DEVELOPMENT OF REMOTELY OPERATED VEHICLE (ROV) FOR UNDERWATER EXPLORATION

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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**Dedicated to my father, Mr. Asmawi bin Hj Sulaiman, my beloved mother, Juliana binti Mais, my family and my special one,
Nor Al-Fidahti Juana bte Sulaiman**

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ABSTRACT

This thesis deals with the development of vehicle design, fabrication and testing of the micro class tethered remotely operated vehicle (ROV) for underwater exploration. It will emphasize on the development of tri-thruster ROV. This will be a new type of design where the ROV will have two motors mounted at the front. Its layout is very different from other conventional ROV which have two horizontal motors mounted at the rear. The development accentuate on mechanical approach. The ROV developed will have hydrodynamic features add to it. The prototype is modeled using SOLIDWORKS™ and the further analysis of the model was done using COSMOSFloWorks™. The quantitative analyses done has determined limiting factor for the ROV as it is desired to be operational in both sea and fresh water for a limited depth. For the fabrication purpose, this project will proceed with PVC pipe as its main component for frame. In methodological section, objective of material selection was to reduce fabrication cost without reducing the performance. The type of onboard control method used simple circuit of double pole double throw (DPDT). Simple circuit were chosen as it is easier to troubleshot and provide more reliability in executing motion compare to complex coding. From COSMOS analysis, the hydrodynamic cover performs very well in decreasing the drag force of developed vehicle. Guided by preliminary result and initial specification, a handmade fabrication will be done to create a prototype to show how this innovative ROV behave underwater, how its drive system response, how the control is functioned and how the motions are perform. The real time testing then runs and the testing bed preferred were surrounding area and control environment. The result was than recorded in video and examination done base on the recorded motion. From real time analysis, the hydrodynamic cover effectively smoothen the prototype motion at underwater and within water surface. The fabricated model can submerge, resurface, move forward and reverse, rotate to left and right. The result of this development will be significantly improved the existing design of ROV and pioneering the future development of remotely operated vehicle for underwater exploration. The fabricated model has installed camera and the first to be equipped with oblique hydrodynamic cover and frontal thruster layout. The development in phrase can be concluded as an innovation of design and invention of layout.

ABSTRAK

Tesis ini membentangkan pembangunan rekabentuk kenderaan, pembuatan dan pengujian terhadap Kenderaan Operasi Berkawalan Jauh (ROV) untuk penerokaan bawah air. Pembangunan ini menekankan kenderaan dengan tiga penujah. Ia merupakan rekabentuk pertama di dunia dengan penujah lintang terletak di bahagian hadapan. Susun atur ini sangat berbeza dimana kebiasaannya penujah diletak dibahagian belakang. Pembangunan ini menggunakan pendekatan mekanikal. Kenderaan yang telah dibangunkan mempunyai penutup hidrodinamik. Model tiga dimensi untuk prototaip ini dihasilkan menggunakan SOLIDWORKS^{TM} dan analisis selanjutnya dibuat menggunakan COSMOSFloWorks^{TM}. Analisis kuantitatif dilakukan untuk menentukan faktor pengehad seperti mana kenderaan ini diperlukan untuk beroperasi di lautan dan kawasan air tawar dengan kedalaman yang terhad. Untuk tujuan pembuatan, projek ini diteruskan dengan pengunaan paip PVC sebagai bahan asas untuk rangkanya. Dalam ruangan kaedah, matlamat pemilihan bahan ialah untuk mengurangkan kos pembuatan tanpa menjejaskan prestasi. Jenis kaedah kawalan atas papan digunakan ialah litar mudah menggunakan suiz. Litar mudah menjadi pilihan kerana cirinya yang mudah diselenggara berbanding pengkodian rumit. Daripada analasis COSMOS, penutup hidrodinamik berjaya mengurangkan daya seretan. Berpandukan keputusan awal dan spesifikasi permulaan, pembuatan tangan dilakukan bagi melihat sifat kenderaan di bawah air, bagaiman sistem pengendaliannya bertindak balas, bagaiman kawalannya berfungsi dan bagaimana gerakannya terlaksana. Pengujian masa sebenar dilancarkan di kawasan sekeliling dan persekitaran terkawal. Keputusan dirakam dalam bentuk video dan anilisa dilakukan berpandukan itu. Daripada ujian masa sebenar, penutup hidrodinamik berjaya melicinkan pergerakan kenderaan di bawah air dan juga di permukaan air. Model yang dihasilkan mampu menyelam, timbul semula, maju kehadapan dan bergerak undur serta berpusing ke kanan dan juga ke kiri. Hasil pembangunan ini membawa penambahbaikan yang ketara terhadap ROV sedia ada dan menjadi perintis terhadap pembangunan yang akan datang. Model yang dihasilkan ini merupakan ROV berkamera dan yang pertama seumpanya dengan ciri penutup hydrodinamik oblik dan susun atur penujah lintang di depan. Pembangunan ini dalam frasa mudah ditakrifkan sebagai inovasi terhadap reka bentuk dan ciptaan baru terhadap susun atur.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF SYMBOLS

μ	Dynamic viscosity
ρ	Fluid density
g	Gravitational force
h	Height
n	Number of propeller rotation per second
v	Speed of object relative to fluid
A	Surface area
C_d	Drag coefficient
D	Height of diameter of the bodies, propeller diameter
F_B	Buoyant force
F_{bottom}	Net upward force
F_d	Drag force
Ft_{op}	Hydrostatic force
K_t	Thrust coefficient
P	Hydro-pressure
Re	Reynolds number
T	Thrust
V	Volume

LIST OF ABBREVIATIONS

3D	Third Dimensional
AUV	Autonomous Underwater Vehicle
CHRIS	Chemical Hazards Response Information System
DIY	Do It Yourself
DPDT	Double Pole Double Throw
FYP	Final Year Project
MBARI	Monterey Bay Aquarium Research Institute
PVC	Polyvinyl Chloride
RF	Radio Frequency
ROV	Remotely Operated Vehicle
UMS	Un-manned System
VGA	Video Graphics Array

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In this chapter, the discussions are focused on the purpose of this project generally. Begin with current issues, then translated into problem statement. The objectives of the project are established, to overcome the problem statement. All the limitations of the project are stated in project scopes.

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1.2 PROJECT BACKGROUND

Within these past few decades, advances in undersea as well as ocean technology have revolutionized our perspective about the oceans and the life within them. New exploration tools such as remotely operated vehicle (ROV) can place researchers into the deepest reaches of the oceans, either directly or by telepresence. The benefit attributed to these advances has been enormous; for example, a new industry, marine biotechnology, has shown impressive returns. Despite these gains, 95 percent of the oceans remain unknown and unexplored (Mineta, 2000). Such provides the abundance of possibility for breakthrough of technology, findings and knowledge. Despite our inadequate understanding of the ocean and the living and nonliving resources it contains, and its undeniable importance to the health of the planet, none ever take a serious approach in this field of exploring; underwater and ocean exploring. Therefore this project is an initial step to promote exploration interest among our society and become a prototype platform for advance ROV development.

Alternative purpose of this project is an encouragement asset for the community to adopt and nurture interest in ROV production industries as well as become an observatory rig for maintaining our beloved natures of the sea. In addition, ROV has been developed with a conventional cube and tubular shape design. As a development project, it is a must to bring the stunning ROV into new looks and explore more possibility that it can achieve with a touch of innovation and invention.

1.3 PROBLEM STATEMENT

ROVs became essential in the 1980s when much of the new offshore development exceeded the reach of human divers. Their tasks range from simple inspection of subsea structures, pipeline and platforms to connecting pipelines and placing underwater manifolds. They are used extensively both in the initial construction of a sub-sea development and the subsequent repair and maintenance. In fact, the deeper half of the ocean has never been explored. This vast area has the potential to meet much of humanity's needs for raw materials.

As the industry advances to meet these challenges, it is undoubtedly that there will be further improvements in these complicated robots. But the lack of exposure upon this magnificent technology caused a stagnant in Malaysia's underwater exploration and ROV industries. With a society being negligent and less interested, nation's marine technology will never move onward. Thus this project will be a basis for such ambitious attempt to promote a research and advance development of ROV whilst an attraction to the society for exploration interest.

On top of that, South China Sea is main naval route use by traders from around the world. Lies on the shallow bed of the seas are the historical treasures leave by the Dutch, Portuguese, Orient Chinese and the British vessels. This historical treasures and discoveries lie at narrow and delicate location demand for recoveries. Such recoveries will return the heritage value to its proper owner. But recoveries need exploration. Exploration demand technologies. And the technology is micro class ROV.

1.4 OBJECTIVES

The objectives that must be achieved are:

i. Develop a new micro class remotely operated vehicle for underwater exploration.
ii. Design and fabricate a real prototype that is capable of basic maneuverability.
iii. Provide a prototype that is ready to be further developed by interested society.

1.5 PROJECT SCOPES

The scopes of this project are

i. Design and fabricate a prototype of ROV equipped with camera and tri-thruster layout for its navigation purpose.
ii. The platform will only consist of simple control system and basic equipment. The ROV falls into micro class.
iii. The maneuverability consisted forward-reverse motion, submerge-resurface motion and left-right rotation.
iv. The depth for testing the prototype will be less than 2m.
v. Environment for testing selected is controllable for control environment and rippling for real water simulation.
vi. Initial specification in consideration is to be operational in both sea and fresh water environment.

1.6 ARRANGEMENT OF REPORT

First chapter describes overall framework of basic information of this project such as project background, problem statement, project objective, project scope and arrangement of report was verified. The main ideas of this project were stated in project background. All requirements that pursue the need to develop the remotely operated vehicle (ROV) for underwater exploration were stated in problem statement. Besides that, objectives and scope of this project also stated.

In second chapter, various reviews on theoretical topics which are required as a background study were present. Every important information and theoretical study related to this project is stated in this chapter. Brief explanations about ROV, history, class and types, and designing principle that will be consider and analyze to achieve the project objectives are reviewed. Some of the explanations give extra information which is useful in conducting this project and for a further development of ROV.

In third chapter, all the work used when conducting this project was described including explanation about process flow chart and Gantt chart. The overall methodological sequence are mentioned and explained in detail. In brief, sequence begin with environment analysis to determined the initial specification of prototype, next is to design a 3D model guided by this requirement, then is to analyze the model before taking out to fabrication. The fabrication will faced several alteration to cope with the deficiency occurred. The real time testing took placed after that and the result was recorded and documented. The final sequence is to conclude the overall project.

Fourth chapter will be a documentation of result with thorough discussion. The results consist of 3D model analysis and real time testing. The discussion will go through each result one by one to explained and confer the outcome within engineering perspective and quantitative basis. The observation result will be confirmed using objective argument where the modification was justified.

The conclusion of overall project, recommendation and future works are stated in fifth chapter of the thesis. The conclusion made based from result obtained, the encountered problem lead to recommendation to troubleshot the predicaments. The area of improvement will be the source of future projects.

Finally, the references of this project were listed and follow by appendices. The related rough designs of future project are included in appendices for general review.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter contains general information on remotely operated vehicle (ROV). The developed ROV is an underwater vehicle consists of mechanical part and electronics. Thus the related review will focus on the behavior of submerged body in terms of its hydrodynamic, classification of ROV, the quantitative theories and the mechanical and electrical component of the ROV. The relevance of the literature review to the project will be included in this chapter as well. The facts and information were collected from reliable source and elaborated based on understanding of the review. The quoted phrases only attached within text as a factual detail whilst others elaborated from the source. All references used in this project will be listed in other chapter although no quotation made to it.

2.2 DEFINITION OF DEVELOPMENT

The word ‘development’ means when individual or objects grows or changes and becomes more sophisticated. It’s synonyms to a recent event which is the latest in a series of related proceedings. In research field, development can be understood as a part of process that tries to find a ways to improve existing products, and to develop new ones. Clearly, it is an action of transforming an existing design into new and advance product.

2.3 REMOTELY OPERATED VEHICLE (ROV)

2.3.1 What is ROV?

ROVs are underwater robots that are tethered to, and powered from, a ship on the sea surface as define by Monterey Bay Aquarium Research Institute (MBARI, 2007). Tether is a group of cables that carry electrical power, video and data signals back and forth between the operator and the vehicle. This allows the vehicle's operator to remain in a comfortable environment while the ROV works in the hazardous environment below. High power applications will often use hydraulics in addition to electrical cabling. In many cases, the umbilical includes additional strength members to allow recovery of heavy device or wreckage.

The vehicle can vary in size from small vehicles for simple observation up to complex work systems, which can have several adroit manipulators, televisions, video cameras, tools and other device. Even simple ROVs are mostly equipped with at least a video camera and lights. Additional equipment is commonly added to expand the vehicle’s capabilities.

Figure 2.1 show the Video Ray Scout sold by Video Ray LLC is the smallest ROV in the world so far. It has mass of 3.6 kg, and dimensions of 0.35x0.25x0.21m.

Figure 2.1: The Video Ray Scout

Source: VideoRay

2.3.2 History of ROV

Remote Operated Vehicles (ROVs) have come a long way since in 1953 when frenchmen Dimitri Rebikoff developed the first tethered ROV named POODLE (Michel, 2006). In early 1960s, most ROV early technology development was funded by US Navy (Fornari, 2002). This technology of science and imaging sensor were first integrated in a manned submersible named Alvin. From this concept of technology; the offshore oil & gas industry created the work class ROVs to assist in the development of offshore oil fields.

ROVs became essential when much of the new offshore development exceeded the reach of human divers. Since then, technological development in the ROV industry has accelerated and today ROVs perform numerous tasks in many fields. They are used extensively both in the initial construction of a sub-sea development, the subsequent repair and maintenance.

Figure 2.2 show the first real low cost observation ROV developed by Chris Nicholson on 1983. The commercial benchmark was then introduced as MiniRover into the market early in 1984 carrying the brand of his founded company named Deep Sea System International Inc.

Figure 2.2: MiniRover

Source: http://www.deepseasystems.com/dshist.htm

Submersible ROVs have been used to locate many historic shipwrecks, including that of the RMS Titanic, the Bismarck, USS Yorktown, and SS Central America. The ROV that responsible in Bismarck discoveries was developed by US Navy at a cost excess of three million dollars (Marx, 2004). In some cases, such as the SS Central America, ROVs have been used to recover material from the sea floor and bring it to the surface.

2.3.3 Observation Class ROV

Current purpose of this class is to reach shallower depth in a cost effective manner and successfully complete a series of critical missions. These may include performing dam inspections, body recoveries, fish assessment or treasure hunting. Today's technology has allowed the development of the advanced systems necessary to complete the job remotely.

The technology used in observation class ROV progressed from vacuum tubes, gear trains and copper/steel cables to microprocessors, magnetic drives and fiber optic/Kevlar cables. it is now can perform task reliably without constant maintenance. The observation class ROV has moved from portable to handheld vehicle that can complete the similar task. The number of operator also reduces significantly. An example of today's observation class vehicle is presented in Figure 2.3.

Figure 2.3: Today's observation class ROV.

Source: Christ and Wernli Sr, 2007

2.4 THE DESIGN OF ROV

2.4.1 The Power Source for ROV

Mean of power source for the vehicle falls into three categories. These categories are surface-powered, vehicle powered and hybrid system. Table 2.1 provides the explanation of these categories in easier form for better comprehension.

Table 2.1: Categories of power source for ROV

Categories	Description
Surface-powered	Vehicle are tethered and power are supply from external environment which mainly from operation ground.
Vehicle powered	All power-producing capacity are stored inside the vehicle in form of battery, fuel-cell or some power storage needed for vehicle propulsion and operation
Hybrid system	A mixture of surface and subsea supplied power where vehicle contain its power-producing capacity and re-attachable tethered for mean of charging or transition from ROV to AUV to allow swim-out.

2.4.2 Degree of Autonomy

Degree of autonomy or modes of operation for unmanned system (UMS) in general are divided into four types which are fully autonomous, semi autonomous, tele-operation and remote control. The mode of operation for ROVs lies in third and fourth category. Table 2.2 documented the description of categories for quick understanding.

Table 2.2: Categories for degree of autonomy

Degree of Autonomy	Description
Fully autonomous	UMS is expected to accomplish its mission within defined scope without human intervention.
Semi-autonomous	Human operator or the UMS plans and conducts requires various level of human-robot interaction.
Tele-operation	Human operator using visual and/or sensory feedback either directly control propulsion system or assigns incremental point, waypoints in mobility situations, on a incessant basis, from off vehicle and via a tether or radio/acoustic/optic linked control device.
Remote control	Human operator without benefit of video or sensory feedback directly controls the propulsion of UMS on a continuous basis, from off vehicle and via tethered or radio-linked control device using visual line-of-sight cues.

2.4.3 Communications Linkage to the ROV

The linkage comes in several forms depending on the distance and medium through which the communication occur. Such linkages include hard-wire communication either electrical or fiber optic, acoustic communication via underwater analog or digital modem, optical communication while on the surface and radio frequency (RF) communication while or near water surface.

Type of information exchange between the operator and the vehicle can be either or mixture of telemetry, tele-presence, control and record. Table 2.3 tabulated the definition of what mean by the type of information exchange mentioned.

Table 2.3: Type of information exchange between ROV and operator

Information Exchange	Detail
Telemetry	Measurement and transmission of data or video through the vehicle via tether, RF, optical or other means.
Tele-presence	The capability of an UMS to provide the human operator with some amount of sensory feedback similar to the operator would receive if inside the vehicle.
Control	The upload or download of operational instruction for autonomous operations or full tele-operation.
Records	The upload or download of mission records and files

2.4.4 Justifications of Tether

The RF is not satisfactory for the communication linkage since it only can penetrates a few wavelengths into water due to water high attenuation (Chris and Wernli Sr, 2007). If it is a low frequency, the waves will penetrates further but data transmission rates suffer. In order to perform remote inspection or high priority exploration, live video is needed at the surface so that decision can be made on navigating the ROV and inspecting the target. Acoustic in-water data is limited to less than 100 kilobytes per second which is not sufficient for high-resolution video images (Chris and Wernli Sr, 2007). A hard wire link to the operating platform is needed in order to have full operational in-water link to the vehicle. Therefore the need exist for tether of some type for real-time underwater inspection task.

2.5 SCIENTIFIC FUNDAMENTALS

2.5.1 Hydrostatic Equilibrium

According to Archimedes's principle, anybody whether partially or totally immersed in a fluid is buoyed up by the force equal to the weight of the displaced fluid.

The equilibrium attitude of the buoyant body floating in calm water is solely determined by relations between the weights of the body that is acting downward its center of gravity and the resultant of the buoyant forces, which is in magnitude equal to the weight of the body acts upward through its center of buoyancy. The body is not equilibrium if these two forces do not pass through the same vertical exist. The body then will correct itself to bring them into vertical alignment to achieve equilibrium static.

Figure 2.4 illustrate the attitude of submersed body. Position of center of gravity and center of buoyancy significantly determined the stability of immersed body. The body considers being stable if center of gravity located below center of buoyancy. It is neutrally stable when the points are coincided. When the center of gravity positioned on top of center of buoyancy, the body is in unstable condition.

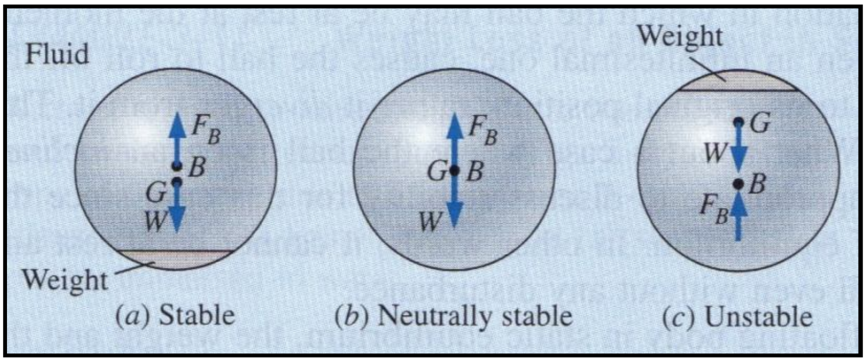


Figure 2.4: Position of center of gravity, G and center of buoyancy, B

Source: Cengel and Cimbala 2006

Figure 2.5 show how the correcting motion occurs when the immersed body experienced unstable condition.

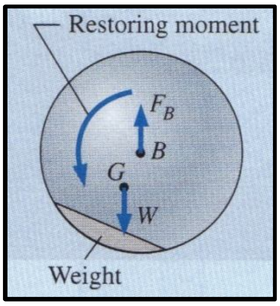


Figure 2.5: Correcting motion via existence of restoring moment.

Source: Cengel and Cimbala 2006

2.5.2 Water Specific Gravity and Buoyancy

According to conventional operating procedure, a positive buoyant vehicle is a must when operating to ensure they will return to the surface if a power failure occurs. This positive buoyancy would be in the range of 0.45 kg for small vehicle (Chris and Wernli Sr, 2007). Fresh water is less saline compare to sea water. Hence, when transforming the ROV from fresh water to sea water, the system demonstrates more positive buoyancy.

Figure 2.6 demonstrate the effect of water specific gravity on ROV buoyancy.

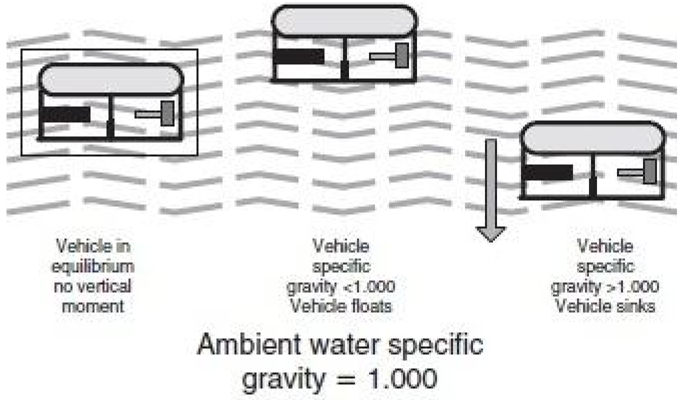


Figure 2.6: Effect of water specific gravity on ROV buoyancy

Source: Chris and Wernli Sr, 2007

2.5.3 Dynamic Stability

Positive stability defined when an upset object inherently rights itself to steady state. Positive longitudinal and lateral stability can be readily achieved by having weight low and buoyancy high on the vehicle. This action produces an intrinsically stable vehicle on the pitch and roll axis. Majority observation class ROV system, higher stability mean easier to control.

In watery environment, external forces do act upon vehicle and produce apparent reduction in stability. Other design characteristics also distress the stability of the vehicle along the anecdotal axis.

Figure 2.7 show vehicle geometry and stability. Relation of thruster placement to stability is illustrated in Figure 2.8.

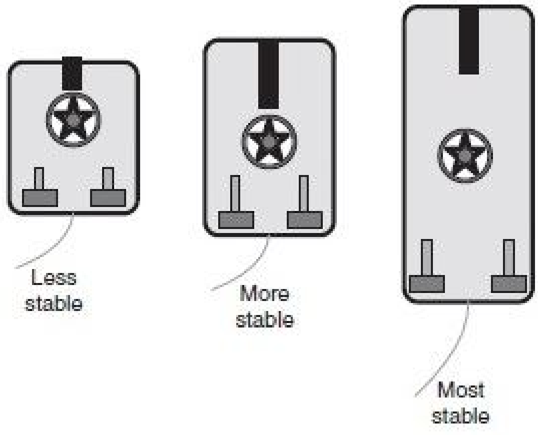


Figure 2.7: Vehicle geometry and stability

Source: Chris and Wernli Sr, 2007

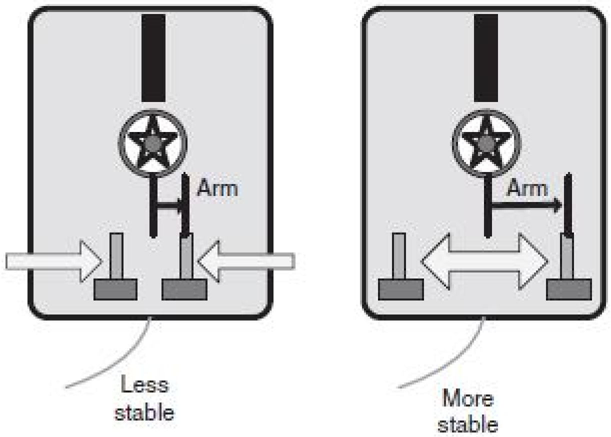


Figure 2.8: Thruster placement and stability

Source: Chris and Wernli Sr, 2007

The optimal aspect ratio which is the total mean length of the vehicles versus total mean width of the vehicle, and thruster placement will be dependent upon the anticipated top speed of the vehicle, and the need to maneuver in confined space.

2.6 QUANTITATIVE THEORIES

2.6.1 Buoyancy

Buoyancy was caused by an upward force exerted by fluid on a body immersed in it. This lifting force is called buoyant force and denoted by F_B. Buoyant force exists due to the increase of pressure in a fluid with depth. When there is difference between smaller hydrostatic force, F_{top} and larger force, F_{bottom}, the net upward force exists, which is the buoyant force.

The example of a flat plate of uniform thickness h submerged in a liquid parallel to the free surface can clearly be seen in Figure 2.9. The area of the top and bottom surface of the plate is the same with volume, V equal to product of area, A and height, h. buoyant force comprise the gravitational force, g and fluid density, ρ.

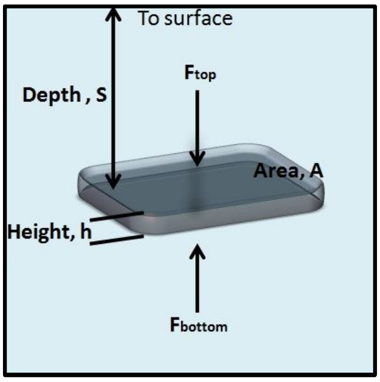


Figure 2.9: A submerged flat plate

In mathematical form, buoyant force is expressed as in Eq. (2.1)

$$F_B = F_{bottom} - F_{top} = \rho g V \quad (2.1)$$

The sovereignty of buoyant force is to the distance of the body from the free surface and the density of the solid body. The relation in Eq. 2.1 is valid for any object regardless of its shape. The buoyant force acting on an immersed body in a fluid is equal to the weight of the fluid displaced by the body, and it acts upward through the centre of the displaced volume.

Figure 2.10 illustrate a solid body dropped into a fluid will sink, float, or remain at rest at any point in the fluid, depending on its density relative to the density of the fluid (Cengel and Cimbala, 2006).

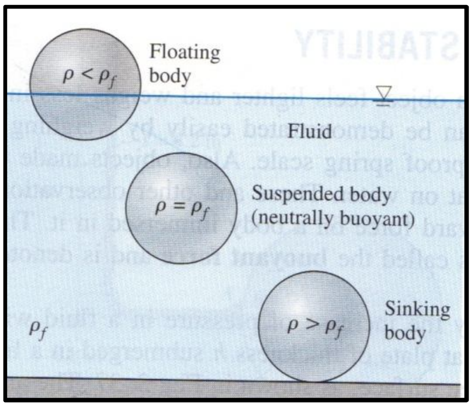


Figure 2.10: A solid body dropped into a fluid

Source: Cengel and Cimbala, 2006

2.6.2 Fluid Resistance

Fluid resistance is a velocity dependent property refers to forces that oppose the motion of a solid object through a fluid which acts in a direction opposite to the instantaneous velocity.

For a solid object moving through watery environment, the drag is the component of the net hydrodynamic force acting opposite to the direction of the movement (Cengel and Cimbala). Drag opposes the motion of the object, and in a powered vehicle, thrust is needed in order to surge.

The mathematical form of drag force show in Eq. (2.2)

$$F_d = -\frac{1}{2}\rho v^2 A C_d \tag{2.2}$$

Power exerted by drag force govern in Eq. (2.3)

$$P_d = F_d \cdot v = \frac{1}{2}\rho v^3 A C_d \tag{2.3}$$

Where;

- P_d is drag power
- F_d is force of drag,
- ρ is density of the fluid
- v is speed of the object relative to the fluid,
- A is reference area,
- C_d is drag coefficient

2.6.3 Thrust

Thrust is a reaction force exerted when a system expels or accelerates mass in one direction; the accelerated mass will cause a proportional but opposite force on that system.

For underwater locomotion, propellers are commonly used to produce thrust and initiate motion. The forces and moments produced by the propeller are expressed in their most fundamental form in terms of a series of non-dimensional characteristics These are completely general for a specific geometric configuration.

Thrust produce by propeller are shown in Eq. (2.4)

$$T = K_T \rho n^2 D^4 \tag{2.4}$$

Where;

- K_T is thrust coefficient
- ρ is fluid density
- n is propeller rotation per second
- D is propeller diameter

2.6.4 Pressure

These cumulative forces per unit area cause by surrounding fluid acted on immersed body will create a pressure.

Eq. (2.5) shows the relation of hydro-pressure in function of depth of fluid, h; density of fluid, ρ, and gravitational force, g.

$$P = h\rho g \tag{2.5}$$

Where;

- P is hydro-pressure
- h is depth of submerge
- ρ is fluid density
- g gravitational

2.6.5 Reynolds Number

Reynolds number can be used to determine the flow regime at the surface of the bodies. This number is a ratio of inertial forces and viscous forces.

Reynolds number is a product of fluid density,ρ flow velocity, v and the diameter, D per unit viscosity, μ as in Eq. (2.6)

$$Re = \frac{\rho v D}{\mu} \tag{2.6}$$

Where;

- ρ is fluid density
- v is fluid velocity or bodies velocity while traveling in a fluid
- D is height of diameter of the bodies
- μ is Dynamic viscosity

2.7 HARDWARE AND CONTROL SYSTEM

2.7.1 Propellers

Propellers are the main drive system for underwater vehicle. This specific component is responsible for the thrust production. Link to the shaft and the motor, the thrust power is proportional to the motor power output.

Depending on the number of blade, number of rotation and diameter of propeller which further will determine the thrust coefficient, the thrust produce is varied. Propellers for open water and under water vehicle come with different type. Such are fixed pitch propellers, ducted propellers, podded and azimuthing propulsors, contra-rotating propellers, overlapping propellers, tandem propellers and controllable pitch propellers.

Propellers have an optimum operational speed and some are optimized for thrust in one direction over another. A common small ROV thruster on the market today uses such propellers for forward and downward thrusting.

2.7.2 Buoyant

There is need for the underwater vehicle to be positively buoyancy. The buoyancy will add a substantial buoyancy force to the submerged body. For the greater body weight, larger buoyancy needs to be added to achieve positive buoyancy. This giving and advantage whereby the body is float when the power supply is disconnected. Hence preventing permanent lost to the whole vehicle.

2.7.3 Control system

Control system translates the operator command to physical movement of device. This desired of motion can be achieved through several ways. Common method is simple circuit consist of switches and programmable integrated circuit. Simple circuit is very easy to maintain, cheaper and replaceable in very short time.

Meanwhile much more complex circuit of need for various components integrated in one. This type of control system is more adequate for device that is equipped with sensors and complicated electronics such as electronic gyro, electronic compass, depth sensor, pressure sensors, sonar, manipulator and global positioning system.

2.8 PREVIOUS RESEARCH AND DEVELOPMENT

ROVs have become the interest of society for quite a time. The research and development either on total system or only involved subsystem has been carried out by passionate individuals. Their study has been review and proof to be helpful in gathering the ideas toward the design of the vehicle, and reference for the project and guideline of conduct toward developing the ROV.

The research ranged from conception of ROV, high maneuverability ROV, new ROV and even to automating the ROV. Such work is scarce in local ROV’s industries. In general, most of the study goal is to create more efficient and reliable underwater ROV.

The study then carefully tabulated in Table 2.4 for quick reviews. The sources also mentioned and contribution of the study on this project is as well stated.

Table 2.4: Previous study and development of ROV

Source	Title	Description	Contribution
Sayer P. 1996	Hydrodynamic Forces on ROVs near the Air-Sea Interface	Control and operability of ROV are strongly biased by their hydrodynamic characteristic especially in the near-surface wave affected zone.	Generated the idea on building hydrostatic cover
Boenig W. Kalman E. 2004	Development of a low cost thruster for the Santa Clara University ROV Program	Alternatives design of major low cost thruster component and recommendation on future work	Recommendation for using PVC as body of vessel and introduction of magnetically coupled drive shaft.
Walker D.G. 2005	Design and Control of an High Maneuverability Remotely Operated Vehicle with Multi-Degree of Freedom Thrusters	High maneuverability achieved through high thrust-to-mass ration in all direction.	Concept on high thrust will greatly provide high maneuverability.
Wagner T.S. 2006	Mechanical Design of a Contra-rotating Propeller Assembly for a Small Underwater ROV	Design and build contra-rotating propeller assembly with production rate greater than one assembly per seven hour day with one machinist and cost less than USD600 per assembly	Understanding of machining small propellers in compare to handiwork need more time unless machine with capability of high speed automated production is provided.
Salcedo I.L. Dutra M.S. 2008	A New Conception Of ROV	Design a ROV with only one helix that can reproduce all traditional movement and using only one mechanism to modify direction of movement.	The important of hydrodynamic study to figure out how the newly design ROV reacts to diverse condition.
Tena I. 2009	Automating the ROV	Present technologies that revolutionize the ROV control process allowing it to undertake monitoring from remote distance.	The path to future develop current project that turns ROV pilot into mission observer.

2.9 RELEVANCE OF THE LITERATURE REVIEW

The reviews provide generalized idea and factual information that act as guidance towards the project. The literatures begin from definition of development to strengthen viewer understanding of the project. The review then moves to introduction of remotely operated vehicle. The review aided scientifically the method of approach and engineering perspectives on how to conclude and understand the project successfully. Without the review, the current status of development will be invalid due to illiterate source. Within this literature review bring forth the previous study; it will help in constantly fuel up the passion for this project. Through it, common idea toward methodological approach of the project can be obtained. The upcoming project then was able to be visualized and realized.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter after the current introduction will describe the method for the development of the remotely operated vehicle (ROV). This begins with analysis of problem first from global view and basic engineering parameters such as working environment properties, drag force, hydrodynamics, thrust and power. This is necessary for initial specification. Next, the overarching design is created to meet these parameters. Each relevance subsystem (hydrodynamic cover, frame and thruster) is analyzed. Next the system is tested in real time and compare to the initial specification. Necessary optimizations are done to increase the performance of the system. Lastly, conclusions are drawn and future work is discussed.

3.2 PROCESS FLOW

The development project will be divided into two major phase. First is, Phase 1 which will be executed on first semester (January-April 2009). The second phase will be carried on second semester (July-November 2009). The detailed flow will be explained in sub-content of this chapter.

Figure 3.1 present overall work flows for the project that had been undertaken during first semester of 2009.

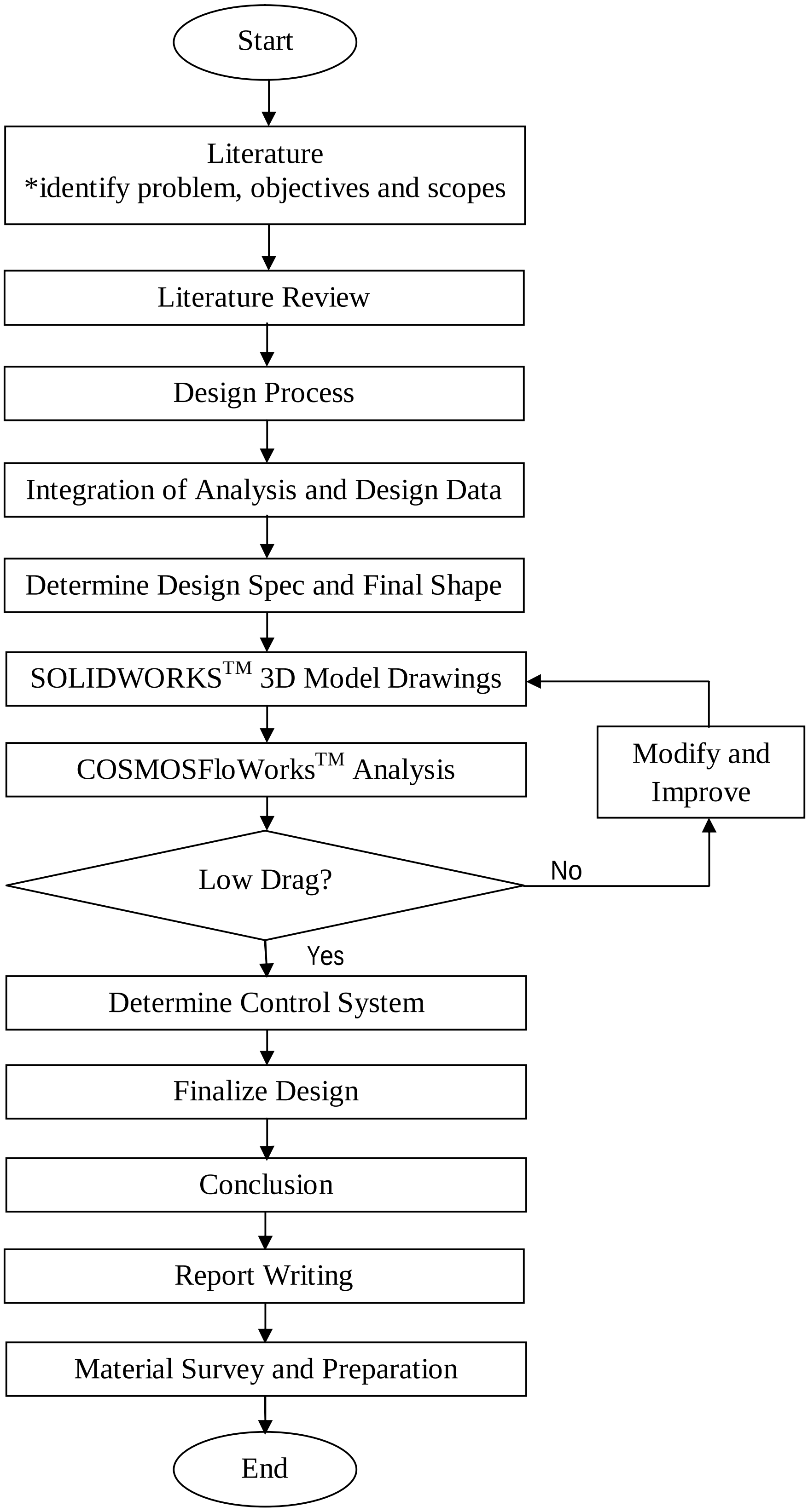


Figure 3.1: Flow chart for Final Year Project (FYP) 1

Figure 3.2 present overall work flows for FYP 2 which last in second semester of 2009.

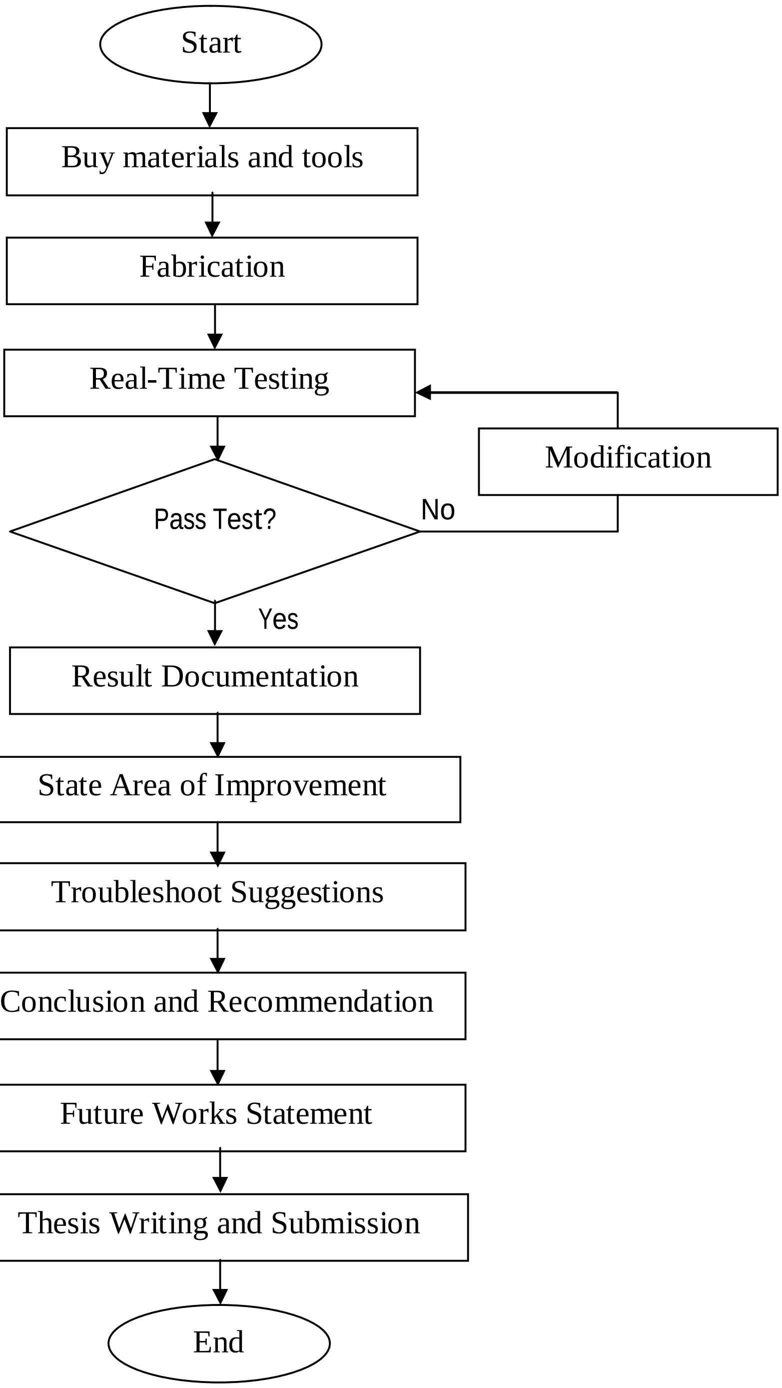


Figure 3.2: Flow chart for Final Year Project 2

3.3 TITLE UNDERSTANDING AND REFERENCES REVIEW

3.3.1 Literature

Literature is a preparation process toward the understanding of the development of remotely underwater vehicle (ROV) for underwater exploration. This process consists of extensive reading of journal, website and relevance literature. From the initial literature, the common ground of problems is found, the objective was set and the scope of project were specify. It was done on the first week of phase 1 and overall progress was finished on 18th January 2009. This process runs along with the literature review in order to get the basic idea of development of the project.

3.3.2 Literature Review

This process is a collective information method. The readings were done on journal, text books, thesis and websites. The collective information hence uses to be the basic guideline and ideas throughout the development of the remotely operated vehicle (ROV). This information is the key of the project. It included the information on quantitative theories, specification and class of ROV, thruster and even the control system. On top of that, this part of process give out definite understanding on what is remotely operated vehicle is, what is the analysis need to be focus on, and all information regarding the hydrodynamic and engineering properties of need to be emphasis on the development of the ROV. This process last for 21 days, begin on 11th January 2009 to 8th February 2009.

3.4 DEVELOPMENT OF DESIGN

3.4.1 Pre-development of Design

The design process was initiated by basic concept of project development. This concept is the backbone for the design process and act as pre-development stage before the detail specification and next process were executed. This pre-development stage was tailored to current situation of the project executer, budget and working environment in order to establish more detailed and smooth process flow. The outline of pre-development of design process can be referred in appendices section.

3.4.2 Design Process

Detailed process is an engineering approach toward the development of the project. During this process, the development is divided into two. First is approaching the project in industrial design where the main element focus is the design of the ROV. Second is through the engineering design where the properties of working environment (sea water and fresh water) were considered seriously. The overall progress starts on 26th January 2009 and end on 2nd April 2009. The result of both process then combine to establish the initial specification of the design. The design process flow can be viewed in appendices section.

3.4.3 Design sketches

A design sketch is an initial step taken in industrial design of ROV. To be reminding, all the sketching were done in manual drawing and no exact dimension were apply. The term sketching here follow the sketching of conceptual design method. This method is widely use in automotive industries when the concept car was in initial stage of development.

This process is mainly focus on the physical innovation and properties of the ROV. It begins with multiple sketches of the vehicle. Then the sketches were filtered after being compared to the existing design. The selection was made by the innovation characteristic and fabricate-ability of the project. Initial sketches were made on the paper and the frame sketch was made by SOLIDWORKS^{TM}. The designs are than filtered. Comparison and result can be view from appendix.

3.4.3 Sketch Comparison

This process continues the comparison on the chosen ROV with existing design of ROV. The main goal here is to develop an innovative design of ROV.

Result from the comparison yield a distinctive characteristic of the project ROV. Not even one existing ROV have a frontal thruster layout. This is the main advantage in the development of ROV because it will be the first ROV in the world with this layout of thruster. Scout video-ray ROV claimed to be the world smallest ROV. By the dimension, this project ROV set the new record for the smallest ROV equipped with camera.

The comparison tables were attached in appendices section of this thesis.

3.4.4 Features Sketching

In this process, the selected design was put back into drawing board for detailed sketches. This sketch includes the thruster design, frame design, hydrodynamic cover and frame. The rough dimension was given as a guideline.

The dimension is not yet valid until the environment properties were determined. This properties and the design are compared next to give a detailed dimension of the ROV.

Figure 3.3 show the feature sketching which would be the detail aided on the developed prototype.

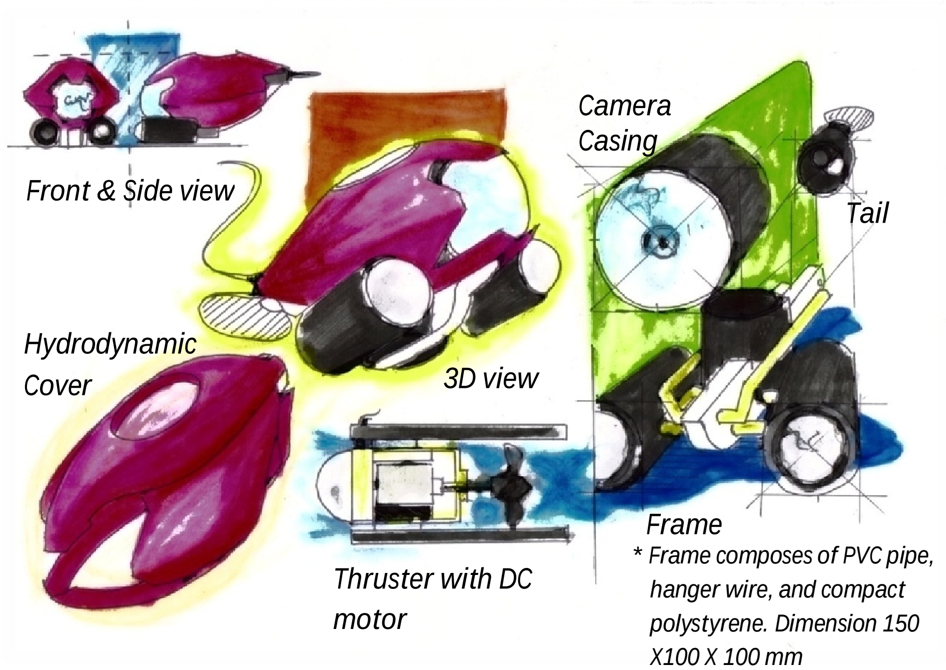


Figure 3.3: Feature sketching of the ROV.

3.5 PROPERTIES ANALYSES OF WORKING ENVIRONMENT

3.5.1 Analogy of Virtual Cubical Body

Properties analysis was concentrated on the properties of the working environment where the ROV is deploy, work and tested. These properties are essential to determine the specification of the ROV, the material and the thrust power needed.

This analysis used a virtual cubical volume to represent a submerged body. This volume is a dimensional boundary where the upcoming ROV will be build less than this dimension. The process is a synonymous of efficiency. It generally proposed by the idea;

“If the cubical volume can work well in the working environment, the streamline body will perform much better with the same component, same thruster power and similar number of thruster as the cubical box shape ROV”.

The purpose of doing so is to have a maximum value in the analysis and the further developed ROV will be able to overcome these maximum values (drag force on cubical volume, buoyancy force on an empty cubical volume and the volume displaced by the cubical volume).

Figure 3.4 show the virtual cubical body. It consist 3.375 x 10^{-3} cubic meter of volume, mass less, drag coefficient of 1.05 and travelling at 0.1 ms^{-1}.

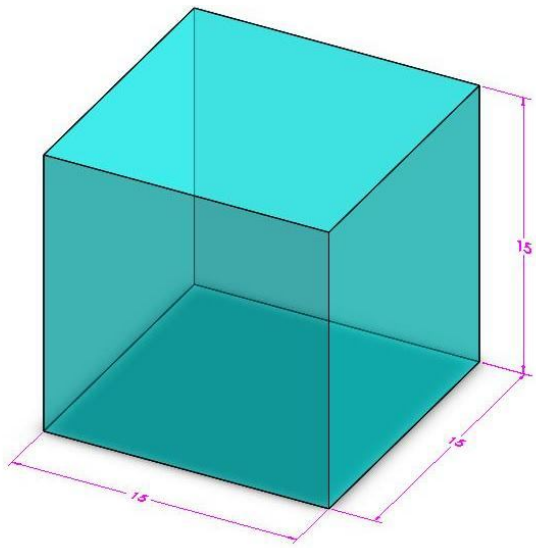


Figure 3.4: Virtual cubical body

This process then followed by analysis on sea water and fresh water. The values for density and dynamic viscosity were referred from US Coast Guard, Chemical Hazards Response Information System (CHRIS) of selected properties of fresh water and sea water. Other values were calculated.

3.5.2 Working Environment: Sea Water

The sea water being considered here is tropical water. That is the sea that lies in equator line. The relevance for the choice made is due to the geographical location of Malaysia.

The suggested temperature for sea water surrounding Malaysia is 28 °C. Properties of sea water were analyzed and calculated. The results then were tabulated in Table 3.1. The properties were based on virtual cubical body analogy with maximum depth of submerge equal to 2 m. The properties of near water-air surface is not consider since the submerge capability is the important result that need to be obtain. Therefore the wavy condition of surface watery environment is neglected in this analysis.

Table 3.1: Properties of sea water

Properties	Value
Temperature, °*C*	28
Dynamic viscosity,μ , $Kgm^{-1}s^{-1}$	8.948×10^{-4}
Density, ρ , Kgm^{-3}	1024.957
Reynolds number, *Re*	17182
Volume, *V*,	3.375×10^{-3}
Buoyancy force, F_B ,*N*	33.935
Drag force, F_D, *N*	5.381
Pressure, *P*, *KPa*,	20.109

3.5.3 Working Environment: Fresh Water

The properties analysis proceeded to fresh water properties. The procedures were the same as in analysis for sea water and due to condition that, Malaysia is in equatorial line; the temperature suggested was 28 °C.

Then the properties were calculated and tabulated in Table 3.2. All properties were also analyzed using virtual cubical body analogy with the same operational depth which is equal to 2 m. Reminded that the situation taken is for submerge condition where the properties of near water-air surface is negligible. Thus, the condition of this analyses will not taking the consideration of wavy surface.

Table 3.2: Properties of fresh water

Properties	Value
Temperature, *°C*	28
Dynamic viscosity, μ , $Kgm^{-1}s^{-1}$	8.352 x 10^{-4}
Density, ρ , Kgm^{-3}	996.080
Reynolds number, *Re*	17889
Volume, *V*,	3.375 x10^{-3}
Buoyancy force, F_B ,*N*	32.979
Drag force, F_D, *N*	5.229
Pressure, *P*, *KPa*,	19.543

3.5.4 Working Environment: Data Comparison

In this process, all the tabulated data were compared in Table 3.3. The comparison discussed on the regime flow surrounding the virtual cubical body, and the maximum values of properties. The flow with Reynolds number less than 10^5 is considered to be laminar.

Table 3.3: Properties of working environment compared

Properties	Sea Water	Fresh Water
Temperature, *°C*	*28	28
Dynamic viscosity, μ , $Kgm^{-1}s^{-1}$	*8.948 x 10^{-4}	8.352 x 10^{-4}
Density, ρ , Kgm^{-3}	*1024.957	996.080
Reynolds number, *Re*	17182	*17889
Volume, *V*,	3.375 x10^{-3}	3.375 x10^{-3}
Buoyancy force, F_B ,*N*	*33.935	32.979
Drag force, F_D, *N*	*5.381	5.229
Pressure, *P*, *KPa*,	*20.109	19.543

From the table, both environments produced laminar regime flow when the virtual cubical body swims through the fluid in 0.1ms^{-1}. Maximum value as marked with '*' shows that sea water properties is the dominant properties in determining the constraint factor for the ROV design.

3.6 CONSTRAINT FACTOR OF DESIGN

Constrain factor is a factor that use to verify the limit of dimension and limit of specification of the ROV. By taking virtual cubical body as a control volume, the volume of developed ROV should not exceeded controls. The constraint factors are sea water buoyancy force, sea water drag force and its hydrodynamics pressure. Hence the ROV will occupy less than 3.375m^{-3} of water volume.

The vertical thruster should be able to produce maximum thrust larger than of 33.935 *N*. The developed ROV should be able to overcome 5.381 *N* of drag force. The drag coefficient of the developed ROV should be less than 1.05. The component and its sealing should be able to withstand 20.109 *KPa* of hydro-pressures. The ROV was tailored to meet these constraint factors.

3.7 INTEGRATION OF ANALYSIS AND DESIGN DATA

The entire outcomes from previous process in analysis and design sketch were integrated in this process. The objective of this process is to give a practical specification and dimension of the ROV. These specifications include the size, the component, the frame and material used in its fabrication.

Table 3.5 documented the information gathered from properties analysis and design. The data collected will set the initial specification of the ROV. With the specification is determined, the design is going toward its finalization.

Table 3.4: Information gathered from properties analysis and design.

Properties analysis	**Design sketch**
Volume < 3.375 x $10^{-3} m^{-3}$ Thrust force = 33.935 *N* Drag Force < 5.381 *N* Drag Coefficient < 1.05 Withstand Hydro- pressure > 20.109 *KPa*	Hydrodynamic cover to reduce drag coefficient. Streamline body reduce drag force Frame built from PVC
ROV specification	
Dimension: <150 X 100 X 100 (1.5 x 10^{-3} m^{-3} of volume) Buoyancy made from polystyrene Frame made from composition of steel wire, compact polystyrene and PVC pipe. Streamline Shape (Drag coefficient: 0.04, Drag force: 0.205 *N*) Speed: 0.1 ms^{-1}	

3.8 FINAL SPECIFICATION AND FINISHING SHAPE

After the analysis and design sketch were integrated, the final specification and final shape was able to be determined. The final specification was set. The practical components were added as a modification of initial spec. These components were the motor size (outer diameter is 0.24*m*) and VGA Camera (for underwater navigation system).

The PVC pipe size also determined which is for body frame, used 1 ½ inches while for the thruster casing used 1 inch pipe size. The type of propeller used is small scale P447 tri-blade propeller. The mean of propulsion is ducted flow.

The shape was maintained due to the innovation value it have. The ROV was inspired by the most streamline shape in the world which is a water drop, the shape of the body than were engineered to be the shape of the boxfish.

The rational of the design is that drag coefficient of boxfish is 0.06 which is closes to the perfect streamline body of 0.04. Thus, the developed ROV in the shape of a boxfish betters the drag coefficient of today's common cubical ROV by more than 90 percent.

Figure 3.5 shows the inspiring nature of boxfish.

Figure 3.5: Boxfish (*ostracion cubicus*)

Figure 3.6 illustrates the wind tunnel model of the boxfish.

Figure 3.6: Wind tunnel model of a boxfish

Source: Mercedez Benz

3.9 SOLIDWORK™ 3D MODEL DRAWINGS

The overall specification and dimension were used to draw 3D model of the ROV in SOLIDWORK™ 2009 version. This process gives the 3D perspective of the design and enabled the simulation to be applied on the ROV.

The overall component was drawn in detailed according to the available dimension of the real parts. These parts include the frame, the wire diameter, the size of the polystyrene, the dimension and shape of the motor, VGA camera and even the shape of the hydrodynamic cover.

Each part was drawn to detail as well as the fabricate-ability issues is thoroughly considered. The drawing will only be done is it is fabricate-able in the real world. The 3D model is shown in Figure 3.7.

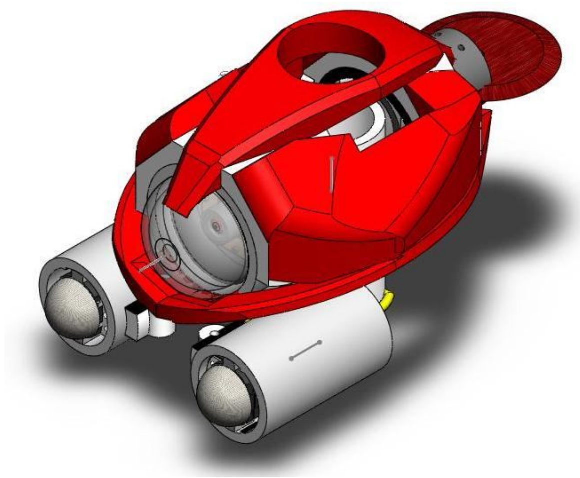


Figure 3.7: 3D model of the ROV

3.10 COSMOSFloWorks™ ANALYSIS

The analysis done in COSMOSFloWorks™ was for the selected component only. The selected component is the hydrodynamic cover, thruster, body frame, tail and the front lens.

The relevance of the selected component is due to the fact that this component makes up the major external characteristic of the ROV.

Type of analysis done is the force on 3 reference axis to resembles the drag force upon surge axis of motion; and the dynamic pressure which resemble the virtual inertia or added mass as the ROV swim along surge path.

General settings of the analysis are external flow, laminar flow, and 0.1 ms^{-1} of velocity. The outcomes of the analysis were considered as preliminary result.

3.11 THE DRIVE SYSTEM

3.11.1 Circuit Design

The circuit design is layout of the controller circuit of the ROV. This circuit functioning by the flip of switch, the switches used in the controller are dual pole dual throw (DPDT) switch.

Figure 3.10 shows an example of DPDT switch that will be used in fabrication of the model.

Figure 3.8: DPDT switch

Figure 3.11 shows the schematic diagram of controller circuit.

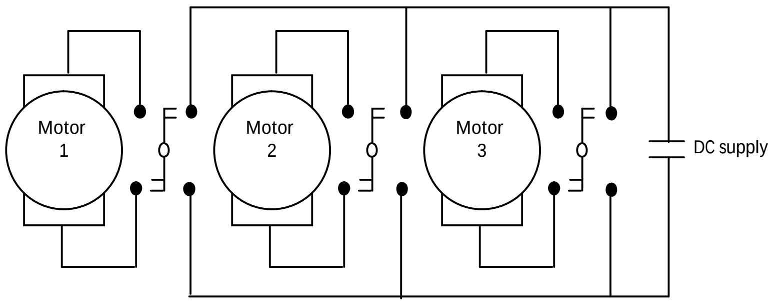


Figure 3.9: Schematic diagram for controller.

3.11.2 Control Configuration

Control configuration is a process to develop the integration between controllers and thruster. This process assigns the particular switches to particular thruster activations. Hence the correlation between switches and ROV motion was accomplished. This ensures that when the switches flip to the right, the ROV will move to the right. The ROV behave as what the controller want it to behave. These integrations were record in the table for clearer view of the process.

The controller was built due to simplicity and combinations of switches that can yield more innovative motion depend on the creativity of the operator. In the development of the ROV, The control configuration was design in this way without any involvement of complicated coding so that it is more reliable and much more easier to troubleshoot.

3.11.3 Quantitative Analysis of Required Thrust

The objective of this process is to determine the appropriate thrust should be produce to overcome the buoyancy force of the ROV. By knowing the thrust needed, than the motor can be selected.

The calculation of the analysis was taking consider the volume occupied by each component of the ROV. Then the density of the component was determined. Upon that, the thrust was calculated and the needed thrust than stated as preliminary result.

Table 3.5 listed the properties of component which by this data will used to determine the thrust of drive system need for surge.

Table 3.5: Properties of Components

Component	Volume , 10^{-4} m^3	Density kg/m^3	Weight, N
Hydrostatic Cover and Buoyant	1.5	17	0.0250
Camera	0.2	4350	0.4905
Thruster Casing	0.2 x 3 = 0.6	1200	0.7063
Motor Seal	0.1 x 3 = 0.3	17	0.0050
DC motor	0.03 x 3 = 0.09		0.5886 x 3 =1.7658
Hip Frame	0.1	1200	0.1177
Head Frame	0.2	1200	0.2354
Tail	0.1	1200	0.1177
Tail buoyancy	0.2	17	0.0033
Tail fin	0.1	17	0.0017
Hull	0.1	17	0.0017
Total	3.49		3.117

Maximum buoyancy force act on the ROV is equal to 3.509 *N*. Since the total weight of the ROV is less than the buoyancy force, the ROV is positively buoyant. This proved the ROV are floating in positive condition. The difference between the weight and the buoyancy force is equal to 0.392 *N*. This was the value need to be overcome by the thruster in order to submerge the ROV.

Beside the buoyancy force, the thruster also need to overcome the drag force and added masses or usually called as virtual inertia. The virtual inertia exists as the ROV move in the fluid and displacing the volume of fluid surrounding it. This inertia resists the motion of ROV. The properties of the propeller were taken account into calculation for the thrust force produce by the thruster system. The calculation was already done and with the result yield in the preliminary result.

Table 3.6 list propeller thrust coefficient K_T as a function of propeller pitch/diameter ratio for tri-blade propeller.

Table 3.6: Propeller thrust coefficient

Propeller pitch/diameter ratio P_P / D_P	**Thrust Coefficient, K_T**	
	Open Propellers	**Ducted Propellers**
0.6	0.26	0.24
0.8	0.37	0.37
1.0	0.48	0.51
1.2	0.51	0.67
1.4	0.54	0.82

Source: Prosser, 1986

In term of thrust system, the property taken for the calculation is ducted propellers with K_T is equal to 0.51. By the result already obtained from this process and the objective of the process was accomplished. The development now can proceed to material selection.

3.12 MATERIAL SELECTION

In this prescribe method and by the result have been obtained from the previous process, the suitable materials were proposed. It was then been filtered and selected to be the best fit in the project.

Major characteristic taken in consideration is the cost. For the thruster system, the practicality of the thrust output was being focus as the criteria of selection.

The material chosen for the frame is PVC pipe schedule 40, thruster motor selected was the brushless DC motor.

3.13 FINALIZED DESIGN

As the design was finalized, the overall objective for the first phase of the development of the ROV was accomplished. The finalized design can be referred in the preliminary result section. This finalization was done by compiling all the result and outcome of the previous process. With the design have been finalized, the upcoming process will be writing and preparation for fabrication.

3.14 MATERIAL SURVEY AND PREPARATION

The final process of the project executed in this semester is preparation for fabrication and real time testing. The objective of this process is to give the general idea on how to fabricate the ROV, where to get the component, material and equipment for fabrication and what type of real time testing should be execute in order to evaluate the ROV performance.

This objective was achieved by referring to the website and appropriate Do It Yourself (DIY) sheet for fabricating ROV. Thus the conclusion from this process is that ROV will be made by simple equipment, the seal method used is epoxy glue, polymer hot glue and cable tie. The testing would be done in control environment and ripples watery environment. With the end of this process, the overall development for the project for phase 1 was achieved.

3.15 OBTAINED REQUIRED TOOLS AND MATERIALS

The method purposed is to obtained real material for real fabrication. The major drawback is to get same material that is equal in specification with surveyed material. The method pursue on buying tools for fabrication and required material to develop the real prototype of the ROV.

3.16 FABRICATION

The fabrication took place as all the materials were completely obtained. The process here is to fabricate the prototype as exactly equal to initial specification unless there are circumstances that justify the modification. In remind, the fabrication will not involve heavy machining and the component that was about to be fabricated is delicately design. The obstacle’s here is to hand fabricating it.

3.17 REAL-TIME TESTING

Real-time testing is done firstly in control environment. From this testing, any alteration to the fabricated prototype will be made in order to allow it to perform under real world simulation

The testing criteria are to observe whether the prototype can perform basic maneuverability of surge, sway and heave.

3.18 RESULT DOCUMENTATION

The method of documentation use external video device to record the testing and the outcome. From recorded video, basic analysis of motion speed were done. The documentation proceeds by tabulating the obtained data.

3.19 IMPROVEMENT AND TROUBLESHOOTING

3.19.1 Area of Improvement

Area of improvement is a procedure where deficiency of prototype is detected. The detected deficiency is called the area of improvement. The handmade prototype will absolutely have several defects. The defects need to be overcome whether within period of project development of later on in future study depending on the time constraint and the priority towards achieving the objectives.

3.19.2 Troubleshooting

In occurrence of the defects, counter measure are need to be taken to troubleshoot the problem. In this methodology, troubleshooting conduct come in term of suggestions and with an objectives to act as preventive measure upon future project.

3.20 CONCLUSIONS OF PROJECT WITH RECOMMENDATION

Finally, to mark and end of the project, the conclusion was done according to the result obtained and referred back whether is the goal achieved or not. The recommendations follow as to improve the prototype for future development. The future works may include as well as development of the prototype is embarking.

3.21 CONCLUSION OF CHAPTER

The methodology carried out was a maturity for the project. Without the methodology, the project will not run smoothly according to plan. The next chapter will be focus on the result. The result is the outcome from the methodology where more technical detailed were presented in engineering view of discussion.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to provide a review of results and followed by discussion related to the results presented. The result obtained from two phases of testing, which are 3D model COSMOS analysis done in Final Year Project 1 and second phase of testing which is the real-time test carried in Final Year Project 2. The first phase was done as virtual simulations concentrating on drag force that affecting the innovative set of hydrodynamic cover. The relevant of testing is to determine whether the addition of hydrodynamic cover will highly increase the mobility of the vehicle. Other components that make up most of the vehicle's body also tested. Apart from that, the design selection and comparison also stated as it is accountable for the progress of the development. As the outcome justify the purpose of hydrodynamic cover, the fabrication of real prototype was took place. As the prototype finished, the real-time test was done in order to observe the performance of manufactured prototype. In conjunction with the progress of the project, several calculations were made so that the vehicle will achieve desired buoyancy and maneuverability. For real time testing, only few numerical values were documented as the test only done by recorded observation. Yet, the observation yield concrete testimonial of the successfulness of the project. Finally, all results were documented chronologically in order to offer sequential flow of result obtained as the development progress from time to time.

4.2 THE DESIGN

4.2.1 Design Inspiration

In so far as the history of the development of the remotely operated vehicle for underwater exploration, the design was unfortunately remain as it was for decades, cubic or cylindrical. The famous shape is still now used for work-class ROV and even the micro-class ‘eyeball’ ROV. The shapes prove to be insufficient due to high drag force exerted on its surface. Such inconveniences lead to higher cost in order to provide high power thruster to counter the efficiency loss. Resulting from the fact of the existing shape isn’t appropriate, oblique hydrodynamic shape was chosen. The inspiration ignited by the nature of water drop let, boxfish and human eyes.

4.2.2 Design Development

The inspiring natures lead to development of design. In result, the design was sketched on paper. The sketched design integrated all characteristic that in consideration would make the vehicle very efficient for underwater locomotion. The comparison again was made between several existing designs. After thorough evaluation, the design was prove to be an innovation and with poise it is able to success hydro-dynamically. As the outcome, the design was transform into third dimensional model and was ready to be analyzed as soon as after its specification was meant to be calculated.

4.2.3 Result of Quantitative Analyses

The calculation initiated into two main analyses of properties which are the environment analysis and determination of the product specification properties. For the environment analysis, two main categories was apprehend, sea water and fresh water. For the product specification, the thrust was the main criteria objected to calculation as well as the component properties especially the density.

Table 4.1 represents the result of environment analysis and obtained factual data on vital parameters in order to successfully develop the ROV. The initial prototype was operating within two meter of depth underwater. Therefore, the maximum pressure will compromise this range for hydro pressure as a limit.

Table 4.1: Result of Environmental Analysis

Parameters	Sea Water	Fresh Water
Temperature,	28	28
Dynamic Viscosity	8.948x10-4	8.352x10-4
Density	1024.957	996.080
Reynolds number	17182	17889
Regime flow	laminar	laminar
Cubical volume displaced	3.375x10-3	3.375x10-3
Buoyancy force	33.935	32.979
Cubical Drag force	5.381	5.229
Maximum pressure	20.109	19.543

Initial specifications consisted collections of components' properties analysis. The vital analysis is the thrust as it is the key element for flawless maneuverability. The calculation yield that thrust of propeller equal to 3.45 N for each thruster. Hence fort the result was set to be minimum qualification of thrust for single propeller. Any value of thrust less than initial specification is not capable in submerging or propelling the ROV.

The vehicle itself made of different components. These component properties affect the overall performance of design. Any missing information will cause the incapability of motor to perform the locomotion task. By the fact without these properties the right type of motor is hardly determined since the thrust must be synchronized with the component and the properties of design.

Table 4.2 numerically records the components' properties. These properties were meant to be the volume sum up and the total weight of vehicle. In consequence, the density of the ROV could be easily resolute.

Table 4.2: Properties of Components

Component	Volume, m^3	Density, kgm^{-3}	Weight, N
Hydro-cover	$1.50 x10^{-4}$	17	0.0250
Camera	$0.20 x10^{-4}$	4350	0.4905
Thruster case	$0.60 x10^{-4}$	1200	0.7063
Seal	$0.03 x10^{-4}$	17	0.0050
DC Motor	$0.13 x10^{-4}$	16000	1.76958
Frame	$0.10 x10^{-4}$	1200	0.1177
Front frame	$0.20 x10^{-4}$	1200	0.2354
Tail	$0.10 x10^{-4}$	1200	0.1177
Rear end	$0.30 x10^{-4}$	34	0.0050
Hull	$0.10 x10^{-4}$	17	0.0017
Total	$3.26 x10^{-4}$		3.117
Overall Density		974.6534	

4.2.4 Design Specifications

Specification was determined as the important calculations were done. The calculation set the specification of the ROV not just by the engineering view but also in term of innovation perspective. The design set apart from any familiar existing design. As the calculations were made, the values were tabulated and the design progressed from initial specification, prototype specification and to commercial benchmark. As for initial specification, the calculations made were detailed to tailor the performance of the ROV.

Table 4.3 present the ROV specification and performance as the result from calculations and real-time testing.

Table 4.3: ROV specification and performance

Parameter	Initial Spec.	Prototype Spec.	Comm. Benchmark
Mass	0.3177kg	0.4523kg	0.400kg
Size (L x W x H)	0.15x0.1x0.1m	0.16x0.135x0.115m	0.15x0.14x0.1m
Maximum speed	0.1 ms^{-1}	0.13ms^{-1}	-

4.2.5 3D Model Drawing

After the quantitative study of component and environment analyses, the initial specifications of the ROV were finally determined. With the specification already in hand, the next result would be the virtual model of the design. This part of result was exclusively necessary in term of the progress of the project. Final drawing of the model is a resemblance of the initial specification of the ROV. The result was assembled components drew using SOLIDWORK™ 2007.

The model generally can be divided into two major parts which are the upper body and the lower body. The upper body consists of hydrodynamic cover, camera case, tail and fin. While the lower body consists of frame, two horizontal thrusters, vertical thruster, and hull.

Figure 4.1 presents the extruded view of hydrodynamic cover. The cover composes of three parts which is buoyant base, top cover and side cover. The hydrodynamic cover allows the design to have a very low drag coefficient compare to any design that have been developed before.

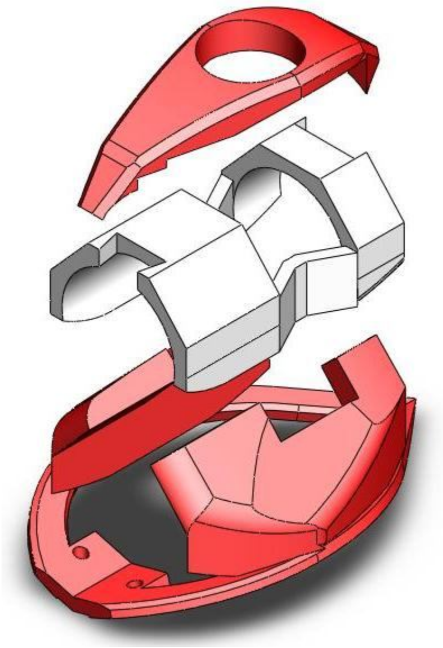


Figure 4.1: An extruded view of hydrodynamic cover

Figure 4.2 shows the hydrodynamic cover. The cover makes out most of the design and the only element that have given the ROV a smooth underwater locomotion. Without the cover, the vehicle only has old tubular shape which was undesired due to higher drag coefficient and less innovative in term of development perspective.

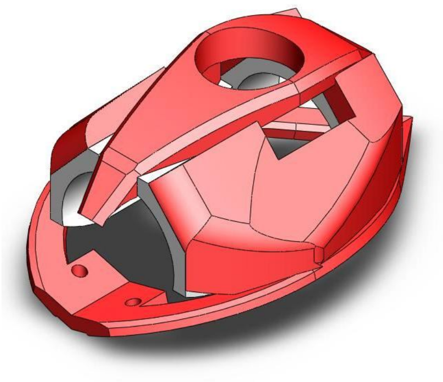


Figure 4.2: Hydrodynamic cover

Figure 4.3 presents the camera case. The case was the holder for the camera and supposes to prevent water from making contact with internal circuit. It was attach with transparent lid and sealed waterproof.

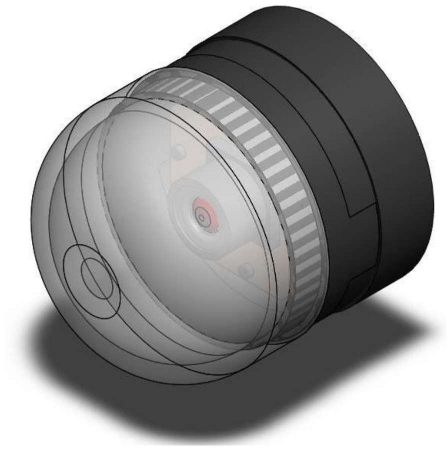


Figure 4.3: Camera case with camera inside.

Figure 4.4 shows the tail and fin of the vehicle. These components act as a balancer and stabilizer of the ROV. During submerging, the ROV will slightly tip at the front due to reaction force acting on the fin. The tilting allows the ROV to have full thruster in used for quick submerging and resurfacing.

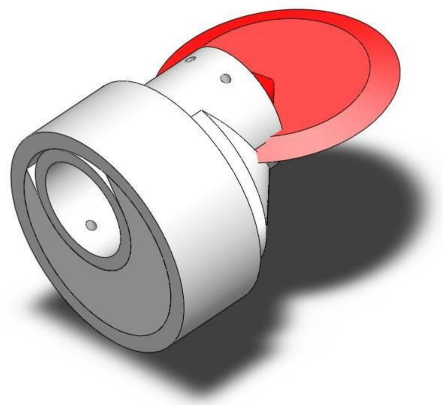


Figure 4.4: The tail and fin

Figure 4.5 illustrated the assembled set for upper body. This specific part acquiesce the distinguish shape of the vehicle.

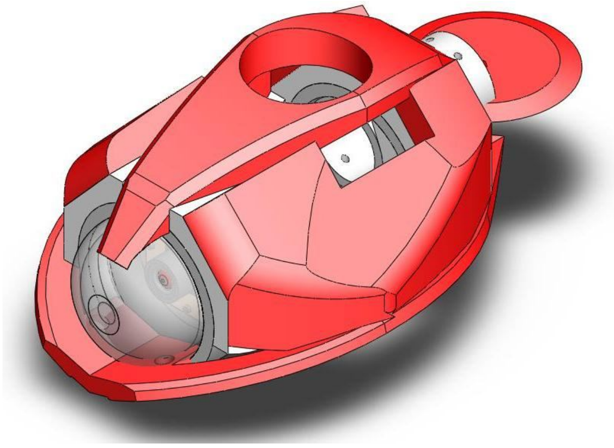


Figure 4.5: Upper body

Figure 4.6 displays the motor with attached propeller and holder. This is the vital part for locomotion as without it no movement or motion could be achieved. The vehicle contains three similar components that were mounted strategically.

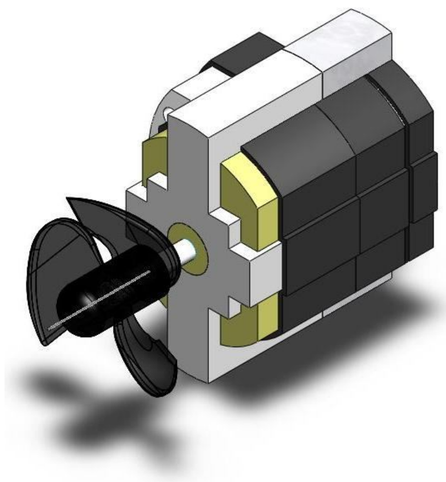


Figure 4.6: Complete motor set

Figure 4.7 illustrates the lower body of the vehicle. The body consist of three thruster mounted on specific area on the hull. One thruster lay in middle vertically and the other two were position horizontally on both side.

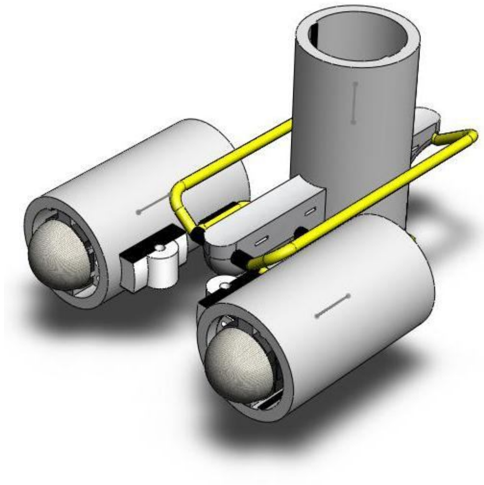


Figure 4.7: Lower body

Figure 4.8 shows the transparent view of the lower body. The position of motor can be clearly seen inside thruster components.

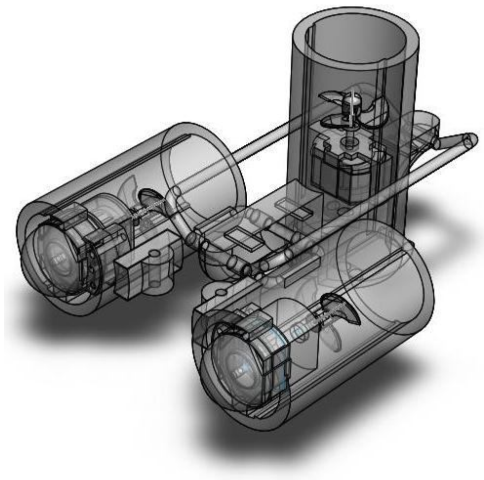


Figure 4.8: .Transparent lower body

The full assemblies of the vehicle are presented in Figure 4.9. The complete set of this model are the initial specification of the ROV. The prototype would be different since there are quandaries during fabrication process. The detailed on this segment will be further discussed within this chapter. Figure 4.10 is the transparent version of the full design.

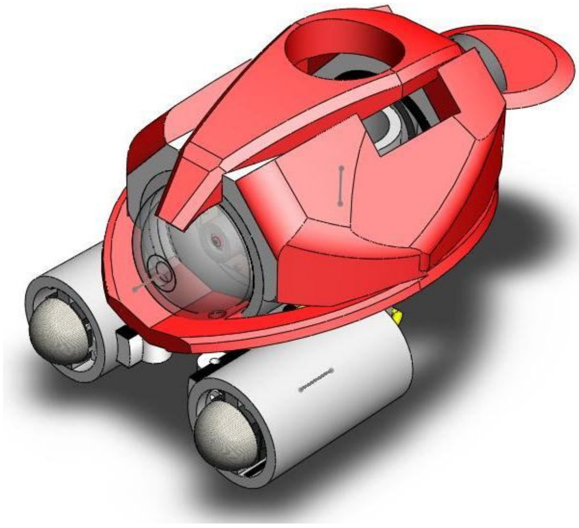


Figure 4.9: The full design of the ROV

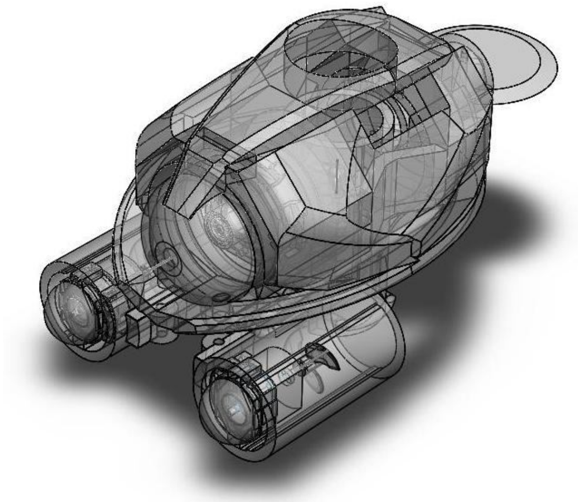


Figure 4.10: The transparent view of full design

4.3 RESULT OF SIMULATION

The simulation was the foremost stage of testing. It was done during the first phase of the project on Final Year Project 1. The simulation will focus on the drag force of hydro-cover and the main components that are greatly affecting the motion of vehicle. The most fundamental result would be the hydro-cover, as it is the pioneering feature that has been developed in this project. COSMOSFLOWORKS™ was utilized in this simulation. Apart of that, the dynamic pressure test also conducted as it will determined how much of pressure exerted on the object as it go through the fluid.

First components tested were the side cover of upper body. The test yield results for dynamic pressure and drag force. Table 4.4 listed the outcome of this test.

Table 4.4: Result of side cover simulation test

Parameter	Result
Dynamic Pressure	4.295 Pa
Drag Force	0.0072 N

The test were done with hundred of iterations. The outcome proves that the side cover is very stream line in shape.

Figure 4.11 exhibit the vector line result of side cover. The blue lines indicate that the flow is not critically altered and signify the smoothness of fluid flow.

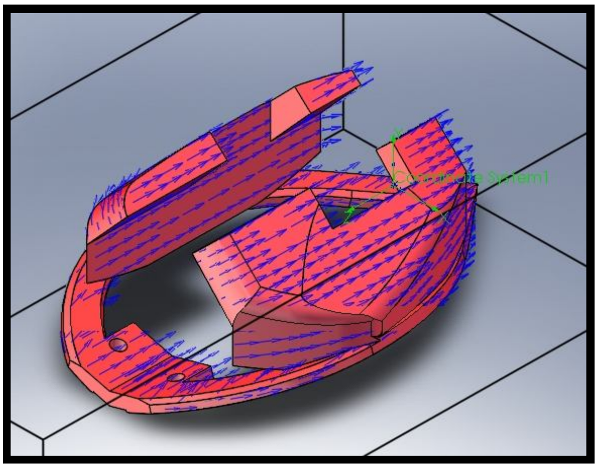


Figure 4.11: Vector line result of side cover

Second component undergo the same simulation test was the top cover. Table 4.5 shows significant result of the test.

Table 4.5: Result of top cover simulation test

Parameter	Value
Dynamic Pressure	3.4183 Pa
Drag force	0.0019 N

The analysis yields imply the top cover that the shape was met the design function which is to provide hydrodynamic body of vehicle. Plus with the model dimension is set to be very small, it help to lower the drag force buy significant amount compare to large size of vehicle. Such condition occurred when the cross sectional area was decreased to minimize surface contact during movement.

The vector line result further strengthens the statement. Figure 4.12 envisage the result.

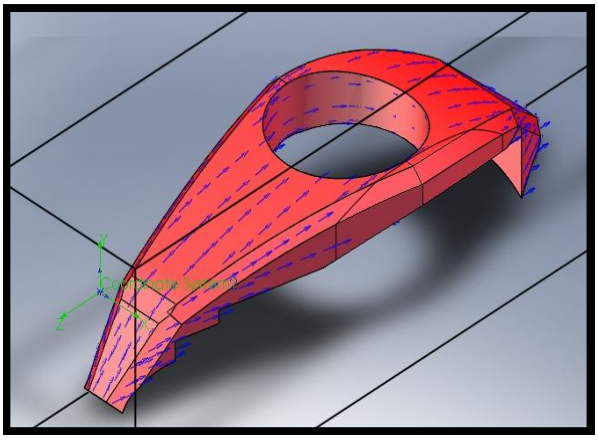


Figure 4.12: Vector line result of top cover

The blue lines designate the outer flow of fluid surrounding the top cover. Cooler color resembles smooth flow while hotter color indicates turbulence. From figure 4.12, the flows remain blue as it passes over the top cover. The top cover was design to be low drag coefficient so that the vehicle can utilize produced thrust efficiently.

The simulation then carried out to front nose, hull, vertical thruster and thruster nose. These components were major layout of the developed ROV. Main interest of the simulation test on the part was its dynamic pressure and drag force.

The simulations go through hundred of iterations. As the iteration increase, the result will approach to the real value. The iterations will stop as the values propagated were no longer differing from previous iterations.

Table 4.6 listed the result of this simulation that was conducted on the stated components.

Table 4.6: Result of simulation of other components

Component	Drag force, N	Dynamic pressure, Pa
Front nose	0.0020	4.1716
Hull	0.0007	4.3584
Vertical thruster	0.5348	12.1168
Thruster nose	0.0012	5.5924

From the results, vertical thruster experienced the highest drag force and dynamic pressure. This result symbolized the situation when the cover was not installed. The real life situation can be seen at existing design of ROV. Due to its basic cubical or cylindrical shape, the ROV face difficulty in turbulence environment. With the information from the analysis, the vertical thruster was located at the center of vehicle, not just for vertical propulsion but also to reduce drag when motion initiated. Hence, the vehicle will have more thrust to use for propulsion than it was used to overcome drag.

4.4 THE FABRICATIONS

The project entered the second stage of development. The previous results from initial stage were implemented into real time fabrications. The fabrications mark the progress of the development as the crucial stage for real time testing. The fabrication initiated strictly according to initial specification unless the predicament prevent it to be so. Whereas certain areas need to be troubleshot, the fabrication differs from initial order. The product manufactured will be the prototype of the project.

The fabrications begin with the base and side cover of upper body. The selected material to made the cover was compact A class polystyrene. The polystyrene then cut into shape according to dimension of initial specification of ROV. The progress frequently refers to drawing to ensure the prototype will be perfectly fabricated.
Figure 4.13 shows the fabricated product of base and side cover. The components were attached together using super glue. Super glue was chosen since it will not disintegrate the polystyrene.

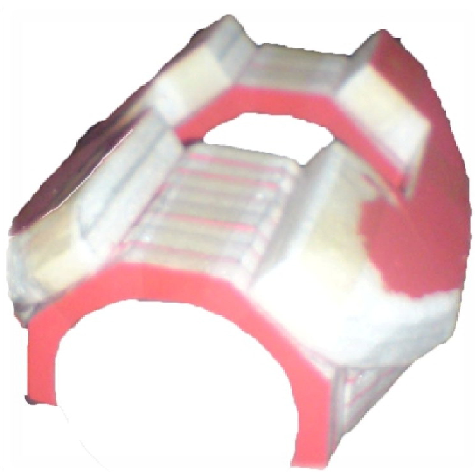


Figure 4.13: Base and side cover

The process continues until the fabrication of hydrodynamic cover was complete. Final result of this fabrication is shown in Figure 4.14.

Figure 4.14: Hydrodynamic cover

Hot glue gun used in this fabrication to attach large component together. Due to this type of glue used, the fabricated product is lack of esthetic value.

Next progress was the fabrication of frame. This lower body of vehicle use PVC pipe as main material for construction. The pipes were cut into desired dimension before the attachment process took place. As for the hull, polystyrene were used as fabrication material. The hanger wires were then carves into position to create a frame for wire and weight mounting. Figure 4.15 envisage the finished product.

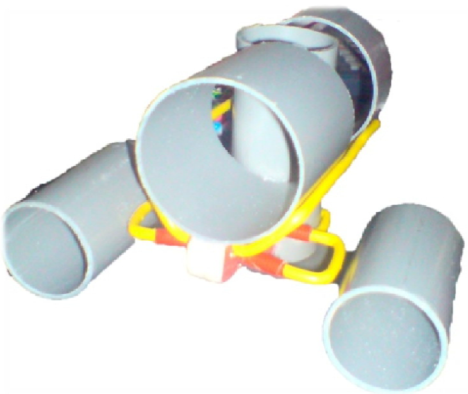


Figure 4.15: Lower body with un-glue camera and tail casing.

In consequence of finished frame, the thruster was made. The hardware was mounted into places. The frame was fortified to support thruster load. The complete installments insinuate finished lower body as seen in Figure 4.16.

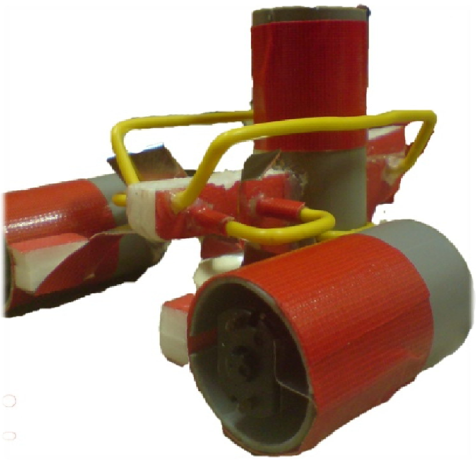


Figure 4.16: Finished lower body.

Figure 4.17 shows rear view of finished lower body. The position of propeller can clearly be seen inside thruster. The propellers were handmade as the custom shop was unable to produce such small delicate device. The design also differs from initial specification in number of blade. The initial model only used three blades as preordained propulsion but the prototype came with four blades for propelling function.

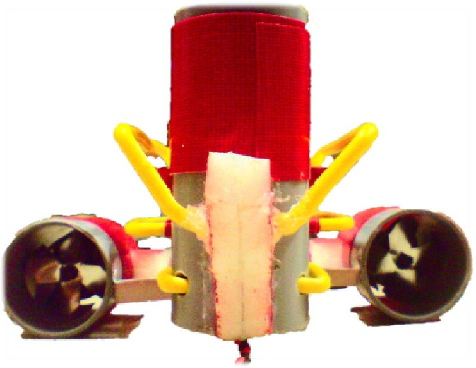


Figure 4.17: Rear view of lower body

The top view of lower body illustrated in Figure 4.18. The propeller of vertical thruster positioned inside. All propellers were made of thin brass plated steel. Figure 4.19 displays the finished handmade propeller.

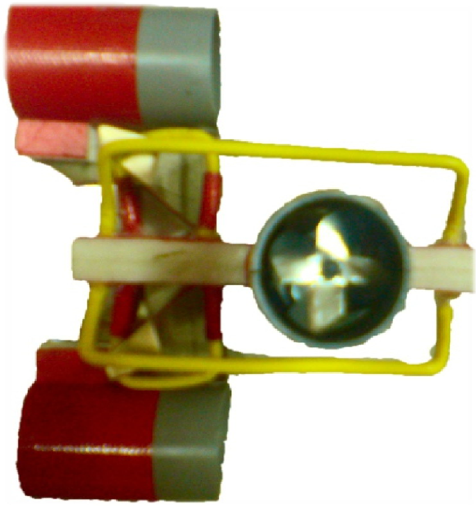
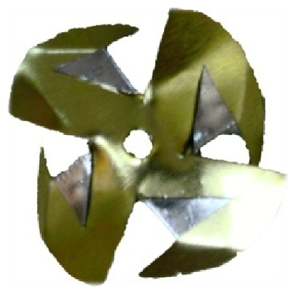


Figure 4.18: Top view of lower body

(a)



(b)

Figure 4.19: (a) top view of handmade propeller (b) bottom view of handmade propeller

The fabricated prototype compiles all of the handmade components with electric hardware. The electronic device; USB interface camera was also installed inside camera case. The next fabrication procedure was to mount and attach lower body to upper body. The hot polymer glue used to hold the components together. The epoxy glue then applied onto merge boundaries in order to fortify the join of the part. The camera case was seal with epoxy to prevent leakage. It was mounted in leaning position in order to avoid water from entering its internal circuit. This preventive measure was taken in case the leakages occur.

Figure 4.20 displays the fabricated prototype. The width of the prototype was slightly larger by 3.5cm compare to the third dimensional model. This modification will increase the dynamic stability of the vehicle.

Figure 4.20: Fabricated prototype

Followed by fabrication of body, the next progress would be the fabrication of user's communication interface. The interfaces consist of switches, DC power supply and directly connected to the ROV. This joystick sent control information to the motor and manipulates its criteria of rotation. There are three DPDT switches act as toggle button with 9V dried cell to energize the thrusters.

The tethered joystick is shown in Figure 4.21.

Figure 4.21: The joystick

4.5 THE MODIFICATION

The prototype undergoes control experiment for buoyancy and stability. The control experiment was done inside a water-fill pail. Results of the experiment indicate the fabricated prototype was flawed and failed the stability test. The front end submerged deeper underwater caused the rear end to float higher from the water surface. This uncompromised outcome left the vertical thruster with minimal water supply since the body was in gradient position. Without ample supply of water, the thrust exerted by the propeller is not sufficient for submerge operation.

This lead to modification of prototype where the weights had been introduces. The feature were fabricated and added into the prototype to counter the overly buoyant rear end. The weights were made of gravels and red soil. The materials were compress inside PVC pipe. To maintain the stability, additional fishing weight were add up at the bottom of vertical thruster.

Figure 4.22 represents the additional weight during its fabrication process. The additional weights will be attached at the rear end of the prototype.

Figure 4.22: Weights

Figure 4.23 shows the additional weights attached to the prototype.

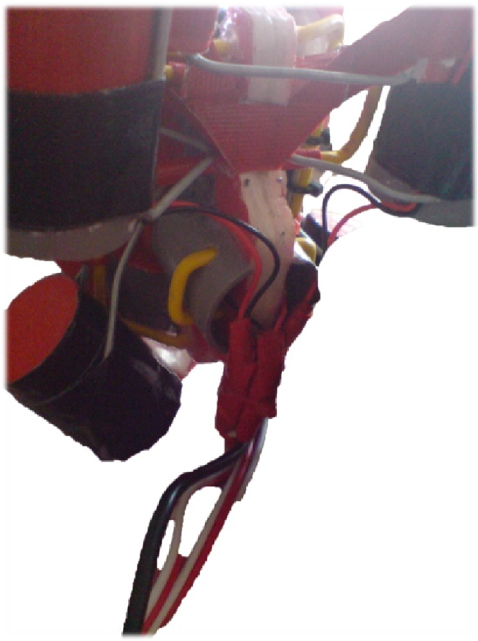


Figure 4.23: Additional weights attached at the bottom.

After the modification, the prototype went through similar test. The test yield promising outcome and the stability were achieved as once desired. With the new features added to the prototype the project were now ready to undergo real time testing. The complete prototype after finishing touch up can be seen in Figure 4.24.

Figure 4.24: The complete prototype

4.6 THE REAL-TIME TESTING

4.6.1 Results of Control Environment Test

The real time testing was a major step taken in the development of project. The testing were categorize according to characteristic of environment. Those parameters were static and undulating water. Before the prototype undergoes outdoor environments, the control test was done in order to investigate the performance of the prototype. The water-fill pail became the testing ground of the project. This set-up resembled static water environment and the submerge capability of the vehicle were determined.

Initial position of the vehicle was taken and measured to be 0.5cm above water level which is 4.34 % of total height remain submerged. If the percentage went higher than 10%, the possibilities to submerge the vehicle using current configuration is almost nil. Figure 4.25 shows initial position of the ROV before the vertical thruster was switch on.

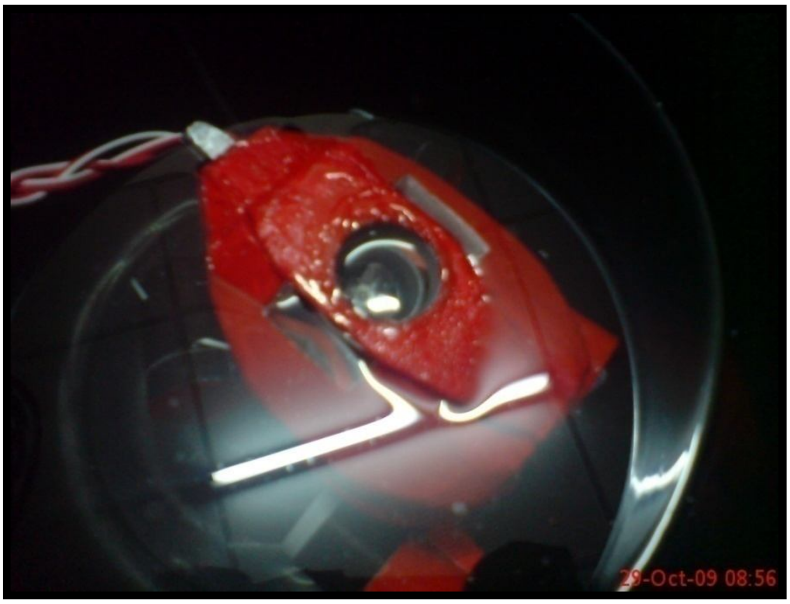


Figure 4.25: Initial position of ROV before the test begin

Figure 4.26 displays the state where the thruster switch were on and the vehicle were in submerging mode. The ROV remain submerged for more than one minute. Figure 4.27 shows the vehicle in submerged position.

Figure 4.26: Submerging mode

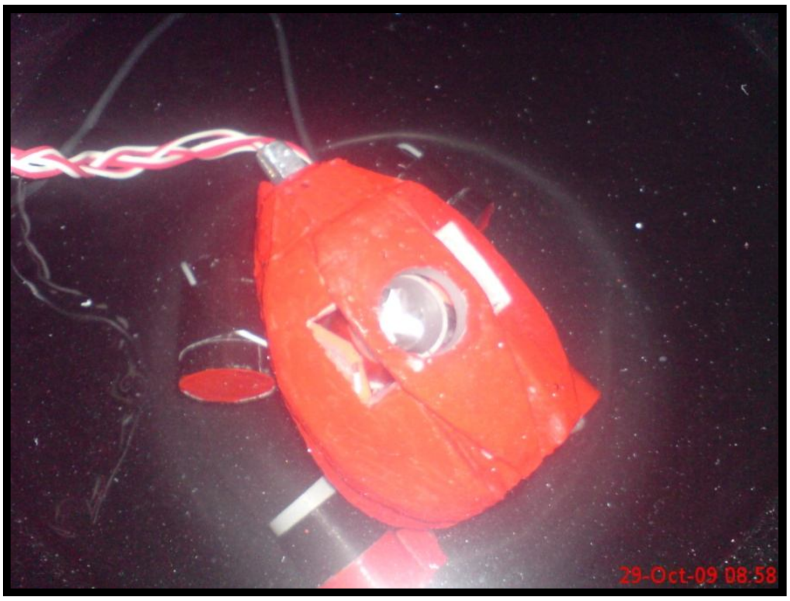


Figure 4.27: Submerged ROV

Figure 4.28 presents the resurfacing mode of vehicle. The overall submerging process took eight seconds and another five seconds to resurface. The times were tabulated in Table 4.7.

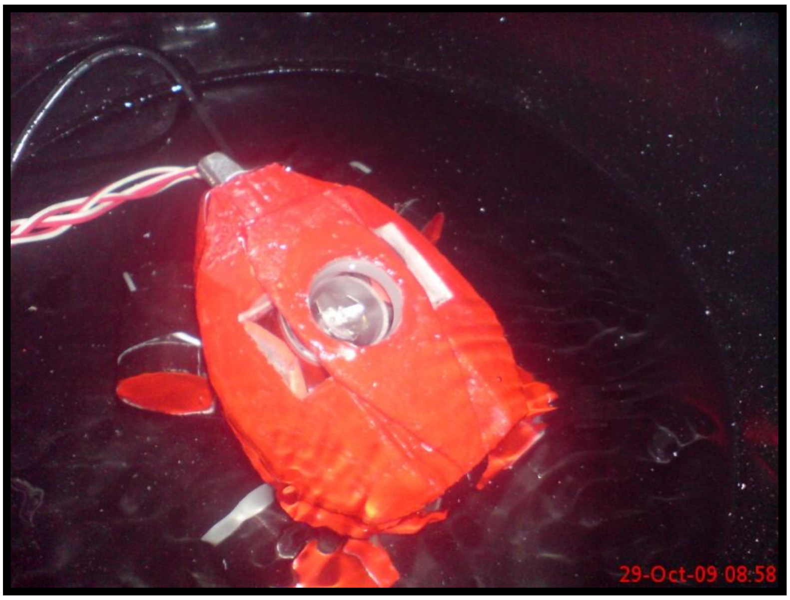


Figure 4.28: Resurfacing mode

Table 4.7: Recorded time of submerging and resurfacing

Mode	Time, s
Submerging	8
Resurfacing	5

The second test was followed but the result was inconsistent with primary test. The vehicle failed to submerge using single thruster. All thruster need to be switch on in order to submerge the ROV. The submerge motion is in gradient line. The problem discovered and the propeller was the cause. The force exerted by flowing fluid effect the pitch angle of the blade. The propeller consequently causes resistance to inner wall of thruster as its initial angle was dispersed. The flaw reduces thrust output from propeller and lead to disorientation of motor as the holder was vibrated when it receives impact from blade resistance. The position of motor is moved away from central point. The thin plate which was the material used to fabricated the propeller is not suitable and cannot sustain the pressure of flowing fluid.

Extensive repairs were carried to correct the propeller pitch. Unfortunately nothing can be done to align the motor orientation since dismembering the prototype is not an option. After the faulty propeller has been repaired, outdoor testing were conducted.

4.6.2 Results of Outdoor Environment Test

The test was carried to outdoor test. The chosen place was the miniature waterfall located in front of UMP Chancellery. The undulating wave created by the waterfall would be the perfect scenario of calm sea. The maneuverability performance was the determined. The test was recorded as proofed of result.

The initial position of the vehicle was captured in Figure 4.29.

Figure 4.29: Initial position of vehicle during outdoor test

Figure 4.30 shows forward motion of the ROV. The maximum speed was $0.13ms^{-1}$. The sequential figures were shown in alphabetical order.

(a)

(b)

(c)

Figure 4.30: Forward motion of ROV

Figure 4.31 sequentially display the motion of vehicle turning to left. The arrangement again used alphabetical order.

(a)

(b)

(c)

Figure 4.31: Left turn maneuver

Figure 4.32 record the reverse maneuver execute by the vehicle. The figure once more arrange in alphabetical order.

(a)

(b)

(c)

Figure 4.32: Reverse maneuver

Figure 4.33 display the sequential order of turning right maneuver execute by the vehicle during outdoor test.

(a)

(b)

(c)

Figure 4.33: Right turn maneuver

Figure 4.34 shows the vehicle in submerge action. From the test, the vehicle was able to submerge and return back to water surface. There is no problem for the vehicle to perform this task. Only slight disturb in buoyancy would greatly affect the mentioned action. The proofs were recorded as when leakage occurs in camera component, the water entered adds extra weight to vehicle. The mounted thruster was unable to counter the weight thus incapable to resurface the ROV. Here, it shows how intrigue the vehicle was and the essentialness to prevent water leakage were deeply comprehended.

Figure 4.34: The ROV was submerging

Table 4.8 records the obtained data of the test. The data comprise two analysis one for surface operation and second for underwater operation.

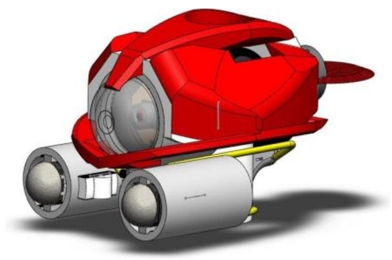
Table 4.8: ROV speed for surface and underwater operation

Movement		**Speed, ms^{-1}**	
		Underwater	**Surface**
Forward		0.13	0.13
Reverse		0.16	0.15
Rotate	90° Right	0.02	0.02
	90° Left	0.02	0.03
Vertical		**Submerge**	**Resurface**
		0.04	0.05

4.7 COMPARISON OF SOLID MODEL AND FABRICATED PROTOTYPE

The initial specification or initial design was compared to the fabricated prototype for any modification and differences in system specification, design and additional features as well as added component. The comparison simplified in tabulated form and can be refer in Table 4.9.

Table 4.9: Comparison between solid model and fabricated prototype

Features	Solid Model	Fabricated Prototype
Photo		
	Device	
Camera	Threaded lid with camera inside	Ready-made Webcam
Thruster motor	9V rated DC motor	9V rated Dc motor
Propeller	Three blades	Four blades
Weight	No additional weights	2 additional A-size battery hand-made weights, 2 fishing weights size 6.
	Product Rating	
Max speed	0.10 ms-1	0.13 ms-1
	Maneuverability	
Heave	Submerge & resurface	Submerge & resurface
Sway	Left & right	Left & right
Surge	Forward & reverse	Forward & reverse
	Component	
Thruster nose	available	Not available
Thruster case	Thick wall PVC pipe	Grey thin wall PVC type
Motor case	available	Not available

4.8 THE PREDICAMENTS

4.8.1 Deficiency of Fabrication Process

Fabrication process encountered several problems especially in the early stage of development. The problems were explained in tabulated form of table 4.10. Listed problem consist negative feedback of supplier, absence of custom shop to fabricated desired component, defective glue for assembly, alteration of material and fragile frame.

Within this statement no company name or personal individual will be mention as it is an obligation to maintain the reputation of the respected personnel. In addition the encountered problem is not due to external fault of individual but due to the current situation and unfortunate circumstances, although all the preventive measure was taken.

Table 4.10: Problems Encountered During the Progress of Fabrication

Quandary	**Description**
Negative Feedback From Supplier	• Initial specifications were design to use DC motor FC-280S-20120-N but no purchase can be made if the order unit is less than 1000 pieces. • Several companies have been contacted for inquiries and purchase deal of particular motor but no positive response up to this date. • No local miniature propeller supplier present within travel radius from state of accommodation.
Absence Of Custom Shop	• Absent of custom shop that capable on fabricating miniature propeller

Table 4.10: Continued

Quandary	Description
Defective Glue	• The adhesive used failed to perfectly attach the component. The affected component was motor holder, frame, thruster case and propeller.
Alteration Of Material	• Alteration of propellers' material and types of camera, type PVC and type of motor affected the buoyancy of vehicle.
Fragile Frame	• The incompetence of polystyrene to hold both thrusters lead to the adjustment on the design of the real model

4.8.2 The Defects of Prototype

Real time testing of fabricated model discovered several defects that decrease the performance of the ROV. The imperfections were arranged in tabulated form and discuss in Table 4.11. The list ranged from the weight of the tethered, the locomotion of vehicle, leakage, the condense water vapor on the lens of camera, the corrosion of conductor pin and faulty device mounted.

Table 4.11: Defects of the fabricated ROV

Defects	Description
Heavy Tether	• Additional weight added by the 1 meter long tethered drag the vehicle underwater preventing it to resurface.

Table 4.11: Continued

Defects	Description
Off-Course Locomotion	• The tendency of vehicle to sway to the left side was due to misalign thruster mounting and un-identical pitch angle of the handmade propeller blade. • Flaw occur due to incoherent of handmade fabrication to cope with precise dimension
Leakage	• The camera casing experience leakage due to rigid epoxy adhesive to follow the flexibility of the USB cord hence produce gap surrounding its hole and cause device failure.
Humidity Effect On Camera Lens	• The colder surrounding temperature was the reason for the condensation of water vapor on camera lens which lead to poor vision.
Corrosion of Conductor Pin	• The corroding internal pin effect the conduction and durability of pin. Soldering also promote the corrosion of internal pin.

4.9 THE TROUBLESHOOTING

4.9.1 Solution of Fabrication's Quandaries

The solution were figured and proposed to eliminate the quandaries. Implementations of solution were done according to possibilities and opportunity available during the project. Some solutions remain as suggestion which is vital to be carried out in future development of the product. Table 4.12

Table 4.12: Solution for quandaries faced during fabrication

Quandary	Description
Negative Feedback From	• The model had been replaced with PC130 motor for propulsion system. • Widen the list of supplier that capable of supplying the right quantity, the right material in the right time. • Long term solution is to find local or international company that capable of fabricating the desired component.
Absence Of Custom Shop	• Quick fix was to fabricate the propeller by hand. Long term solution is to cooperate with other institution or custom shop locally or internationally to develop or fabricate the custom propeller.
Alteration Of Material	• Quick fix is to add weights to control the buoyancy. • Long term solution is to use a specific material in fabrication; material that capable of maintaining the desired buoyancy where no changes are made to the initial specification and design of the ROV.
Fragile Frame	• Replace affected component with stronger material such as PVC, acrylic, carbon fiber and fiber glass coating.

4.9.2 Recommendation to Counter Prototype's Imperfection

The recommended solutions were essential in future project. The issue here was to detect the flaw of the current prototype before refined products are developed in the future. The refinement consist of countermeasure for heavy tethered, off-course locomotion, leakage, humidity effect on camera lens and the corrosion of conductor pin. The recommended solutions were tabularized in Table 4.13.

Table 4.13: Countermeasure for defection of fabricated ROV

Defects	Countermeasure
Heavy Tether	• Use underwater grade tether cable which is equipped with buoyancy jacket which is less than 120m. Anymore and voltage loss will compromise the performance.
Off-Course Locomotion	• Send the design of ROV to fully equipped shop in order to perfectly manufacture it. • Delicate parts are ensured to be precisely made using special tools and specific machine. Such mold machine for hydrodynamic cover and laser machine to fabricated complex propeller blade.
Leakage	• Each wire connection connected from inner to outer side of the casing will be fitted with cap.
Humidity Effect On Camera Lens	• Internal casing will undergo vacuum fabrication progress to perfectly empty the casing. For quick fix, silica powder will be coat the inner wall of the casing to absorb humid.

Table 4.13: Continued

Defects	**Countermeasure**
Corrosion of Conductor Pin	• The cylindrical cap to seal the motor will be made. These caps functioning as to create a waterproof casing for the motor without affecting its performance. Grease also applies to the component to prevent corrosion damage and maintain smooth mechanism.

4.10 CONCLUSION OF CHAPTER

By the end of this chapter, the fabricated ROV had performed it task successfully although there are several flaw faced. Even during the early stage of fabrication getting to the material was not as smooth as planned. The schedule was fortunately met although the project experienced complex difficulty. The predicament face was the result of keen observation and countermeasure to eliminate the problem were suggested. Result of the test shows that the ROV can submerge, resurface, left turn, right turn, forward and reverse. The hydrodynamic cover success to provide smooth propulsion of vehicle. The humidity affects the vision severely. Leakages in camera casing cause device failure. For the propeller itself, handmade blade lead to inconsistency of propeller blade pitch angle. Misalign thruster greatly affect the locomotion. With several imperfection occur, the refinement were than suggested to prevent deficiency. Overall conclusion will further explained in the next chapter. The future work then with brief explanation will be stated.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will conclude the development of the project. The outcome of the project will be related to the scope and objective of the project. From that, the project will be determined whether its objective was achieved or not. The future development were also stated and described. Whereas the practical refinements will be explain in further detail as it vital to be carried in next project. Apart from that, the finding also include for reviews. This chapter was outline to begin with conclusion, findings of prototype, refinements and future project.

5.2 THE CONCLUSION

5.2.1 The Findings

The development thru up to date literature reviews believe that the fabricated ROV was the smallest ROV in the world that's equipped with three thrusters and camera aided navigation. Smallest existing ROV in the market is the VideoRay Scout series with the dimension of 30.5x23x21cm. It has almost the same specification with the fabricated ROV.

The development also notices that, it is the only ROV with conceptual frontal thruster layout. Up to this date, there are none within the source of information gathered or knowledgeable source and even any literature and journal stated a developed front thruster layout ROV. The benefit of having this innovative conceptual design is the stability of maneuverability. The similarities can be made as comparing front wheel drive car and rear wheel drive car. Car with front wheel drive are more stable in making tight corner turn compare to rear wheel drive. Same as the ROV when it maneuvering inside tight spaces, front thruster layout can achieve that great stability without affecting its movement speed.

From the developed layout, great possibilities of improvements, development and even innovation can be made. Such responsibilities honored to the society.

5.2.2 The Overall Conclusion of Project

The conclusion of the project can be declared as successful. The development progress within it scope and obligate the schedule. The testing was done in a believed to be precisely control and thorough. No bias in term of interpreting the results and the comment were neutrally made.

The entire objective was concretely achieved. The project had developed a new type of micro ROV which implement the conceptual frontal thruster layout. Thru the development process, the ROV has been design and fabricated with innovative hydrodynamic cover and inventive frontal thruster layout. Real time test prove that this conceptual design work and can perform basic movement of forward, reverse, submerge, resurface, turn left and turn right. The movement also can be combined in order to initiate complex maneuverability.

The outcomes of this development are ready to further develop by the society. In simple phrase, the prototype fabricated was an innovation on design and an invention of layout. Which is non ever been emphasize on the development of remotely operated vehicle for underwater exploration.

5.3 FUTURE DEVELOPMENT

5.3.1 Executable Refinements

The polystyrene is not suitable to use as hydrodynamic cover alone. Hence a fortification or much durable and smoother material will be use. Acrylic is suggested to be used along with polystyrene as it is easier to shape and has very good surface finished.

Since the prototype are developed with separated cord. The refinement can be done is to integrate the joystick tethered with USB cord interface webcam. Therefore the control and vision input can be synchronized into one tether. Control can be made from laptop or personal computer.

5.3.2 Future Projects

The prototype now is still in the early phase before commercial benchmarks. Toward perfecting the prototype to be the best ROV, future project are enlisted and described in tabulated form.

Table 5.1: Future Projects

Project	Description
Development of robotic arm with human dynamics finger	• The robotic arm equipped with human thumb mechanism which allow it to perform various task. The robotic arm when attached to the ROV will significantly increase its function.

Table 5.1: Continued

Project	Description
Development of miniature multi degree of freedom thruster	• This featured increase the movement capability of ROV. The thruster will replace the fix mounted thruster.
Development of wireless fidelity for underwater communication	• Wireless communication will give almost infinite freedom of ROV when maneuver underwater. No more entangled communication line
Development of mini controllable propeller blade pitch	• This feature were only used in commercial line cruise ship and never been implemented in small scale water craft. The development will benefit in efficiency of propulsion
Development of artificial intelligent operating system for underwater operation	• The feature will increase the independency of ROV from human input data thus giving it virtually infinite duration of operation
Transformation of current prototype from shallow water exploration to deepwater exploration	• This will make the prototype as favorite tools for deep sea exploration

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APPENDIX A

GANTT CHART FOR FYP 1

No.	Task		Date		Duration	Q1 - January				Q2 - February			Q3 - March				Q4- April
			Start	End		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
1	*Literature*	*Searching article for basic understanding*	1.1.09	4.1.09	*4 days*	■											
2		*Comfirming psm project with supervisor and brief meeting*	5.1.09	18.1.09	*14 days*		■	■									
3		*Gathering material for deep understanding*	11.1.09	8.2.09	*21 days*			■	■	■							
4	*Design and analysis*	*Design sketch for ROV frame*	26.1.09	8.2.09	*14 days*				■	■							
5		*Compare design with other existing ROV*	8.2.09	15.2.09	*7 days*						■						
6		*Properties analysis and Finalize design*	8.2.09	22.2.09	*14 days*						■	■					
7		*Solidwork draw and Analyze design*	23.2.09	28.2.09	*7 days*							■					
8		*Determine control system and type of propulsion*	1.3.09	14.3.09	*14 days*								■	■			
10	*Finalization*	*material selection*	7.3.09	21.3.09	*14 days*									■	■		
11		*Finalyzed ROV overall design*	15.3.09	2.4.09	*7 days*										■		
12	*Preparation for presentation*	*Preparation for presentation*	3.4.09	5.4.09	*7 days*											■	
13	*Weekly Logbook Update*	*Weekly Logbook Update*	5.1.09	5.4.09	*77 days*		■	■	■	■	■	■	■	■	■	■	■
14	*Presentation in Seminar 1*	*Presentation in Seminar 1*	6.4.09	10.4.09	*5 days*												■

Figure 6.1: FYP 1 project planning

APPENDIX B

GANTT CHART FOR FYP 2

No.	Task		Q1 - July				Q2 - August			Q3 - September				Q4 - October
			W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
1	*Fabrication*	*Obtained material and tools for fabrication*												
2		*Prototype Fabrication*												
3	*Test and Refinement*	*Real time testing*												
4		*Result documentation*												
5		*Define area of improvement*												
6		*Rule in future work and recommendations*												
7		*Overall conclusion of the project*												
8		*Final Year Project presentation*												
9	*Logbook update*	*Logbook update*												
10	*Thesis writing and submission*	*Thesis writing and submission*												

Figure 6.2: Project planning for FYP 2

APPENDIX C

ROV CLASSIFICATION

Table 6.1: Exploration ROV classification.

Class		Specification	Description	Purpose	Chassis
Eyeball	Micro	±3 kg	Very small in size and weight.	Alternative to a driver Exploring tight and small place (i.e. sewer, pipeline or small cavity)	plastic PVC, light weight metal such as aluminum
Eyeball	Mini	±15 kg	Can be transport, deploy and perform complete operation by one person without any outside help.	Alternative to a driver. Exploring dense coral distribution, underwater caves and other place where human may not fit.	Stainless steel, aluminum
General		<5HP (propulsion)	Three finger manipulators grippers installed. May equip with sonar unit. Working depth is less than 1000 but able to resist a 7000m depth.	Light survey applications. Deep sea biological research.	Conventional Stainless steel, aluminum

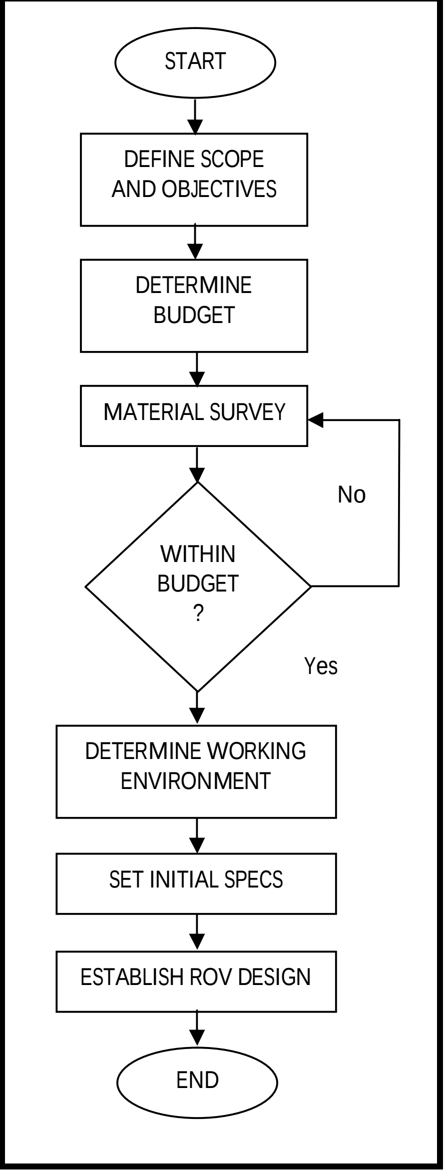
APPENDIX D

OUTLINE OF PREDEVELOPMENT PROCESS

Table 6.4: Outline of predevelopment process for the project done on March '09

No	Procedure		Description
1	Define the project scope and objectives	VALIDATING CONSTRAIN FACOTR: THE MATERIAL AND COMPONENT WILL BE TAILORED DUE TO COST	Status : Confirmed • design and fabricate simple ROV • develop a micro class ROV
2	Determine the budget		Status : Initial Estimation • RM 200 / student **with the current economy, the budget should be less than this.* **budget is a major constrain factor*
3	Material survey		Status: Done • with tight budget, the option left is to use 9V DC motor (avg. 2.7W), scheduled 40 PVC pipe, simple DPDT switch
4	Determine the project duration		Status : Estimation • finalized design; Jan – Apr '09 • simulation, fabrication and test ; Aug –Sep '09 • Optimization and writing; Oct-Nov '09
5	Determine the working environment parameter	SPECIFICATION WILL BE TAILORED TO WORKING ENVIRONMENT	Status : Done • Buoyancy force in fresh water and sea water calculated.
6	Determine the ROV initial specifications		Status: Done • Basic engineering parameters such as dive, surge and reverse speed.
7	Outcome		Status: Done • All the parameters and specification were take account into designing the ROV

Flow Chart



APPENDIX E

COMPARISON OF DEVELOPED ROV WITH EXISTING DESIGN

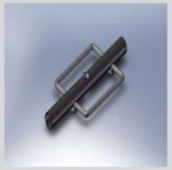
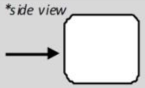
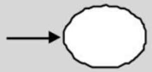
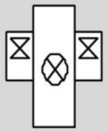
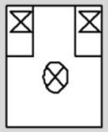
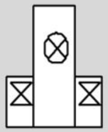
Table 6.3: Comparison of prototype ROV with other exiting design in the market

Design	*Project ROV*	*Observer 3.1 Subsea Tech*	*Scout Video-Ray ROV*	*LVB150BE Seascape Seabotix*
Figure				
Dimension (mm) Length x width x height	169 x 90 x 100	450 x 270 x 210	305 x 230 x 210	530 x 245 x 254
Weight in air	<2.0kg	6kg	3.6 kg	12 kg
Propulsion	Three, 3 volt brushed DC thruster - 1 vertical and 2 horizontal	Three, brushed DC thruster – 1 vertical and 2 horizontal	Three, Brushed DC thruster- 1 vertical and 2 horizontal	Four, Brushless DC thrusters - 2 horizontal, 1 vertical and 1 lateral.
Material	PVC pipe act as internal component protection and material for base frame	Polyethylene case and modern grade aluminum.	Modern grade aluminum and plastics material	Polyethylene case, modern grade aluminum and stainless steel.
Power supply	3volt AA batteries, USB power supply capable	110-200VAC	100-240 VAC	100-240VAC
Cost	< RM 150	$76998 USD Approx: RM 269493.00	$5995.00 USD Approx : RM 20982.50	$16182.87 USD Approx: RM 56640.04
Speed	0.095 knots 0.05 m/s (submerged) 0.1 m/s (forward)		1.9knots 0.9774 m/s	3knots 1.54m/s
Depth	2m	150m	76m	150m
For home fabrication (similar specs to related ROV)	Fabricate able. Due to abundant of supply and tools	The design is easy to fabricate with change of material.	High cost, complicated without appropriate tools and material.	Need a special machine or fabrication tools in order to be handmade.

APPENDIX F

LAYOUT COMPARISON

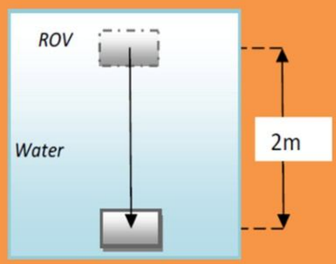
Table 6.4: Layout comparison between developed ROV and other handmade product by enthusiast

Design	Tubular / Long	Rectangular / Box shape	Project ROV
Figure	 *solely frame	 *solely frame	 *solely frame
Dimensions (mm) Length x width x height	500 x 200 x 50	300 x 250 x 200	100 x 90 x 90
Simplified model *when cover is attached	*side view 	*side view 	*side view 
Drag Coefficient , C_D ~as been refer in Table 11-1, Table 11-2, Y.A.Cengel, Fluid Dynamics pp 573-574	1.0	1.2	0.5
Thruster Layout  = Horizontal thruster  = vertical thruster	 *geometry : more stable *placement : less stable	 *geometry : more stable *placement most stable	 *geometry : more stable *placement : most stable
Description	Mimic conventional AUV and Navy's ROV (the Snoopy)	Common design for conventional ROV.	An innovative approach in design, and thruster configuration
Variables – Constants	Material (PVC), number of thruster (3), depth rating (2m), speed (0.05 m/s), environment (fresh and sea water)		
Variables – Manipulative	Dimension, design, thruster layout		
Variables – Dependent	Drag coefficient, drag force, stability, maneuverability, motor power		

APPENDIX G1

ANALYSIS OF PROPERTIES

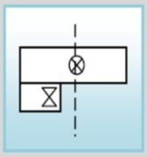
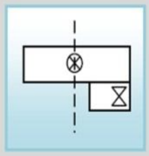
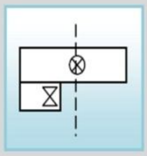
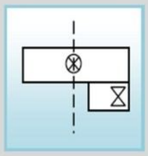
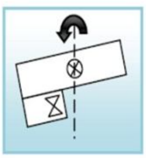
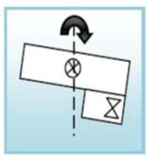
Table 6.5: Analysis of properties

Diagram		
**Assume the flow region is Laminar, Re_L = 1e5 , calm water condition *Properties at 80°F (26.67°C) since this is average temperature of Malaysian waters *Motor power, P_m = 0.9 W*		
Fluid Properties	***Fresh Water***	***Sea water***
Reynolds number , ***$Re = \rho vL / \mu$*** *Velocity, v = 0.05 m/s* *Dynamic viscosity, μ* *Fluid density , ρ* *ROV Length, L*	ρ =994.82 kg/m^3 μ = 8.58e-4 kgm^{-1}s^{-1} Re = 994.82 x 0.05 x D/ 8.58e-4 = 57973.19D Re = Re_L L = 1e5 / 57973.19 = 1.72 m	ρ =1022kg/m^3 μ = 8.15e-4 kgm^{-1}s^{-1} Re = 1022 x 0.05 x D / 8.15e-4 = 62699.39D Re = Re_L L = 1e5 / 62699.39 = 1.60 m
Buoyancy Force, F_B ***$F_B = V\rho g$*** *Where g is gravity acceleration g= 9.81m/s* *Volume of submerge body, V*	F_B = V x 994.82 x9.81 = 9759.18V N	F_B = V x 1022 x 9.81 = 10025.82V N
Buoyancy Power, P_B ***$P_B = F_B v_{submerged}$*** *Where $v_{submerged}$ is submerge velocity = 0.05m/s*	P_B = 9759.18V x 0.05 =487.96V W P_m =P_B V = 0.9 / 487.96 = 1.84e-3 m^3	P_B = 10025.82V x 0.05 =501.29V W P_m =P_B V = 0.9 / 501.29 = 1.79e-3 m^3
Speed by single motor, ***$v = P_m / \rho gAH$*** *Cross sectional area for propeller casing,* *$A = \pi r^2 = \pi 0.0125^2 = 4.91e\text{-}4\ m^2$* *Depth, H = 2m*	v= 0.9/(994.82 x 9.18 x 4.91e-4 x 2) =0.1m/s	V= 0.9/(1022x 9.18 x 4.91e- 4 x 2) =0.09m/s
Pressure ***$P = \rho gh$*** *Gravity acceleration, g= 9.81 m/s* *Depth, h =2m*	P = 994.82 x 9.81 x 2 = 19.52 KPa	P =1022 x 9.81 x 2 = 20.05 KPa
Conclusion	From the analysis we can determine the limiting factor for the design hence yield the ROV specification; ***ROV length < 1.60 m, volume < 1.79e-3 m3 , submerged velocity is 0.05 m/s , motor power is 0.9 W minimum , minimum cross sectional area for propeller casing is 4.91e-4 m2 , deep rating is 2m maximum, and must survive 20.05 kPa of pressure.***	

APPENDIX G2

THRUSTER LAYOUT COMPARISON

Table 6.6: Thruster layout comparison between developed ROV and conventional ROV

Parameters		
Constant: type of motor, power of motor, type of propeller, number of motor (3 motor; 1 vertical, 2 horizontal), material of ROV, weight of ROV and dimension of length, width and height. *Manipulative: Thruster layout,* *Responsive : Resulting thrust in submerge and resurface motion, stability in straight line* **this is a theoretical comparison set to give clear view what is the different between front mount and rear mount thrusters. Further analysis will be carried out in real time testing*		
Properties	Front mount	Rear mount
Simplified model *= horizontal thruster* *= vertical thruster* *= body*	*front* *back*  *side view	*front* *back*  *side view
Description	This project is developing this kind of thruster layout. From thorough reading and research, none ever develop this configuration for tri-thrusters ROV. **claim: this type of ROV will be the first in the world and set a new class of ROV in term of thruster layout.*	This configuration is typical throughout all ROV design where the horizontal thruster (usually called longitudinal thruster) are mount at the rear end.
Weight distribution *Weight of ;* *Body = W_B* *Thruster = W_T*	*front* *back*  Weight, W: $= 0.5\,W_T + 2\,W_T + 0.5W_B$ $= 2.5\,W_T + 0.5W_B$ $= 0.5(5\,W_T + W_B)$ Weight, W: $= 0.5\,W_T + 0.5\,W_B$ $= 0.5(W_T + W_B)$ *side view	*front* *back*  Weight, W: $= 0.5\,W_T + 0.5\,W_B$ $= 0.5(W_T + W_B)$ Weight, W: $= 0.5\,W_T + 2\,W_T + 0.5W_B$ $= 2.5\,W_T + 0.5W_B$ $= 0.5(5\,W_T + W_B)$ *side view
Resting *Drag Force of;* *Front = $F_{D, front}$* *Rear = $F_{D, rear}$* *Condition: $F_{D, front} = F_{D, rear}$*	*front* *back* W > FD  W < FD **due to heavier weight at the front, the ROV will slightly tilt counter clockwise*	*front* *back* W < FD  W > FD **due to heavier weight at the back, the ROV will slightly tilt clockwise*

APPENDIX G3

THRUSTER LAYOUT COMPARISON

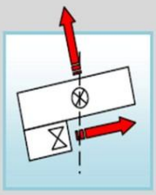
Table 6.6: Continued

<table>
<tr><td colspan="3">Parameters</td></tr>
<tr><td colspan="3">Constant: type of motor, power of motor, type of propeller, number of motor (3 motor; 1 vertical, 2 horizontal), material of ROV, weight of ROV and dimension of length, width and height.
Manipulative: Thruster layout,
Responsive : Resulting thrust in submerge and resurface motion, stability in straight line

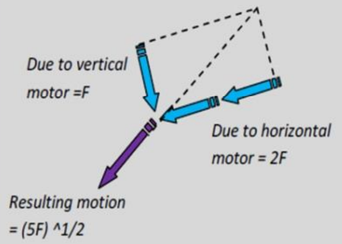
*this is a theoretical comparison set to give clear view what is the different between front mount and rear mount thrusters. Further analysis will be carried out in real time testing</td></tr>
<tr><td>Motion
Submerging

= thrust
= motion
= resultant motion

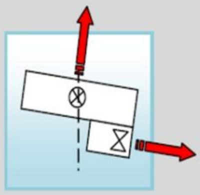
F is reactions force which its magnitude is equal to the force produce by thrust but act in opposite direction.</td>
<td>Front mount
front back



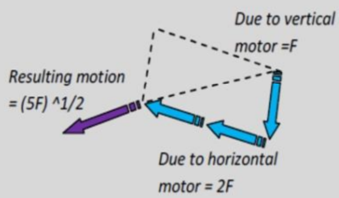
Motion:
Motion is always in opposite direction of thrust.



</td>
<td>Rear mount
front back



Motion:
Motion is always in opposite direction of thrust.

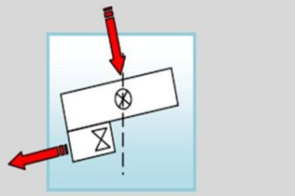
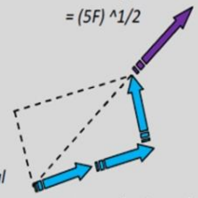
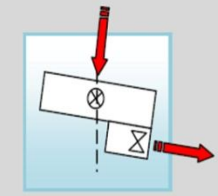
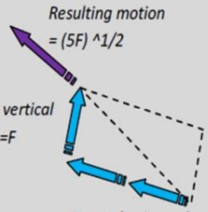


</td></tr>
<tr><td>Finding</td>
<td>All three thrusters are operational in submerging the ROV. Compare to the steepness of the resulting motion, this ROV can descend faster and in shorter distance. Thus getting to the bottom destination is easier and faster. Which a very good design aspect in considering an exploration ROV.</td>
<td>All three thrusters are operational in submerging the ROV but to a curtain point where there is enough degree of angles to allow horizontal thrust gain enough force to eliminate the downward motion. Therefore to maintain a smooth descend, higher vertical thruster power to horizontal thrusters' power ratio needed. With this current configuration, it's less suitable for exploration and scout task due to extra duration and distance taken for it to reach destination.</td></tr>
<tr><td></td><td colspan="2">*why distance and duration?
It is important to get the exploration deployed fast, because the data, sample and reading varies time-dependently. Due to unpredictable behavior of underwater environment, we might miss an important event because of long duration taken to reach the destination. Longer duration is time consuming which is directly related to operation cost.</td></tr>
</table>

APPENDIX G4

THRUSTER LAYOUT COMPARISON

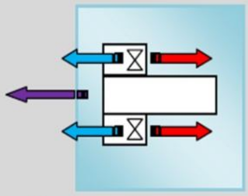
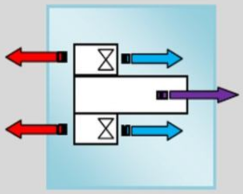
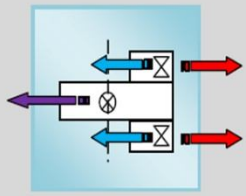
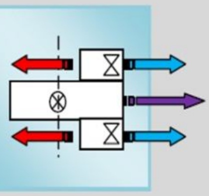
Table 6.6: Continued

Parameters		
Constant: type of motor, power of motor, type of propeller, number of motor (3 motor; 1 vertical, 2 horizontal), material of ROV, weight of ROV and dimension of length, width and height. *Manipulative: Thruster layout,* *Responsive : Resulting thrust in submerge and resurface motion, stability in straight line* **this is a theoretical comparison set to give clear view what is the different between front mount and rear mount thrusters. Further analysis will be carried out in real time testing*		
Motion **Resurface**  *F is reactions force which its magnitude is equal to the force produce by thrust but act in opposite direction.*	**Front mount** *front* *back*  **Motion:** Motion is always in opposite direction of thrust. 	**Rear mount** *front* *back*  **Motion:** Motion is always in opposite direction of thrust. 
Finding	All three thrusters are operational to resurface the ROV. While setting the horizontal thrust to push backward, it performs faster and has shorter distance climb. But, in doing this, it will sacrifice the navigation system. Analog comparison is like driving a car uphill on a twisty road, and doing it in reverse without looking at the rear view mirror. This is bad for ROV, especially the work class ROV that need to carry and retrieve loads and perform a delicate task in a challenging course. This leave it with an option to climb slowly to the surface with both thrusters set to forward.	All three thrusters functioning well in resurface motion. Faster climb time and short climb distance is good properties for work class ROV. This configuration has advantages in wreck retrieval, underwater work and any task that need it to deliver material from seabed to surface in naked time. But in exploration view, to surface faster is not a major interest. The interest is to explore, which literally mean to stay longer in an interested area.

APPENDIX G5

THRUSTER LAYOUT COMPARISON

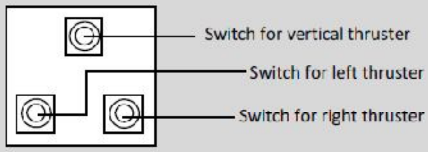
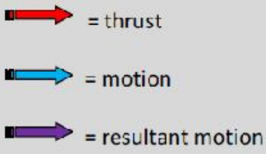
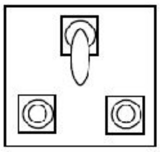
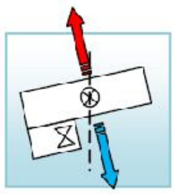
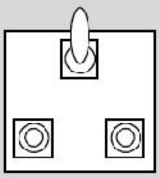
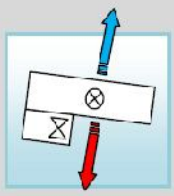
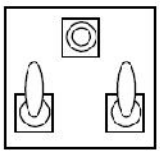
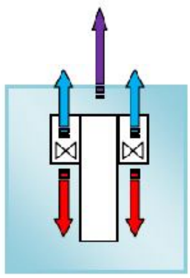
Table 6.6: Continued

Parameters		
Constant: type of motor, power of motor, type of propeller, number of motor (3 motor; 1 vertical, 2 horizontal), material of ROV, weight of ROV and dimension of length, width and height. *Manipulative: Thruster layout,* *Responsive : Resulting thrust in submerge and resurface motion, stability in straight line* **this is a theoretical comparison set to give clear view what is the different between front mount and rear mount thrusters. Further analysis will be carried out in real time testing*		
Motion	**Front mount**	**Rear mount**
Straight line = thrust = motion = resultant motion *Quality of forward motion is needed here as it help a lot in navigation, especially when the task is exploration.*	*front* *back*  **Forward:** Heavier weights at the front produce higher inertia. Higher inertia makes the ROV more resilience to sway. Which helping in maintain the straight-line motion.  **Reverse:** Lack the inertia to maintain a straight line motion.	*front* *back*  **Forward:** Lighter weights at front reduce inertia. As the ROV swim forward, it will easily sway side to side. To maintain the ROV in a straight line is quiet challenging.  **Reverse:** Got the inertia to maintain a straight line motion.
Special Case	*front* *back*  ***Condition:*** 1. $F_{D, rear} >> W_{rear}$ 2. **Submerged too fast** *This condition is possible, where the ROV might tilt approx. 180 degrees counter clockwise. In this position, the head dive submerge is possible due to exchange position of horizontal thruster to vertical thruster.*	*front* *back*  ***Condition:*** 1. $F_{D, front} >> W_{front}$ 2. **Submerged too fast** *The ROV might tilt approx. 180 degrees clockwise. In this position, the exchange position of horizontal thruster to vertical thruster will add more thrust to resurface the ROV.*

APPENDIX H1

CONTROL SYSTEM

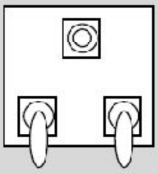
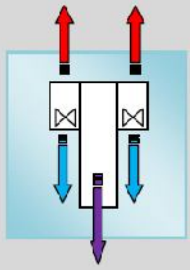
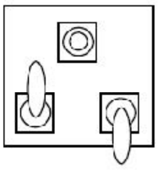
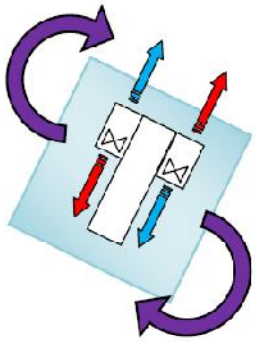
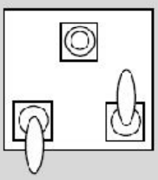
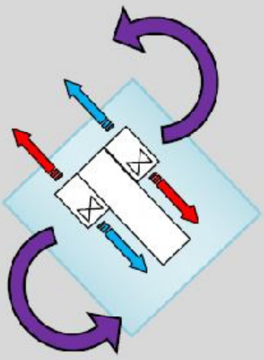
Table 6.7: Relation between switch toggle directions on motion of vehicle

Motion	Controller		ROV (simplified model)
Neutral/ static	 *switch in neutral position		
Submerged	 *top switch flip down	Activate vertical thruster to produce upward thrust; submerging the ROV	
Resurface	 *top switch flip up	Activate vertical thruster to produce downward thrust; resurface the ROV	
Forward	 *both left and right switch flip up	Activate horizontal thruster to produce backward thrust; pushing the ROV forward	

APPENDIX H2

CONTROL SYSTEM

Table 6.7: Continued

Motion	Controller	ROV (simplified model)
Reverse	 Activate horizontal thruster to produce forward thrust; pushing the ROV backward *both left and right switch flip down	
Right	 Activate left thruster to produce forward thrust, while the right thruster produce backward thrust; turn the ROV to the right * left switch flip up, and right switch flip down	
Left	 Activate left thruster to produce backward thrust, while the right thruster produce forward thrust; turn the ROV to the left * left switch flip down, and right switch flip up	

APPENDIX I1

3D MODEL

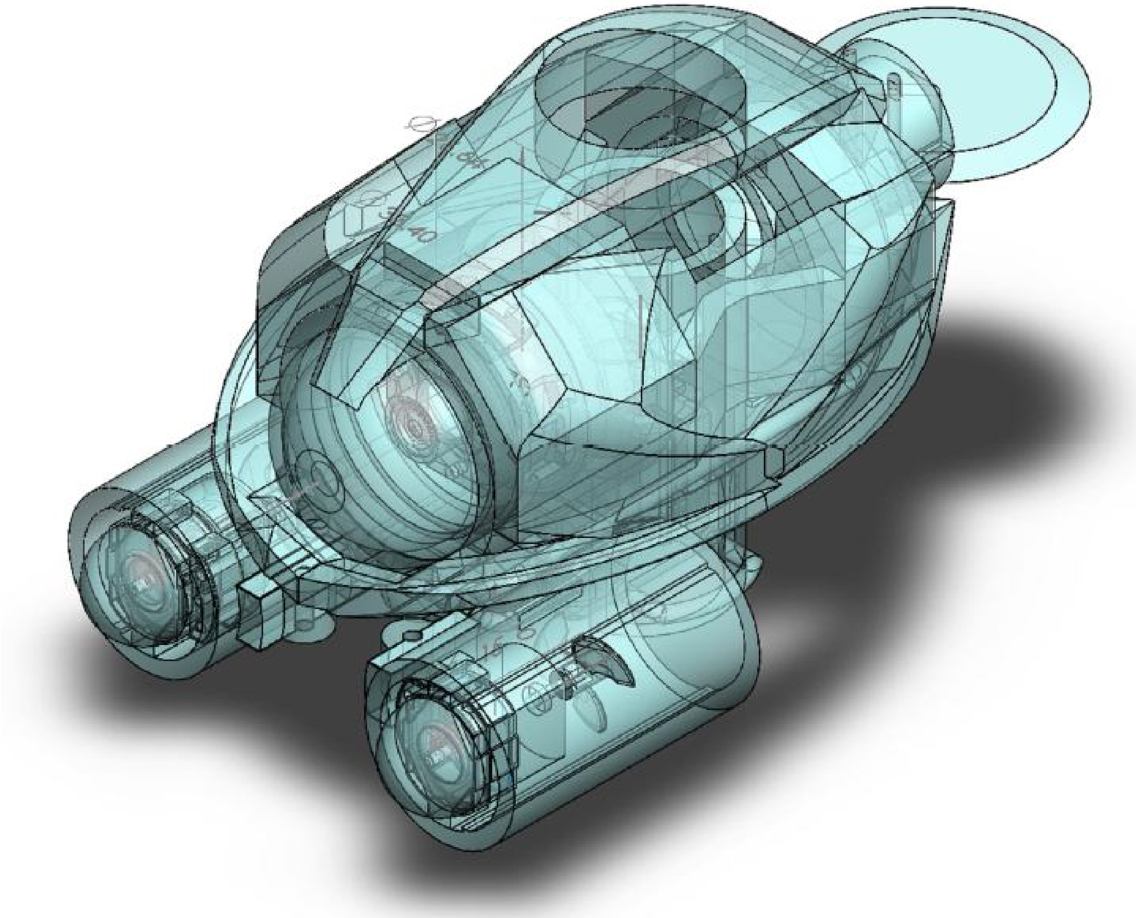
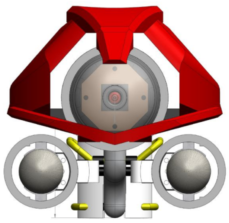


Figure 6.3: Transparent view of the developed ROV

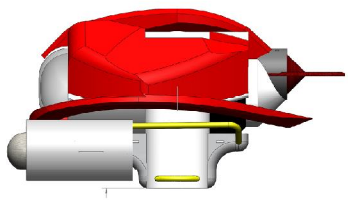
APPENDIX I2

3D MODEL

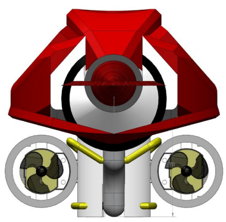


Front view

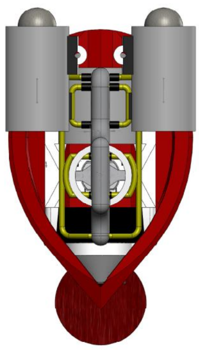
Top view



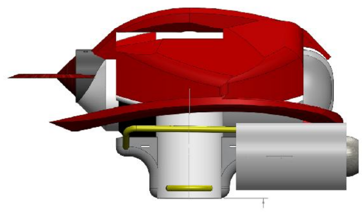
Right view



Rear view



Bottom view



Left view

Figure 6.4: 3D Model of developed ROV

APPENDIX I3

ROV ENGINEERING DRAWING

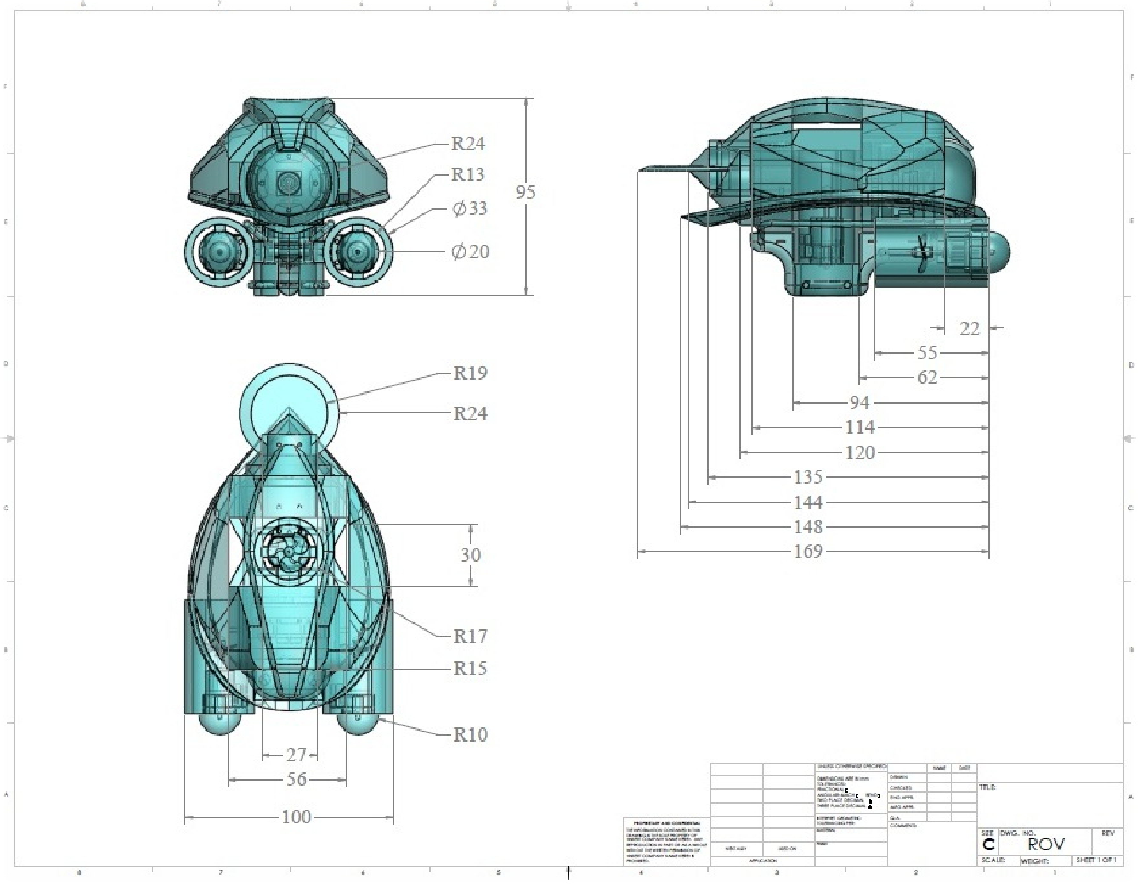


Figure 6.5: Drawing of ROV

APPENDIX I4

ROV ENGINEERING DRAWING

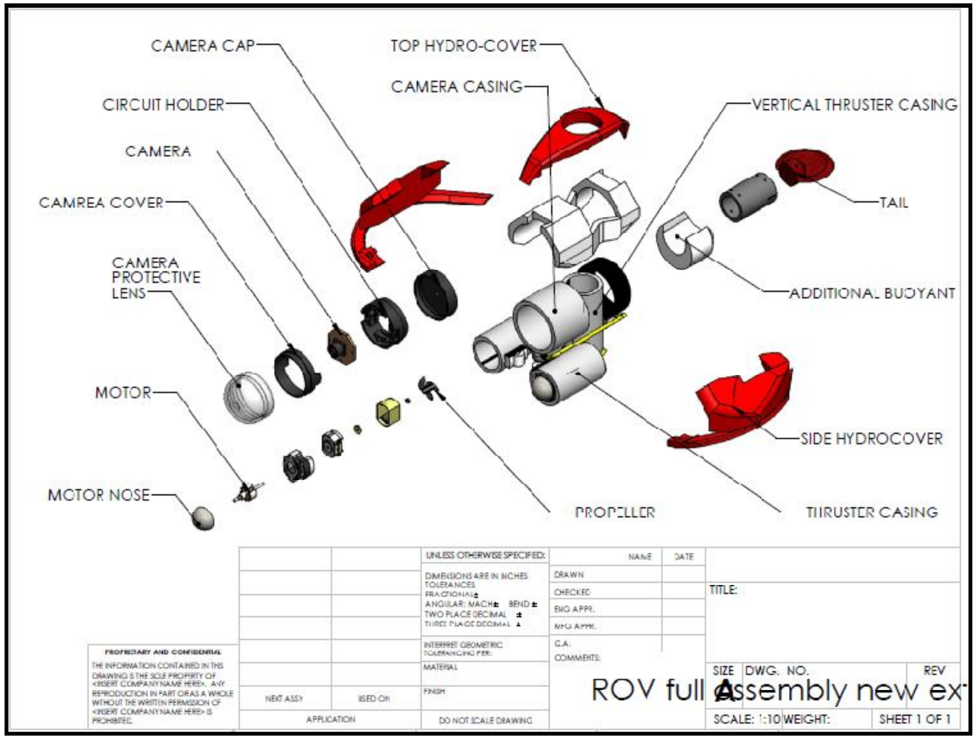
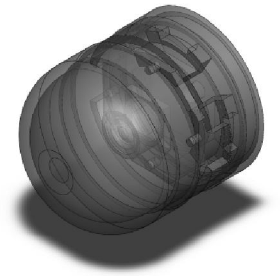
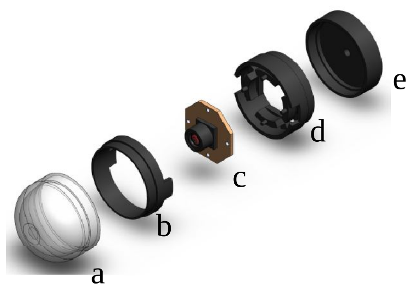
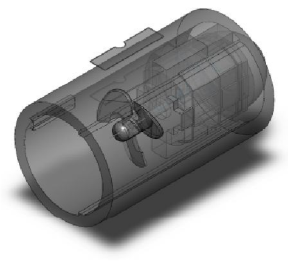
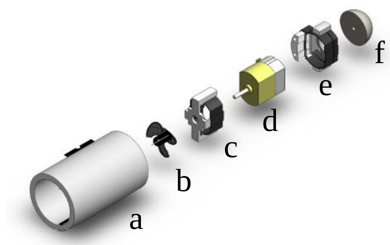


Figure 6.6: Exploded view of the ROV

APPENDIX I5

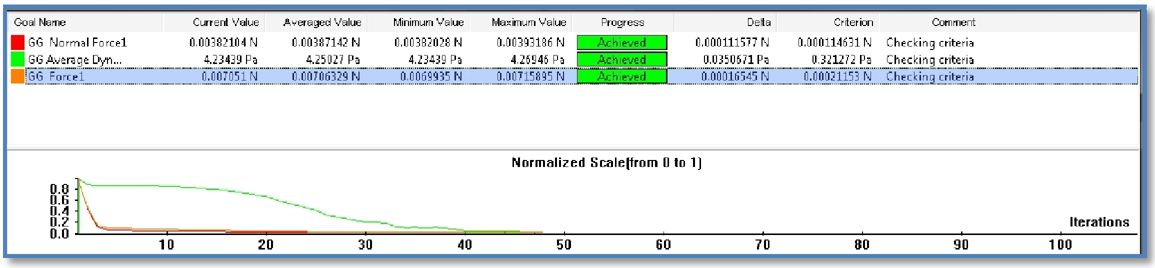
INTERNAL COMPONENT

Table 6.8: Camera and Thruster component of ROV

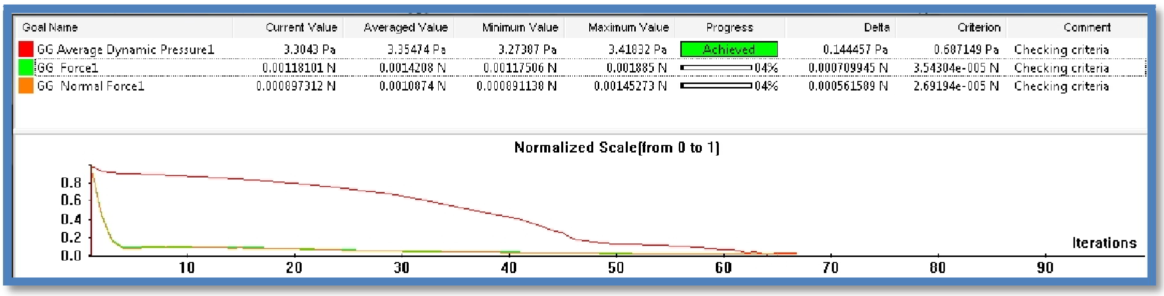
Camera	
Assembled view	
Extruded view a. Lens b. Lens holder c. Camera circuit d. Circuit holder e. Camera end-cap	
Thruster	
Assembled view	
Extruded view a. Thruster case b. Propeller c. Motor seal: rear d. DC motor e. Motor seal: front f. Thruster nose	

APPENDIX J

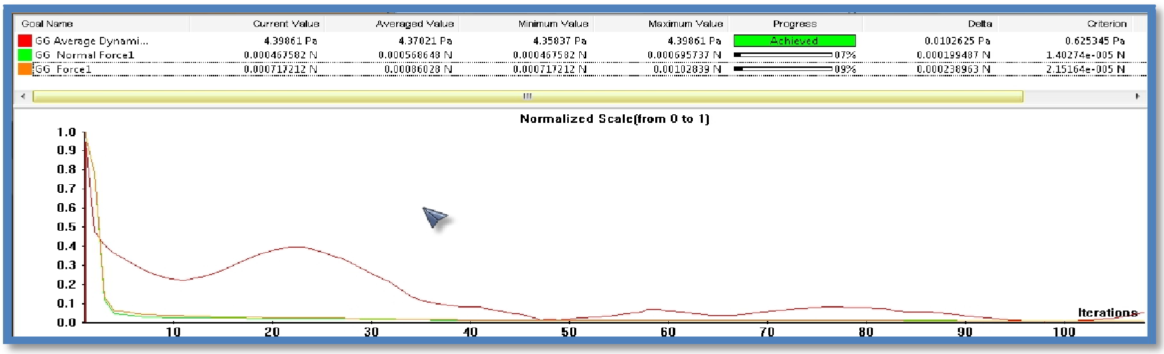
RESULT OF COSMOS ANALYSIS



a)



b)



c)

Figure 6.7: COSMOS result a) hydrodynamic cover, b) top cover and finally c) the hull.

APPENDIX K

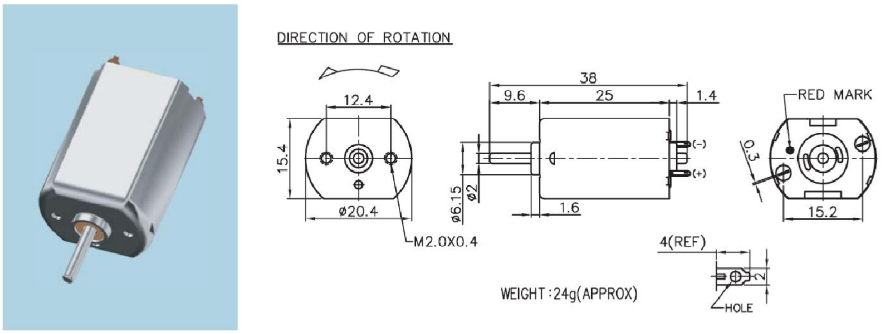
MOTOR SPECIFICATION

PC-130

NICHIBO DC MOTOR

POINT：Rearview Mirror、Vacuum Cleaner
Head Light Beam Level Adjuster、Printer

用途：後視鏡鏡面調整、汽車光軸調整、印表機、吸塵器



MODEL	VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY						STALL		
	OPERATING RANGE	NOMNAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	EFF	CURRENT	TORQUE	
			rpm	A	rpm	A	g-cm	mN-m	W	%	A	g-cm	mN-m
PC-130F-18120T-N	3.0 - 4.5	3.0V CONSTANT	9500	0.16	6200	0.505	8.10	0.79	0.52	35.63	1.40	31.00	3.04
PC-130F-12240T-N	3.0 - 9.0	6.0V CONSTANT	9500	0.10	6800	0.254	6.95	0.68	0.49	33.39	0.66	27.70	2.72
PC-130SF-09400T-N	6.0 -24.0	12.0V CONSTANT	7000	0.06	5100	0.150	14.32	1.40	0.75	42.50	0.45	57.70	5.66
PC-130SF-09480T-N	6.0 -24.0	12.0V CONSTANT	6000	0.05	4800	0.108	12.33	1.21	0.61	49.60	0.37	55.00	5.39

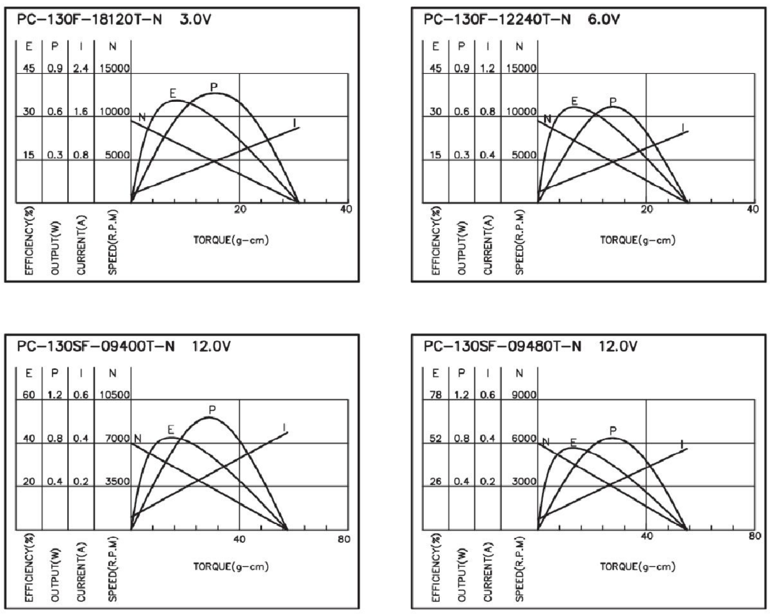


Figure 6.8: Data sheet for motor inside thruster component.

APPENDIX L

FINISHED PROTOTYPE

Figure 6.9: Finished prototype with attached weight

APPENDIX M

BILL OF MATERIALS

Table 6.9: List of components and tools used for this project

Component	Material	Size	Quantity	Price
Hydro-cover	Polystyrene	1.0x0.6x0.006m	1	RM 12.80
Camera	VGA Webcam	0.04x0.025x0.02m	1	RM 25.00
Thruster case	1” PVC pipe	0.05m	3	RM 0.50
DC Motor	9V PC-130	0.015x0.025x0.015m	3	RM 36.50
Frame	1 ½ “ PVC PIPE	0.13m	1	RM 1.00
DPDT switch	-	-	3	RM 4.50
Tether	Hard wire	3m	1	RM 6.99
Wire Frame	Hanger wire	-	1	RM 6.50
Battery	9V	6LR61	1	RM 9.40
Battery holder	-	-	1	RM 2.00
For attachment				
Adhesive			**Quantity**	**Price**
Epoxy fixsuper steel			1	RM 10.49
Glue stick			6	RM 5.49
Super glue			2	RM 5.80
Cloth tape			1	RM 2.79
Fabrication Equipment				
Tools			**Quantity**	**Price**
Hot glue gun			1	RM19.90
Pipe handsaw			1	RM 1.99
Mini table vice			1	RM 7.99
Hand drill			1	RM 12.00
Handsaw			1	RM 6.99
Project Board			1	RM 19.90
Finishing				
Material			**Quantity**	**Price**
Paint			2	RM 5.00
Paint Brush			1	RM 1.00
Faulty Device Replacement				
Device		**Type**	**Quantity**	**Price**
Camera		USB 2.0 Sensonic Webcam	1	RM 35.00
			Total	**RM 239.53**