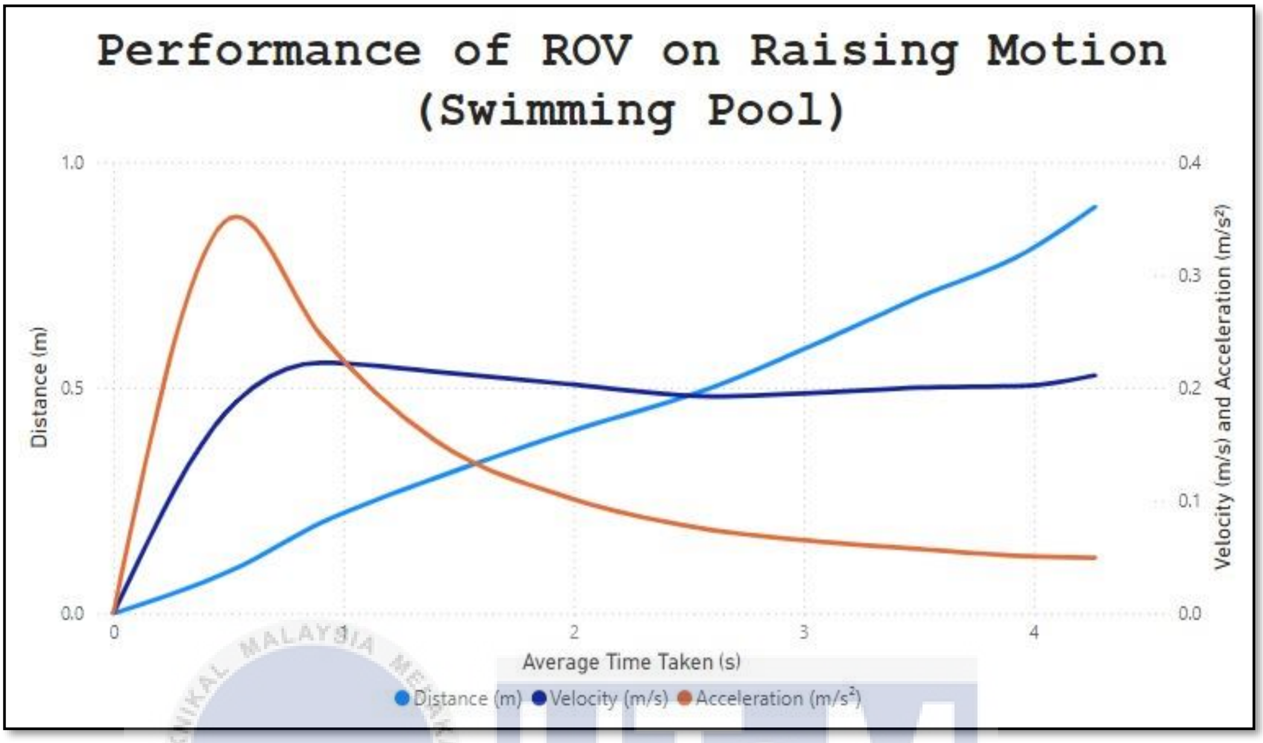


Figure 4.9: Graph of Performance of ROV on Raising Motion (Swimming Pool)

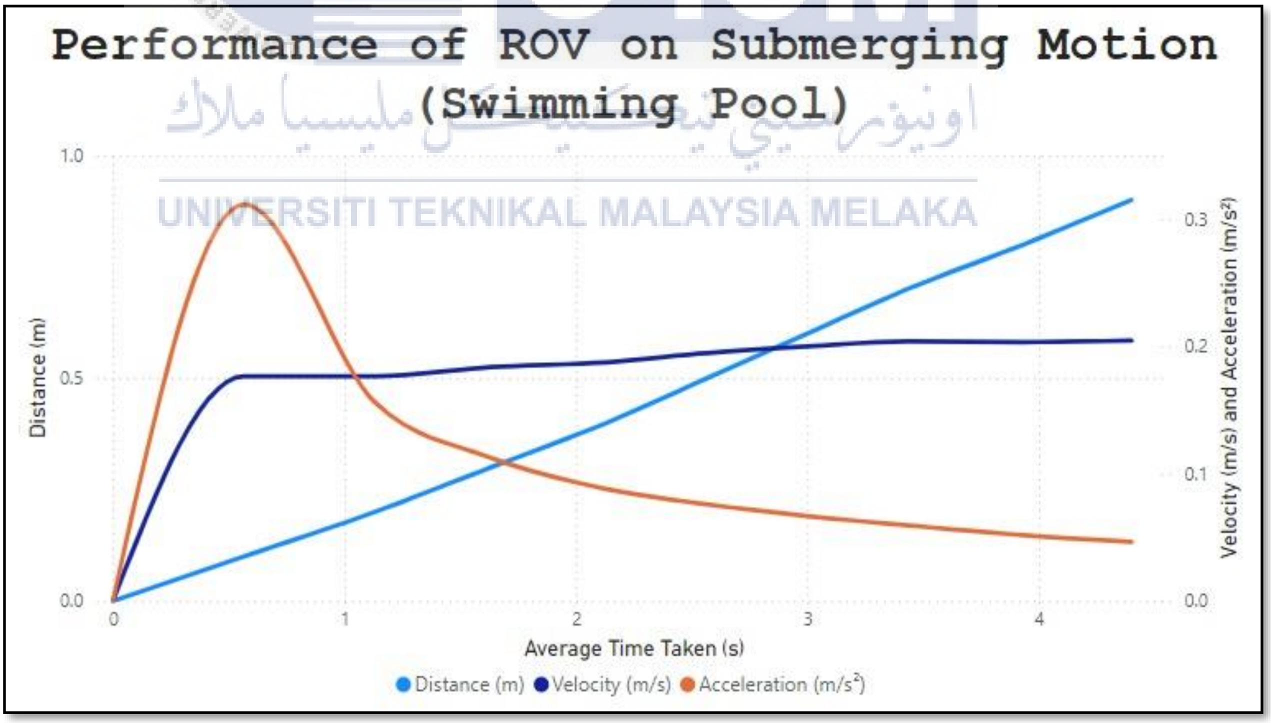


Figure 4.10: Graph of Performance of ROV on Submerging Motion (Swimming Pool)

4.7.3 Discussion on Raising & Submerging Motion

Discussion:

The experiment of raising and submerging are taken in two different venues which are lab pool and swimming pool. Refer to the figure 4.7, 4.8 ,4.9 and 4.10, the ROV has successfully raising and submerging at consistent vertical speeds. On the other hand, the velocity measurement obtained in both raising and submerging are stable. Besides, the uniform propulsion forces of ROV have been successfully shown by the symmetrical acceleration and deceleration profiles obtained.

The objective has achieved, and the data obtained are tabulated in table 4.17 to table 4.24. The hypothesis was accepted as the ROV has demonstrated the consistent speed and symmetrical velocity and acceleration profiles during raising and submerging in two different venues. This reliable vertical movement capability is important for the underwater operations requiring depth adjustments which is underwater inspections.

4.8 Analysis on Manoeuvrability of ROV

Table 4.25: Average Data on Manoeuvrability of ROV

Direction	Lab Pool		Swimming Pool	
	Average Velocity (m/s)	Average Acceleration (m/s^2)	Average Velocity (m/s)	Average Acceleration (m/s^2)
Forward	0.6331	0.6567	0.6513	0.2304
Backward	0.6324	0.7559	0.6774	0.2523
Submerge	0.19146	0.26004	0.1731	0.0968
Raise	0.16991	0.19612	0.1828	0.11501

Table 4.26: Average Data on Turning Left & Right

Direction	Average Angular Velocity (rad/s)	Average Angular Acceleration (rad/s^2)
Left	0.90076	0.64738
Right	0.82712	0.53076

Discussion:

The data above has shown that the ROV demonstrates efficient and reliable performance in both linear and angular movements across different environments which are lab pool and swimming pool.

ROV has maintain its consistency in velocity for the movement of forward, backward, submerging, and raising movements across both test environments, with slightly higher velocities in the swimming pool.

Besides, the ROV achieved higher acceleration in the lab pool for both linear and vertical movements. This has shown that faster response times in a controlled environment compared to the swimming pool.

For the turning right and left motion, the ROV has a balanced but slightly asymmetric angular control. The ROV prone to rotating faster and accelerating more quickly to the left than to the right.

This characteristic has shown that ROV is well-designed for various underwater environments, offering a robust and reliable performance with a slight edge in manoeuvrability in controlled settings. Hence, it is extremely suitable for underwater inspection purposes because of its advantageous in precise and responsive movement.

4.9 Summary

In summary, the ROV designed has met all the objectives and hypotheses set for the experiments. Each aspect of the ROV's performance either from strongness and durability of mechanical design or manoeuvrability of ROV was rigorously tested and validated, ensuring it is suitable for underwater inspection tasks.

In experiment 1, the outcome has proved that the designed aesthetic ROV frame is strong enough to dive at maximum rate of 5 meters. This has successfully met the required structural integrity for safe operation at the specified depth.

In experiment 2, the outcome has shown that the electric housing is successfully prevent any happening of water ingress, ensuring there is safety and functionality of the electronic circuit of ROV

In experiment 3, the result has shown that ROV has successfully achieved 90% negative buoyancy. This buoyancy level has proved its stability and ease of maintaining its position during inspections.

For the Manoeuvrability of ROV, a positive outcome is obtained from the experiment 4,5 and 6. ROV maintained consistent velocity for forward, backward, submerging, and raising movements in both test environments which are lab pool and swimming pool. For the test of turning right and left experiment, the results obtained has shown that the rotational performance during turning right and left was symmetrical, ensuring effective manoeuvrability in tight spaces and maintaining directional control

In a conclusion, the ROV's design and functionality have been thoroughly validated through these experiments. These experiments has successfully demonstrate that the ROV designed can perform effectively in underwater environment especially for the underwater inspection purpose.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion:

The goal of this project is to design and development of an Unmanned Underwater Remotely Operated Vehicle (ROV) for Underwater Inspection. The ROV designed will undergo the underwater tasking about the maximum diving rate of 5 meters underwater. The designation of overall prototype is built in Fusion 360 and tested on FEA analysis. This will ensure the reliability of our ROV prototype to improve its overall performance. The FEA analysis has successfully proved that ROV designed is able to withstand the pressure until 50.3 kPa which is 5 meters underwater. This has given assurance the prototype designed is able to fulfil its requirements which is able to dive at a maximum rate of 5 meters underwater. Hence, the objective 1 is achieved with the development of strong and aesthetic acrylic frame.

Besides, the ROV designed is successfully achieved 90% negatively buoyancy by attaching 0.8kg of load to it at the bottom of the ROV. Hence, objective 1 is achieved by making ROV reach negative 90 buoyancy which is advantageous for improved stability, better control, enhanced inspection quality, and making it less prone to floating away. Considering the ROV might be used to explore seawater with different sea densities, it is designed with customizable load attached at different spaces. Users can add suitable weight of load depending on the density of seawater explored.

To ensure the well functionality of ROV, the waterproofing technique of electric housing is done perfectly. Several experiments have been conducted to ensure the electric housing is totally waterproof to prevent water ingress. There is also a leakage sensor attached which acts as a safety measure to detect any water leakage. A buzzer is installed which is activated when it detects of water, the users can then quickly surface the ROV to avoid electrical hazards.

Along with the experiments that has been done, the ROV is successfully capable of movement with four degrees of freedom controlled by wireless PS2 joystick. The ROV can demonstrate forward and backward movement with precise control over its speed and acceleration. Besides, the ROV is also able to perform turning motions to the left and right (180-degrees), and raising and submerging motions with optimal velocity and acceleration. Therefore, objective 2 is successfully achieved as the propulsion system's design is able to achieve satisfactory motion control and speed.

Not only that, a pressure sensor and a surveillance camera have been integrated into its design to further enhance the functionality and versatility of the ROV, these additions allow the ROV to provide critical data and visual feedback necessary for detailed underwater exploration and marine research projects. The pressure sensor used is a Bar02 Pressure Sensor, a multi-functional device that is capable of measuring temperature and pressure with high accuracy. Besides, A waterproof camera has been integrated into the ROV, providing real-time visual feedback of the underwater environment. This camera makes underwater research and tasks much easier and allows the user to navigate the ROV much more easily. Together, these enhancements make the ROV a more versatile and powerful tool for underwater exploration and research, capable of meeting the evolving demands of scientific and practical applications.

In a nutshell, the Underwater ROV is successfully developed, meeting all the initial objectives and demonstrating effective performance in various manoeuvrability. The outcomes have shown that the ROV is well-suited underwater inspection tasks, demonstrating strong stability, control, and protection against water ingress.

5.2 Future Works

Despite the successful development and achievement of all the aimed objectives, there are several areas where the SMART ROV's design can be further enhanced to improve its features and overall performance.

First of all, the functionality and capabilities of the ROV can be further increased by adding mechanical robotic arms. At the moment, the ROV is only capable of providing information such as giving visual feedback through the camera and providing temperature and pressure with the installed equipment. With the addition of mechanical robotic arms, the ROV will be able to handle basic tasks such as working with cables and retrieving items from underwater. Not only that, by installing mechanical robotic arms on the ROV, it can also allow the ROV to perform inspections and monitoring tasks more effectively. When studying objects underwater, the arm can manipulate and rotate objects for detailed inspection, providing the ability to turn or adjust components to examine them from different angles. This is valuable in both scientific research and industrial applications. Furthermore, while performing underwater inspections, there will be a lot of situations where moving debris out of the way is easier and more efficient that manoeuvring around it. Which can make the ROV much more efficient at its job.

The installation of mechanical claws can also a considerable upgrade to the ROV, similar to mechanical robotic arms, mechanical claws can be used to cut underwater cables, which is useful for tasks such as removing debris or conducting maintenance on underwater infrastructure. For example, if a fishing net gets entangled in a coral reef, the ROV can cut and remove it without causing further damage to the environment. In some situations, a mechanical claw can be way more useful than a mechanical robotic arm.

Moving on, the ROV can also be further enhanced and improved with an Autonomous Navigation and Control System. Because the current ROV requires human control to be navigated, the implementation of advanced autonomous navigation algorithms can enable the ROV to perform inspection tasks with minimal human intervention. This includes features such as obstacle avoidance, path planning, and station keeping, which will improve operational efficiency and safety. With the addition of such features, basic and simple tasks such as daily routine checks can be performed with the use of the algorithm, saving the need for human interventions and also reducing the risk of man-made accidents and human error.

However, a lot of these upgrades and enhancements do require additional equipment and potentially major changes to be made on the ROV. Meaning that a lot of factors such as the weight, power of thrusters, and the arrangements of already present equipment will have to be reconsidered to ensure that the ROV's capabilities are not affected negatively by the new changes. For example, the addition of mechanical robotic arms can contribute to a significant increase in the weight and voltage used for the ROV. And these changes and factors must be taken into account and further studied before its implementation.

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APPENDICES

APPENDIX A GANTT CHART OF FYP 1

No	Duration	OCT				NOV				DIS				JAN		
	Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	**Briefing about FYP 1**															
2	**Project Title Understanding**															
2	**Literature Review**															
3	i) Search & review all reliable resources including journals, articles, reference books and available samples of ROV.															
	ii) Do the comparison about the research found															
4	**Introduction**															
	i) Define the problem statements, objectives, and scopes of the projects															
5	**Methodology**															
	i) Itemization															
	ii) Tether Part Configuration															
	ii) Prototype Drawing															
	iv) Propulsion System Design															
	v) Overall Prototype Design															
6	**Preliminary Results**															
	i) Finite Element Analysis of Hardware															
	FYP 1 Seminar															
	Progress report FYP 1															
	Report FYP 1 submission															

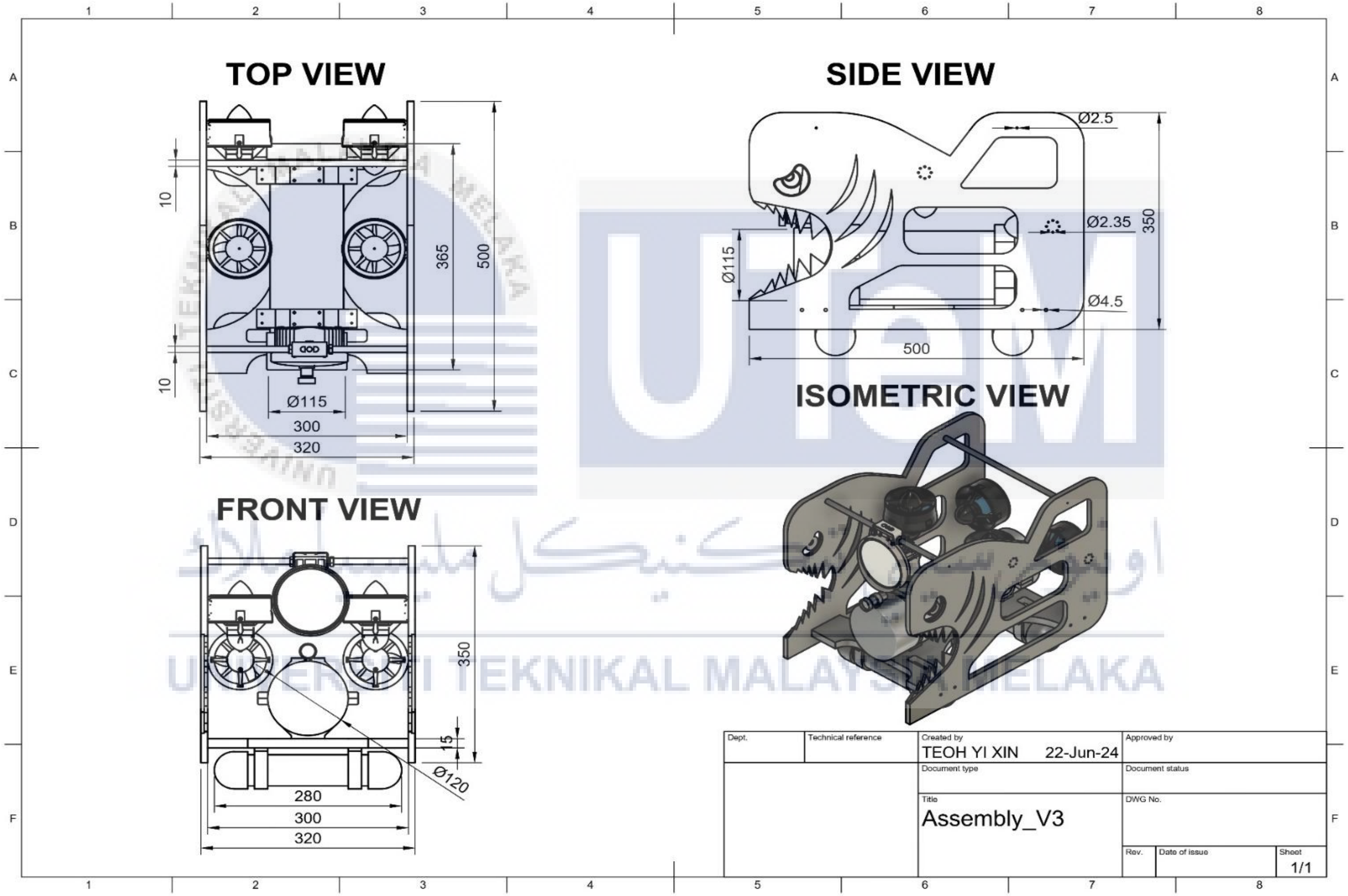
	Completed
	In Progress
	Delayed

APPENDIX B GANTT CHART OF FYP 2

No.	Duration	MAC				APR				MAY				JUN		
	Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	**Hardware Manufacture**															
	i) Parts and Materials Purchase															
	ii) Laser cutting on hardware design (Body Frame)															
2	**Electrical Circuit Design**															
	i) Light Dimmer Circuit															
	ii) Motor Controller Circuit															
	ii) Leakage Sensor Circuit															
	iii) Pressure Sensor Circuit															
	iv) Surveillance Camera Circuit															
3	**Software Integration**															
	i) Arduino Software															
	ii) Processing Software															
	iii) Surveillance Camera System															
4	**Assemble Prototype**															
	i) Assembling the prototype with available components															
	ii) Analysis and troubleshooting the models															
4	**Result and Discussion**															
5	**Submission of draft Report FYP 2**															
6	**Presentation FYP 2**															
7	**Preparation Final Report FYP 2**															
8	**Report FYP 2 Submission**															

	Completed
	In Progress
	Delayed

APPENDIX C ORTHOGRAPHIC PROJECTION



APPENDIX D PROGRAMMING CODE FOR MANOEUVRABILITY OF ROV

```
/*******************************************************************************
 * This file is part of PsxNewLib.                                             *
 *                                                                             *
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 *                                                                             *
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 *******************************************************************************
 *
 * This sketch will dump to serial whatever is done on a PSX controller. It is
 * an excellent way to test that all buttons/sticks are read correctly.
 *
 * It's missing support for analog buttons, that will come in the future.
 *
 * This example drives the controller through the hardware SPI port, so pins are
 * fixed and depend on the board/microcontroller being used. For instance, on an
 * Arduino Uno connections must be as follows:
 *
 * CMD: Pin 11
 * DATA: Pin 12
 * CLK: Pin 13
 *
 * Any pin can be used for ATTN, but please note that most 8-bit AVRs require
 * the HW SPI SS pin to be kept as an output for HW SPI to be in master mode, so
 * using that pin for ATTN is a natural choice. On the Uno this would be pin 10.
 *
 * It also works perfectly on OpenPSX2AmigaPadAdapter boards (as it's basically
 * a modified Uno).
 *
 * There is another similar one using a bitbanged protocol implementation that
 * can be used on any pins/board.
 */


#include <DigitalIO.h>
#include <PsxControllerHwSpi.h>
#include <Wire.h>
#include "MS5837.h"
#include <Servo.h>
```

```
#include <avr/pgmspace.h>
#include "I2Cdev.h"
#include "pitches.h"//tone library

#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
    #include "Wire.h"
#endif

MS5837 sensor;
Servo esc1, esc2, esc3, esc4;

const int ESC_PIN3 = 3;
const int ESC_PIN4 = 4;
const int ESC_PIN5 = 5;
const int ESC_PIN6 = 6;
const int RELAY_PIN9 = 9;
const byte PIN_PS2_ATT = 10;
const byte PIN_BUTTONPRESS = A0;
const byte PIN_HAVECONTROLLER = A1;
const int threshold = 128;

typedef const __FlashStringHelper * FlashStr;
typedef const byte* PGM_BYTES_P;
#define PSTR_TO_F(s) reinterpret_cast<const __FlashStringHelper *> (s)

const char buttonSelectName[] PROGMEM = "Select";
const char buttonL3Name[] PROGMEM = "L3";
const char buttonR3Name[] PROGMEM = "R3";
const char buttonStartName[] PROGMEM = "Start";
const char buttonUpName[] PROGMEM = "Up";
const char buttonRightName[] PROGMEM = "Right";
const char buttonDownName[] PROGMEM = "Down";
const char buttonLeftName[] PROGMEM = "Left";
const char buttonL2Name[] PROGMEM = "L2";
const char buttonR2Name[] PROGMEM = "R2";
const char buttonL1Name[] PROGMEM = "L1";
const char buttonR1Name[] PROGMEM = "R1";
const char buttonTriangleName[] PROGMEM = "Triangle";
const char buttonCircleName[] PROGMEM = "Circle";
const char buttonCrossName[] PROGMEM = "Cross";
const char buttonSquareName[] PROGMEM = "Square";

const char* const psxButtonNames[PSX_BUTTONS_NO] PROGMEM = {
  buttonSelectName,
  buttonL3Name,
  buttonR3Name,
  buttonStartName,
  buttonUpName,
```

```
  buttonRightName,
  buttonDownName,
  buttonLeftName,
  buttonL2Name,
  buttonR2Name,
  buttonL1Name,
  buttonR1Name,
  buttonTriangleName,
  buttonCircleName,
  buttonCrossName,
  buttonSquareName
};

PsxControllerHwSpi<PIN_PS2_ATT> psx;
boolean haveController = false;
boolean relayState = false;



byte psxButtonToIndex (PsxButtons psxButtons) {
  byte i;

  for (i = 0; i < PSX_BUTTONS_NO; ++i) {
    if (psxButtons & 0x01) {
      break;
    }

    psxButtons >>= 1U;
  }

  return i;
}

FlashStr getButtonName (PsxButtons psxButton) {
  FlashStr ret = F("");

  byte b = psxButtonToIndex (psxButton);
  if (b < PSX_BUTTONS_NO) {
    PGM_BYTES_P bName = reinterpret_cast<PGM_BYTES_P> (pgm_read_ptr
(&(psxButtonNames[b])));
    ret = PSTR_TO_F (bName);
  }

  return ret;
}

void dumpButtons (PsxButtons psxButtons) {
  static PsxButtons lastB = 0;
```

```
  if (psxButtons != lastB) {
    lastB = psxButtons;     // Save it before we alter it

    Serial.print (F("Pressed: "));

    for (byte i = 0; i < PSX_BUTTONS_NO; ++i) {
      byte b = psxButtonToIndex (psxButtons);
      if (b < PSX_BUTTONS_NO) {
        PGM_BYTES_P bName = reinterpret_cast<PGM_BYTES_P> (pgm_read_ptr
(&(psxButtonNames[b])));
        Serial.print (PSTR_TO_F (bName));
      }

      psxButtons &= ~(1 << b);

      if (psxButtons != 0) {
        Serial.print (F(", "));
      }
    }

    Serial.println ();
  }
}


void dumpAnalog(const char *str, const byte x, const byte y) {
    Serial.print(str);
    Serial.print(F(" analog: x = "));
    Serial.print(x);
    Serial.print(F(", y = "));
    Serial.println(y);
}

const char ctrlTypeUnknown[] PROGMEM = "Unknown";
const char ctrlTypeDualShock[] PROGMEM = "Dual Shock";
const char ctrlTypeDsWireless[] PROGMEM = "Dual Shock Wireless";
const char ctrlTypeGuitHero[] PROGMEM = "Guitar Hero";
const char ctrlTypeOutOfBounds[] PROGMEM = "(Out of bounds)";

const char* const controllerTypeStrings[PSCTRL_MAX + 1] PROGMEM = {
  ctrlTypeUnknown,
  ctrlTypeDualShock,
  ctrlTypeDsWireless,
  ctrlTypeGuitHero,
  ctrlTypeOutOfBounds
};

void setupPressure() {
    Wire.begin();
```

```
  while (!sensor.init()) {
      Serial.println(F("Init failed!"));
      Serial.println(F("Are SDA/SCL connected correctly?"));
      Serial.println(F("Blue Robotics Bar30: White=SDA, Green=SCL"));
      delay(5000);
  }
  sensor.setModel(MS5837::MS5837_02BA);
  sensor.setFluidDensity(997); // kg/m^3 (freshwater, 1029 for seawater)
}

void loopPressure() {
 // Update pressure and temperature readings
 sensor.read();

 Serial.print(sensor.pressure());          //Print Pressure
 Serial.print(",");
 Serial.print(sensor.temperature());            //Print Temperature
 Serial.print(",");
 Serial.print(sensor.depth());                  //Print Depth
 Serial.println(" ");
 delay(500);
}

void loopLeakageSensor() {
 int value1 = analogRead(A2);//read value
 int value2 = analogRead(A3);//read value

 if (value1 < 500 || value2 < 500) {//check condition
   Toneone();
   delay(100);
   Serial.print("Heavy rain  LED on ");
 } else {
   noTone(8);
 }
}

void Toneone() {
 int melody[] = { //tone array
   NOTE_C4, NOTE_G3, NOTE_G3, NOTE_A3, NOTE_G3, 0,
   NOTE_B3, NOTE_B3, NOTE_B3, NOTE_B3, NOTE_A3, NOTE_G3,
   NOTE_B3, NOTE_B3, NOTE_B3, NOTE_B3, NOTE_A3, NOTE_G3,
   NOTE_C4, NOTE_G3, NOTE_G3, NOTE_G3, 0
 };
 int noteDurations[] = {4, 8, 8, 4, 4, 4, 8, 8, 8, 8, 4, 4, 8, 8, 8, 8, 4, 4, 4, 8, 8, 4,
4};
 for (int thisNote = 0; thisNote < 23; thisNote++) {
   int noteDuration = 1000 / noteDurations[thisNote];
   tone(8, melody[thisNote], noteDuration); //play tone
```

```
    int pauseBetweenNotes = noteDuration * 1.30;
    delay(pauseBetweenNotes);//delay
    noTone(8);//tone off
  }
}

void setup() {
  fastPinMode(PIN_BUTTONPRESS, OUTPUT);
  fastPinMode(PIN_HAVECONTROLLER, OUTPUT);
  delay(300);

  Serial.begin(9600);
  while (!Serial);
  Serial.println(F("Ready!"));

  esc1.attach(ESC_PIN3, 1000, 2000);
  esc2.attach(ESC_PIN4, 1000, 2000);
  esc3.attach(ESC_PIN5, 1000, 2000);
  esc4.attach(ESC_PIN6, 1000, 2000);
  pinMode(RELAY_PIN9, OUTPUT);

  setupPressure();
}

void loop() {

  loopPressure();
  loopLeakageSensor();

  fastDigitalWrite(PIN_HAVECONTROLLER, haveController);

  if (!haveController) {
  if (psx.begin ()) {
    Serial.println (F("Controller found!"));
    delay (300);
    if (!psx.enterConfigMode ()) {
      Serial.println (F("Cannot enter config mode"));
    } else {
      PsxControllerType ctype = psx.getControllerType ();
      PGM_BYTES_P cname = reinterpret_cast<PGM_BYTES_P> (pgm_read_ptr
(&(controllerTypeStrings[ctype < PSCTRL_MAX ? static_cast<byte> (ctype) : PSCTRL_MAX])));
      Serial.print (F("Controller Type is: "));
      Serial.println (PSTR_TO_F (cname));

      if (!psx.enableAnalogSticks ()) {
        Serial.println (F("Cannot enable analog sticks"));
      }
```

```
    if (!psx.enableAnalogButtons ()) {
      Serial.println (F("Cannot enable analog buttons"));
    }

      if (!psx.exitConfigMode ()) {
        Serial.println (F("Cannot exit config mode"));
      }
    }

    haveController = true;
  }
} else {
  if (!psx.read ()) {
    Serial.println (F("Controller lost :("));
    haveController = false;
  } else {
    fastDigitalWrite (PIN_BUTTONPRESS, !!psx.getButtonWord ());
    dumpButtons (psx.getButtonWord ());
    boolean l1Pressed = psx.getButtonWord() & (1 << 10); // Check L1 (bit position 10)
    boolean r1Pressed = psx.getButtonWord() & (1 << 11); // Check R1 (bit position 11)
    boolean squarePressed = psx.getButtonWord() & (1 << 15); // Check Square button (bit
position 15)

    if (squarePressed) {
        // Toggle relay state
        relayState = !relayState;
        digitalWrite(RELAY_PIN9 , relayState ? HIGH : LOW);
        Serial.println(relayState ? F("WhiteLight ON") : F("YellowLight ON"));
        delay(10); // Debounce delay
    }

    if (l1Pressed && r1Pressed) {
        // Both L1 and R1 pressed, stop motor
        // You can add code here to stop the motor
        esc2.write(90);
        esc3.write(90);
      } else if (l1Pressed && !r1Pressed) {
        // Only L1 pressed, move motor down
        // You can add code here to move the motor down
        esc2.write(180);
        esc3.write(180);
      } else if (!l1Pressed && r1Pressed) {
        // Only R1 pressed, move motor up
        //You can add code here to move the motor up
        esc2.write(0);
        esc3.write(0);
      } else{
        // Neither L1 nor R1 pressed, stop motor
```

```
        // You can add code here to stop the motor
        esc2.write(90);
        esc3.write(90);
      }

    byte lx, ly;
    psx.getLeftAnalog (lx, ly);
    // Determine direction based on thresholds
    if (ly > threshold) {
      // Move clockwise
      int leftspd = map(ly, threshold, 255, 1500, 2000); // Map Y-axis value to speed
range (0 to 180)
      esc1.writeMicroseconds(leftspd); // Adjust center value accordingly
    } else if (ly < threshold) {
      // Move anticlockwise
      int leftspd = map(ly, threshold,0,  1500, 1000); // Map Y-axis value to speed range
(0 to -180)
      esc1.writeMicroseconds(leftspd); // Adjust center value accordingly
    } else {
      // Stop if stick is at center
      esc1.writeMicroseconds(1500);
    }

    byte rx, ry;
    psx.getRightAnalog (rx, ry);
    // Determine direction based on thresholds
    if (ry > threshold) {
      // Move clockwise
      int rightspd = map(ry, threshold, 255, 90, 180); // Map Y-axis value to speed range
(0 to 180)
      esc4.write(rightspd); // Adjust center value accordingly
    } else if (ry < threshold) {
      // Move anticlockwise
      int rightspd = map(ry, threshold,0,  90, 0); // Map Y-axis value to speed range (0
to -180)
      esc4.write(rightspd); // Adjust center value accordingly
    } else {
      // Stop if stick is at center
      esc4.write(90);
    }
  }

  delay(1000 / 60);
 }
}
```

APPENDIX E PROGRAMMING CODE FOR GRAPHICAL USER INTERFACE (GUI)

```
// Import Meter library
import meter.*;

// Import serial library
import processing.serial.*;

Serial port; // Define a port

Meter m, m2, m3;

void setup(){
  // First we need to create a empty window
  size(950, 700); // Size of the window (width, height)
  background(0, 0, 0); // Background color of window (R,G,B)

  // Create new port
  port = new Serial(this, "COM7", 9600); //name of the port would be different for linux

  // Lets add a default meter to empty window
  // TEMPERATURE METER
  m = new Meter(this, 25, 80);  // here 25, 10 are x and y coordinates of meter&apos;s
upper left corner

  m.setTitleFontSize(20);
  m.setTitleFontName("Arial bold");
  m.setTitle("Pressure (mbar)");

  // Change meter scale values
  String[] scaleLabels = {"0", "1000", "2000", "3000", "4000", "5000", "6000", "7000",
"8000"};
  m.setScaleLabels(scaleLabels);
  m.setScaleFontSize(18);
  m.setScaleFontName("Times new roman bold");
  m.setScaleFontColor(color(200, 30, 70));

  // We can also display the value of meter
  m.setDisplayDigitalMeterValue(true);

  // Lets do some more modifications so our meter looks nice
  m.setArcColor(color(141, 113, 178));
  m.setArcThickness(15);

  m.setMaxScaleValue(8000);

  m.setMinInputSignal(0);
  m.setMaxInputSignal(8000);

  m.setNeedleThickness(3);

  // HUMIDITY METER
  // lets take some refference from first meter
  int mx = m.getMeterX(); // x coordinate of m
  int my = m.getMeterY(); // y coordinate of m
  int mw = m.getMeterWidth();

  m2 = new Meter(this, mx + mw + 20, my);

  m2.setTitleFontSize(20);
  m2.setTitleFontName("Arial bold");
  m2.setTitle("Temperature (deg C)");

  // Change meter scale values
  String[] scaleLabels2 = {"0", "10", "20", "30", "40", "50", "60", "70", "80", "90",
"100"};
  m2.setScaleLabels(scaleLabels2);
  m2.setScaleFontSize(18);
  m2.setScaleFontName("Times new roman bold");
  m2.setScaleFontColor(color(200, 30, 70));

  // We can also display the value of meter
  m2.setDisplayDigitalMeterValue(true);
```

```
  // Lets do some more modifications so our meter looks nice
  m2.setArcColor(color(141, 113, 178));
  m2.setArcThickness(15);

  m2.setMaxScaleValue(100);

  m2.setMinInputSignal(0);
  m2.setMaxInputSignal(100);

  m2.setNeedleThickness(3);

  ////Potentiometer

  // lets take some refference from first meter
  int mx1 = m.getMeterX(); // x coordinate of m
  int my1 = m.getMeterY(); // y coordinate of m
  int mw1 = m.getMeterWidth();

  m3 = new Meter(this, 250, 400);

  m3.setTitleFontSize(20);
  m3.setTitleFontName("Arial bold");
  m3.setTitle("Depth (m)");

  // Change meter scale values
  String[] scaleLabels3 = {"0", "10", "20", "30", "40", "50", "60", "70", "80", "90",
"100"};
  m3.setScaleLabels(scaleLabels3);
  m3.setScaleFontSize(18);
  m3.setScaleFontName("Times new roman bold");
  m3.setScaleFontColor(color(200, 30, 70));

  // We can also display the value of meter
  m3.setDisplayDigitalMeterValue(true);

  // Lets do some more modifications so our meter looks nice
  m3.setArcColor(color(141, 113, 178));
  m3.setArcThickness(15);

  m3.setMaxScaleValue(100);

  m3.setMinInputSignal(0);
  m3.setMaxInputSignal(100);

  m3.setNeedleThickness(3);
}

void draw(){
  // Lets give title to our window
  textSize(30);
  fill(0, 255, 0); // Font color , (r,g,b)
  text("UROV Meter", 400, 40); // ("text", x, y)

  if (port.available() > 0){
    String val = port.readString(); // read incoming string on serial port
    // First we need to separate temperature and humidity values
    String[] list = split(val, &apos;,&apos;); // splits value separated by
&apos;,&apos;
    float pressure = float(list[0]); // first value is Temperature
    float temp = float(list[1]);  // second value is Humidity
    float depth = float(list[2]);  // third value potentiometer
    m.updateMeter(int(pressure)); // int is used due to updateMeter accepts only int
values
    m2.updateMeter(int(temp));
    m3.updateMeter(int(depth));
    println("Pressure: " + nf(pressure, 0, 2) + " mbar  " + "Temperature: " + nf(temp,
0, 2) + " deg C  "+"Depth: "+ nf(depth, 0, 2) + " m");
  }
}
```