DESIGNING AN ROV FOR UNDERWATER INSPECTION

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Electrical & Electronic Engineering
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in partial fulfillment of the requirement for the
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Approved by,

____
(AP Dr. Mohd Noh bin Karsiti)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
SEPTEMBER 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements,
and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Ahmad Syahmi Bin Salim

ABSTRACT

Design and construct a remotely operated vehicle (ROV) which fitted with three thrusters, a video transmission and a control system for the manoeuvrability is the main target of this project. This ROV is made up from aluminium frame and water proof enclosure to protect the controller system. Besides, this project also develop a closed loop system for auto depth function. This auto depth function is very important to make sure that the ROV is always at the desired depth. In addition, this ROV is also equipped with on board power to avoid the voltage drop along tether. The scope of studies for this project divided into two which are electrical and mechanical part. For the electrical part, the best controller circuit design need to be designed to ensure it gives the best manoeuvrability. Meanwhile, for mechanical part, the frame of the ROV need to be designed based of few considerations.

ACKNOWLEDGEMENTS

There are so many challenges and valuable experience throughout the completion of my final year project. First of all, I would like to praise Allah for his strength and blessing throughout the completion of my project. Many people have implicitly help me throughout my final year project. I would like to acknowledge my supervisor, AP Dr Mohd Noh Karsiti for all his guidance and supervision throughout the completion of my final year project. I would like to thank to technicians from the Electrical and Electronics Department who give valuable opinion and suggestion towards the completion of my final year project. I also would express my appreciation to my colleagues for the ideas and support to accomplish my final year project. My appreciation would be incomplete without giving tribute to my family for giving full support to complete my final year project.

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INTRODUCTION

1.1 Project Background

An unoccupied underwater vehicle being controlled from the surface by a trained operator is called remotely operated vehicle (ROV). Joystick will be used by the trained operator to control the position of the ROV with the help of video that display the surrounding of the ROV. A tether will be used to send the control signal from the surface to the ROV.

The first ROV was developed by Dimitri Rebikoff in 1953. The main objective of the development is for archaeological research. Later, the US Navy takes further step by producing an operational system in order to recover the lost torpedoes on the seafloor. The development was awarded to VARE industries where they develop XN-3. This industry grew rapidly and it is estimated that there are more than 3000 vehicles have been developed [1].

The demand of ROV in various industry also grew rapidly. For example, offshore oil industry required an advanced underwater vehicle. The development of underwater structures and complexes are exceeding 3000 meters which is far beyond the diver's depth. Therefore, offshore industry has teamed with ROV developers to ensure integrated systems are being designed. For instance, during the Gulf of Mexico oil spill, ROVs have been used to stop the gushing oil well. ROVs are the unsung heroes of Gulf of Mexico oil spill.

Thus, develop and produce an ROV prototype for underwater inspection is the main target for this project. Video camera, lights and other basic equipment will be equipped together with this prototype. Besides, auto depth function and on board power also will be installed and considered as the improvement of the ROV.

1.2 Problem Statement

ROVs have become a crucial tool in the oil and gas industry. Various types of ROV has been developed in order to supply the demand of the offshore industry. They inspect the pipes, being an observer during oil exploration and placing underwater manifolds are among their tasks. However, most inspection ROVs do not equipped with auto depth function which will maintain the ROV at the desired depth. In addition, most ROVs are being powered from the surface.

1.3 Objectives

The main objectives for this project are as follow :

1. Design and construct a working ROV prototype.
2. Install auto depth function.
3. Install on board power.

1.4 Scope of studies

This project consists of two scope of studies which are electrical part and mechanical part. For the electrical part, the suitable electronic circuitry need to be designed to control the manoeuvrability of the ROV. A basic programming knowledge is required to write programming for the microcontroller to control the thrusters. Besides, the suitable motor driver circuit also need to be designed to drive the motor. Mechanical part is the most important part where the ROV should have almost zero buoyancy so that the ROV can achieve maximum stability. A waterproof enclosure also need to be designed. The main function of this waterproof enclosure is to make sure that the electronic circuitry is always dry during the operation. These two areas of knowledge are very important to achieve the objectives of this project. Study of previous projects would become really helpful in order to gain more knowledge and better understanding.

1.5 Relevancy of project

The notion of the project is to design and develop an ROV prototype. The aim to improve the ROV system which can give the maximum performance during the operation. In order to make further improvement to the ROV, a good understanding in basic physics especially in Archimedes' principle is needed to ensure that the ROV achieves the hydrostatic equilibrium. Besides, advanced knowledge in electrical is required for ROV manoeuvres and advanced knowledge in mechanical to design the ROV. Therefore, it is relevant to start this project.

1.6 Project feasibility

ROV consists of electrical and mechanical part. The electrical will be developed during the first semester. The best controller design will be produced during the first semester. At the end of the first semester, the best controller design for the ROV should be produced. For the second semester of the final year, the mechanical part will be developed. Besides, further improvements also will be made during the second semester of the final year.

LITERATURE REVIEW

2.1 ROV Classifications

There are few ROV categories and they are:

- Micro Observational Class
- Mini Observational Class
- Light & Medium Work Class
- Heavy Work Class
- Seabed Working Class

2.2 Micro Observational Class

This category of ROV typically light weight, optimised for portability and designed only for observation in water for less than 100m. Typical uses include ship, pier and pipe inspections. VideoRay LLC is an example of this category :

Figure 1 : VideoRay LLC

2.3 Mini Observational Class

The role of this category is quite similar to micro observational class vehicles but the only difference is it is designed with heavier duty construction techniques that make them more suited to the deeper depth which approximately about 1000 m.

2.4 Light & Medium Work Class

This category of ROV is quite big compared to two categories above. These light and medium work class ROV's are typically equipped with a small manipulator to give the ability to hold or handle an object. Besides, this category of ROV has less power thrusters compared to heavy work and seabed working class which gives less power payload lift capacity. Saab Seaeye Lynx is an example of light and medium work class ROV :

Figure 2 : Saab Seaeye Lynx

2.5 Heavy Work Class

Designed to perform the most challenging underwater tasks and extreme depths which up to 6000 m. At least two manipulators, specialised tools, multiple cameras and lights and self- stabilisation system being fitted with this ROV. Besides, this type of ROV fitted with the most powerful thrusters to give the maximum payload capacity.

Figure 3: Saab Seaeye Jaguar

2.6 Seabed Working Class

Lay undersea pipes and cables are among tasks for this category of ROV. Most of them are equipped with special tools that adapted them to specified underwater project.

Figure 4: Seabed working class ROV

2.7 ROV Buoyancy and Stability

Basically, any vehicle that moves has six degrees of freedom and three rotations as shown in Figure 5 [3]. Pitch and roll are normally not equipped together with ROVs. As shown in Figure 6, the ROV will the maximum stability when it has a high centre of buoyancy and a low centre of gravity [4]. Almost all small ROVs are equipped with a fixed ballast with variable positioning so that the ROV can nose up or nose down.

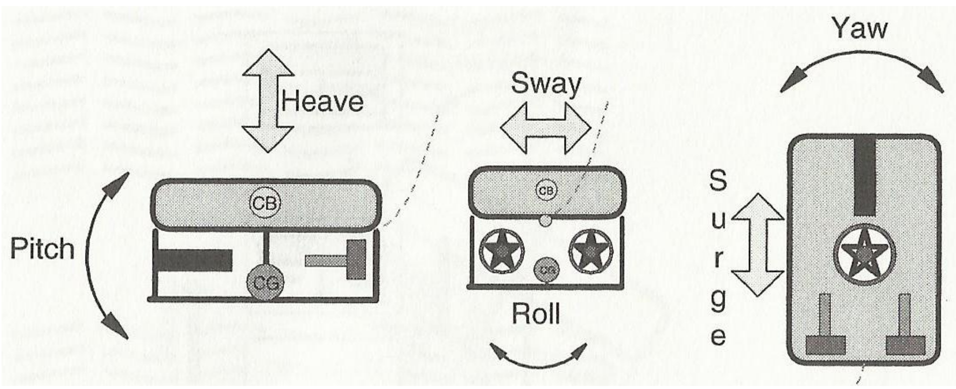

Figure 5: Freedom degrees of ROV

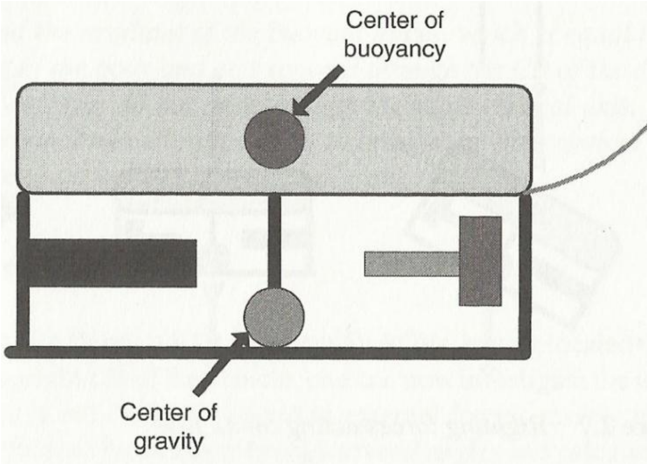

Figure 6: Stability of ROV

2.8 Hydrostatic Equilibrium

When an object immersed in the fluid, it will experience a buoyant force that is equal to the force of gravity on the displaced fluid. Therefore, underwater vehicle flotation systems need to balance the negative buoyancy so that the vehicle can produce almost zero buoyancy [5].

Figure 7 shows the displacement of fluid due the weight forces which being centred at the body of the ROV. The centre weight is called centre gravity. The righting forces acting on an ROV is shown in Figure 8. 'Centre of buoyancy' is the result of the buoyant forces that counter the gravitational pull. These buoyant forces acting through the centre of the displaced fluid. Metacentre is the point where the centre buoyancy is intersect the hull centreline and metacentric height is its distance from the centre gravity. The main consideration of building an ROV is that the vehicle is very close to zero buoyancy [6].

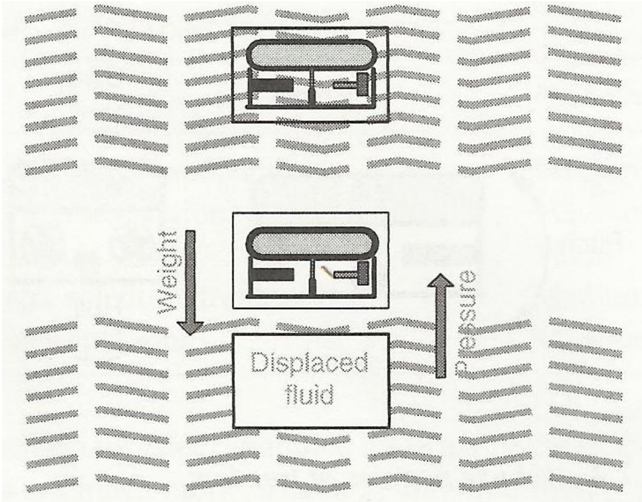

Figure 7: Hydrostatic equilibrium of ROV

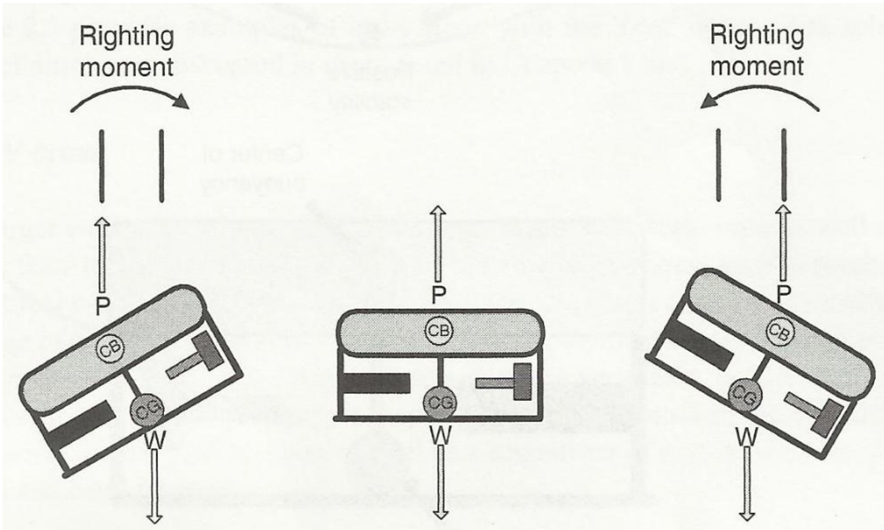

Figure 8: Righting forces acted on ROV

2.9 Dynamic Stability

A low weight and high buoyancy of the vehicle caused a positive longitudinal and lateral stability. Therefore, a stable vehicle on the pitch and roll axis can be produced. With the highest stability, the ROV can be manoeuvre easily. In addition, external forces such as the underwater sea current may effect the stability of the ROV.

A good design of an ROV is to have an aspect ratio between the width and length. Normally, the length of the ROV should be twice of the width of the ROV. With this kind of design, the maximum stability can be achieved [7]. Figure 9 shows the which design gives the best stability. Besides, the placement of the thrusters is also important. The thrusters should be placed at the edge of the frame so that it would give the maximum stability. Figure 10 shows the best thrusters placement.

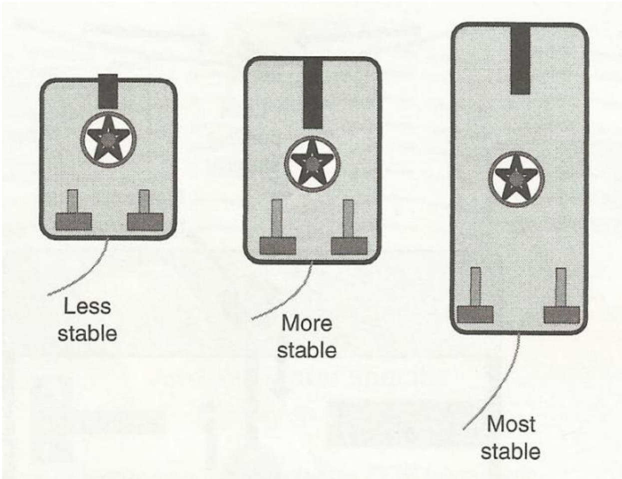

Figure 9: ROV design and stability

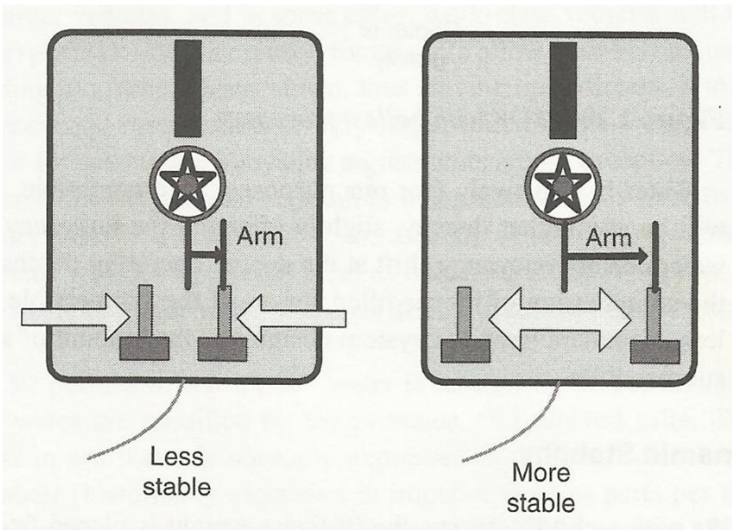

Figure 10: Placement and stability of thrusters

2.10 Drag

Drag is another critical part building an ROV. The drag must be considered first before start building an ROV to ensure the ROV can give the maximum performance during manoeuvrability. Two types of drags may acted to all bodies [8]:

1. Skin friction drag - Friction drag will be produced when there are frictional forces that acted between the skin of the body and the water. Production of resistance of the vehicle is caused by viscous shear drag of water flowing tangentially over the surface [9]. Resistance can be reduced by minimizing the exposed surface area and the velocities over the skin. Besides, having a smooth surface also will reduce the resistance. 'Reynolds number' can be used to determine the condition of flow about a body and the relative effect of fluid viscosity:

$$R_e = \frac{pVl}{m} \qquad \text{Equation 1}$$

$$R_e = \frac{Vl}{v} \qquad \text{Equation 2}$$

where:

$p = density\ of\ fluid$ ($^{kg}/_{m}3$)

$V = velocity\ of\ flow\ (m/s)$

$m = coefficient\ of\ viscosity\ (kg - s/m^2)$

$v = m/p = kinematic\ viscosity\ (m^2/s)$

$l = characteristic\ length\ of\ the\ body\ (m)$

2. Form drag - When the water moved outward to make room for the body, form drag happened. This drag is actually a function of cross-sectional area and shape. There is no resistance in an ideal non-viscous flow and the net result is zero force in the direction of motion even though there are pressure differences between the bow and stern of the vehicle. The action of viscosity will reduce the momentum of the flow but there will be pressure build up over the bow of the submersible, the

corresponding pressure recovery at the stern is reduced, and as the result there is no resistance in the direction. Varying sections over a long body will minimize this form of drag. The vehicle drag can be calculated using Equation 3 below:

$$Vehicle\ drag = \ 1/2\ x\ \sigma A V^2 C_d \qquad \text{Equation 3}$$

where:

$\sigma = \ density\ of\ sea\ water/gravitational\ acceleration$

$A = cross\ sectional\ area\ of\ the\ vehicle$

$V = Velocity\ in\ metre\ per\ second$

$C_d = Non - dimensional\ drag\ coefficient. Ranges\ from\ 0.8\ to\ 1.$

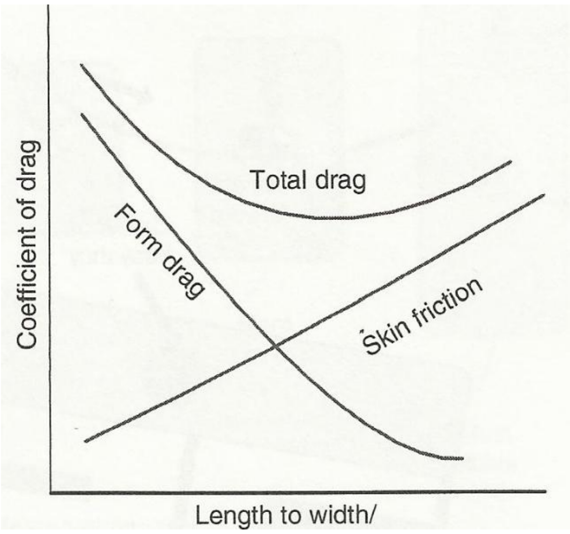

Figure 11: Drag curves of vehicle

2.11 Tether effects

A stability testing on a small ROV using water tunnel. The characteristics of the vehicle's handling is being observed and computed while the water flow being brought up slowly [10]. There will be 'bow up' turning moment since the line of thrust is considerably above the tether pull point of this vehicle as shown in Figure 12. The vehicle still able to maintain control by counteracting the 'bow up' shift with vertical thrust-down as the speed being levitate with little tether in the water. When the tether being lengthened at a constant speed, an increasingly higher tether turning moment will be produced and therefore will subjugate the vertical thrusters and pull the vehicle to the surface in uncontrolled manner.

There will be parasitic drag due to the skin friction and form drag from the thrusters discharge flow across the tether if the tether is placed in close proximity to the thrusters. A good tether placement is where the tether pull point is close to the centre point of thrust to balance any turning moment due to the tether pull point.

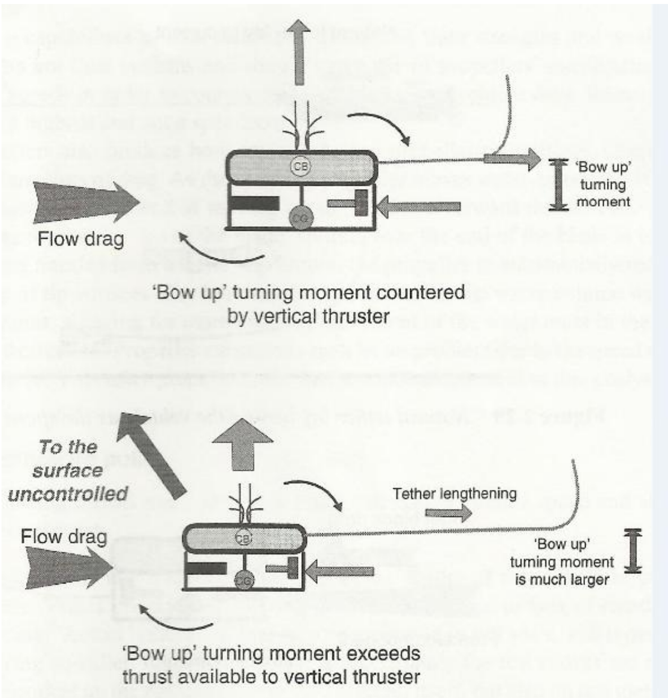

Figure 12: Considerations of vehicle stability

2.11.1 ROV and tether hydrodynamic

Normally, the tether settles behind the vehicle and slopes in the current as it feeds toward the surface. The flow drag on the tether correspondingly melds the tether into its wake when the vehicle speed ramps up and therefore forming a 'sail' of sorts behind the vehicle as shown in Figure 13 [11]. The reduced angle of incidence to the oncoming water flow reduced the drag.

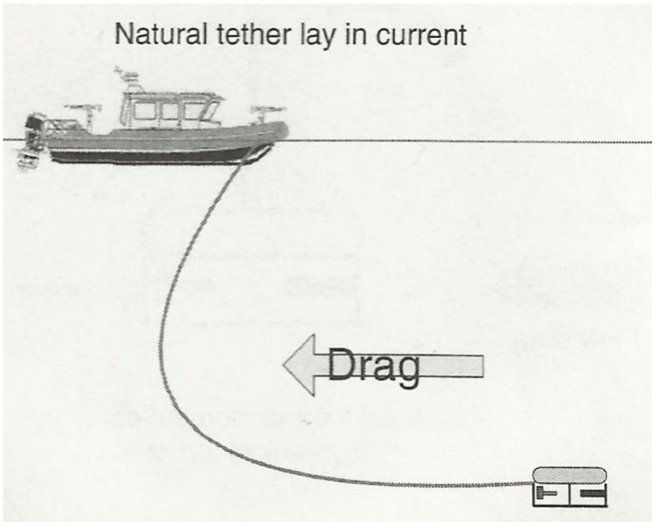

Figure 13: Drag caused by tether.

METHODOLOGY

3.1 Research Methodology

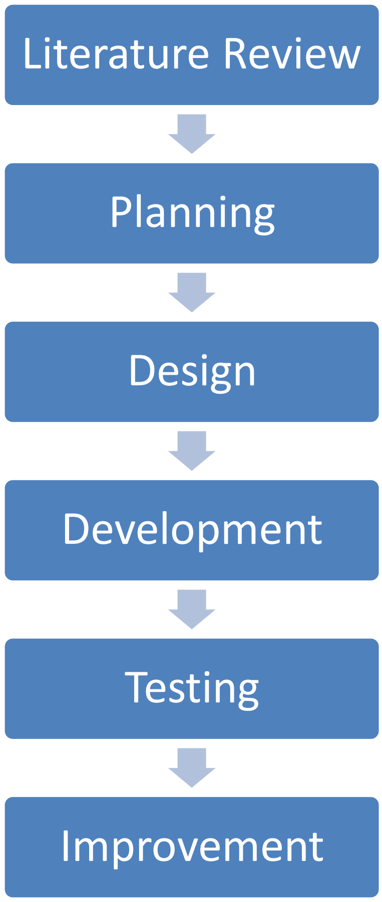

Figure 14: Research methodology flow

3.2 ROV System Block Diagram

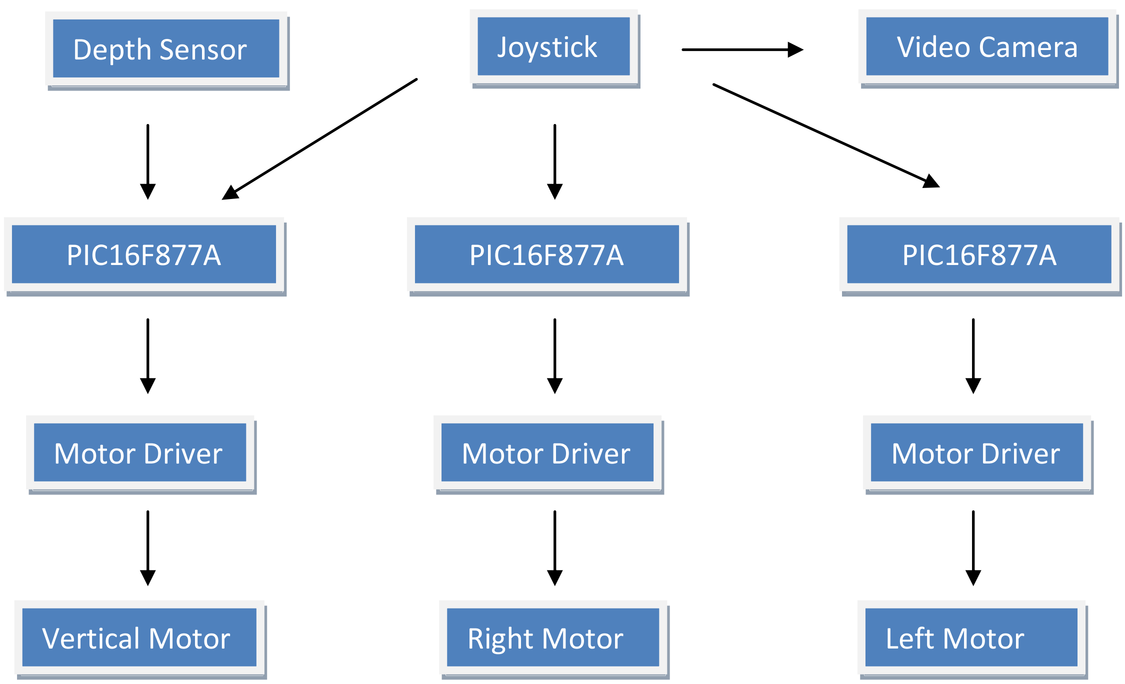

Figure 15: ROV system block diagram

3.3 Project Activities

Table 1: Project activities

Activities	Description
Literature Review	The main objectives of this project have been determined. Outlining the direction of the project by referring to the previous research.
Planning	Planning which part should be done first as this project consists of mechanical and electrical part. Each part of the project is crucial to make sure this project will succeed.
Design	The electrical part of the ROV is being designed using Microsoft Visio meanwhile the mechanical part using Solidworks 2012.
Development	Develop the electrical circuitry and apply it to the mechanical part which is the frame of ROV.
Testing	Testing the developed ROV and analyze the performance of the ROV.
Improvement	Start to make further improvement on the ROV.

3.4 Key milestone

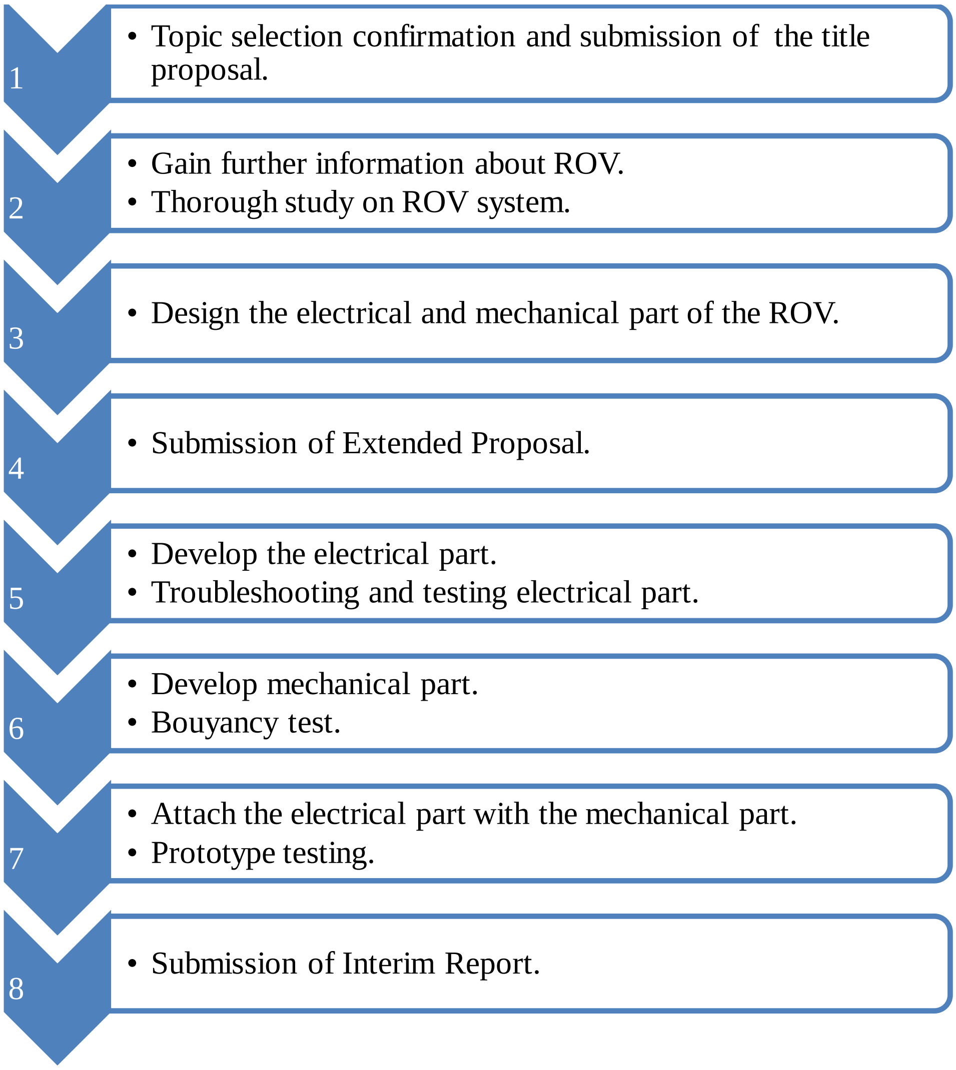

Figure 16: Key milestone

3.5 Tools

3.5.1 Hand Tools

Table 2: List of hand tools

No.	Tools	Use
1	Wire cutter	Strip wire.
2	Screw driver	Driving screw
3	Multimeter	Measuring voltage, current and connectivity
4	Soldering gun	Soldering electronic parts
5.	Allen key	Drive bolts and screw

3.5.2 Software

Table 3: List of software

No.	Software	Use
1.	Microsoft Word	Report writing
2.	Microsoft Visio	Circuit drawing
3.	Solidworks 2012	Mechanical part drawing

3.5.3 Hardware

Table 4: List of hardware

No.	Hardware	Use
1.	Aluminium square tube	Frame for the ROV
2.	Washers	Provide weight to achieve neutral buoyancy.

RESULT AND DISCUSSION

4.1 Frame Design

The main purpose of the frame is to give support to the water-proof enclosure, thrusters and any trimming weights. The frame design was initially draw using Solidworks 2012. The main consideration of this design is to make sure that there is maximum water flow through the frame to minimize drag. Below is the drawing of the ROV frame. The dimension of the frame is 25cm(W) x 25cm(H) x 50cm (L). 1.5 inch square tube aluminium will be chosen to be used as the material for the frame. Below are the reasons why square tube aluminium has been chosen to be used as frame:

- Provide positive buoyancy.
- Robust and tough compared to PVC pipes.
- Easily available.

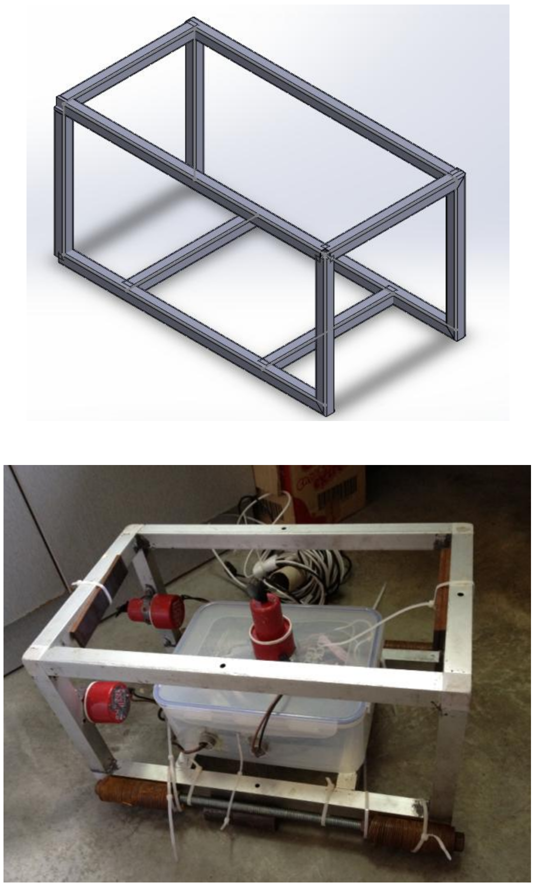

Figure 17: Isometric view

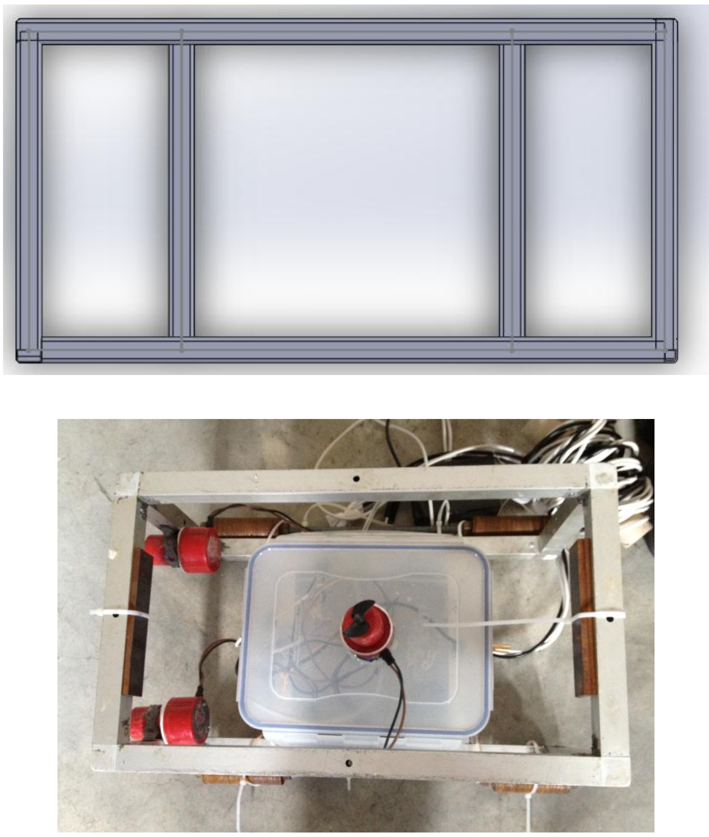

Figure 18: Top view

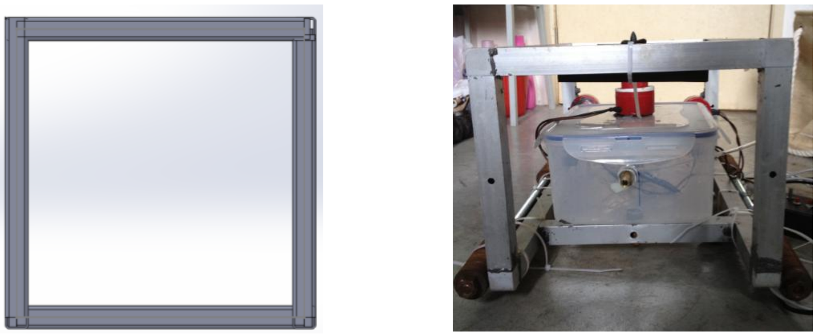

Figure 19: Front view

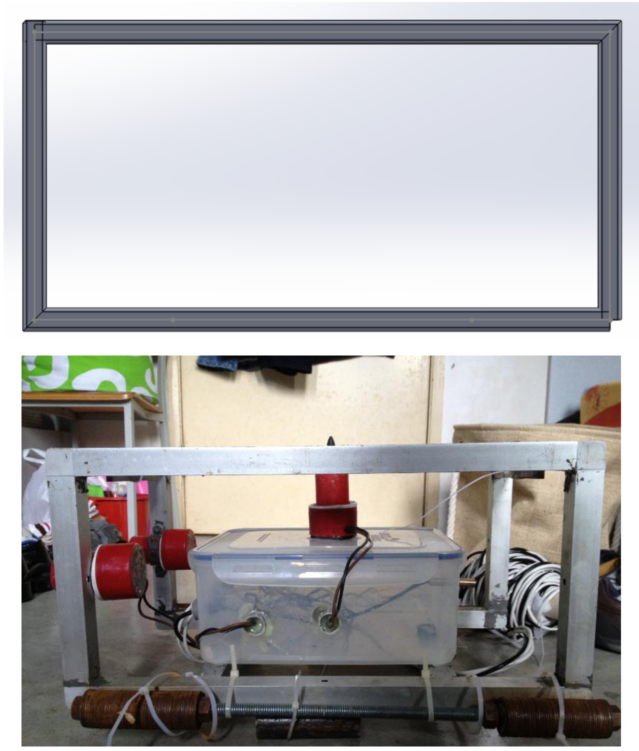

Figure 20: Side view

After doing some buoyancy testing, it is found that the aluminium frame is leaking at every joint and water fill the aluminium frame at certain places. The stability of the frame was affected since water fill the aluminium frame only at certain places. Even though epoxy has been applied at the frame, water still get inside the aluminium. To solve this problem, few holes has been made at the frame to let the water fill the frame. Since every part of the frame has been filled with water, the maximum stability can be achieved. In addition, to achieve the neutral buoyancy, several metal plates and washers has been attached together with the frames. The main reason why washers have been used is because the total weight of the washers can be easily manipulated by adding or reducing the number of the washers.

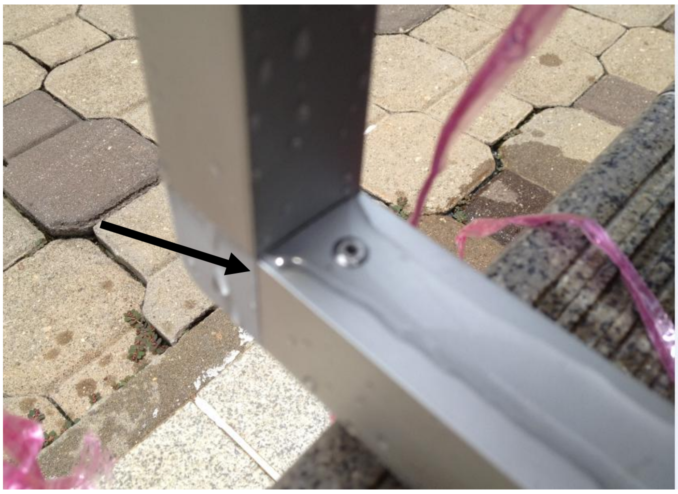

Figure 21 : Leakage at joint

Figure 22 : Metal plates

Figure 23 : Washers

4.2 Waterproof Enclosure

All underwater electronics will be put inside the waterproof enclosure. The hardest part of this project is how to keep water out from this enclosure at all cost. A considerable research was done and the requirements of this enclosure are:

- Waterproof
- Accessible
- Modifiable
- Uncompressible

Lock and Lock food container has been chosen to be used as the enclosure since it meets all the requirements above. This type of food container used a lock system and a layer of rubber to keep the container waterproof. Few holes have been made at the food container for the thrusters wires and controller wires. To prevent the water from getting inside the food container, epoxy has been applied at every hole that have been made. The epoxy has been applied at the inner and outer part of the food container for double protection.

Figure 24 : Lock and Lock food container

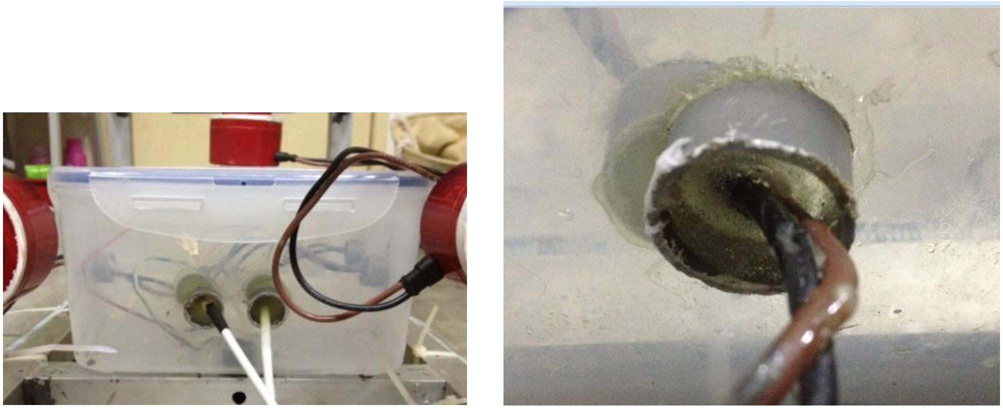

Figure 25: Epoxy has been applied at the enclosure

4.2.1 Waterproof Testing

Keeping this enclosure waterproof is very crucial. Therefore, several waterproof testing has been done. Before the waterproof testing is being done, the epoxy that has been applied to the wire holes have been checked to ensure that all epoxy were already perfectly bonded to the enclosure. During the first test, it is founded that there were some water in the enclosure. The tether was found ripped and the water flow through the tether to get inside the enclosure. To solve this problem, epoxy has been applied at the ripped part of the tether. For double protection, epoxy also has been applied at the end of the tether inside the enclosure. There was no water founded in the enclosure during the second testing.

4.3 Thrusters Modification

This project will use three units of Rule 27D 11000gph Marine Bilge Pump. This bilge pump has been selected to be as the thrusters because this pump is made up with a powerful DC motor which is very crucial in order to give a sufficient thrust to the ROV. Besides, this pump is also totally sealed which will keep the DC motor dry. However, a slight modification will be needed so that a propeller can be attached at the pump. The turn the bilge pumps into ROV thrusters, following steps were undertaken :

1. Unclip the blue protective shroud.
2. Machine away the white outer shell to expose the sealed body and impeller.
3. Remove the impeller
4. Apply epoxy to the motor shaft and propeller.
5. Repeat two more times.

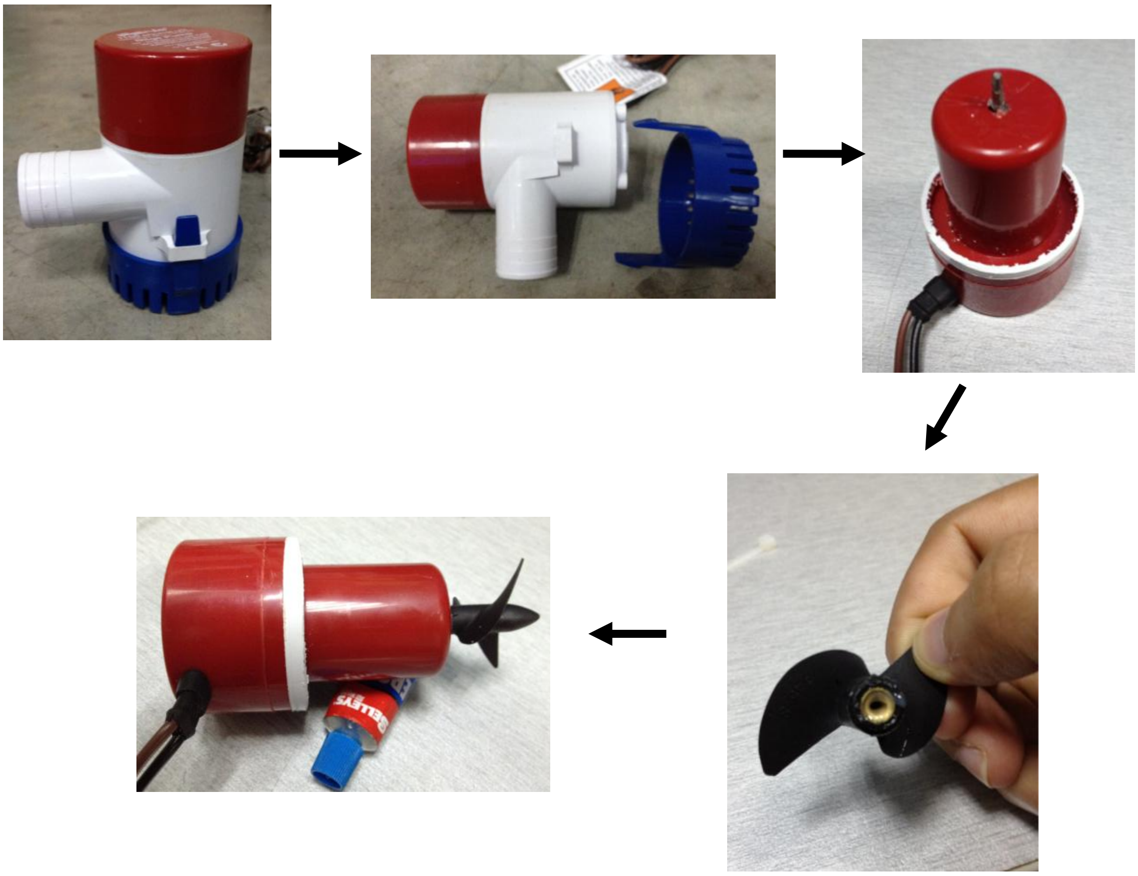

Figure 26 : Conversion of bilge pump to thrusters

4.3.1 Impeller Selection and Rotation

Finding an impeller that fit with the thrusters was a very difficult task. 2 blade remote control motor boat impeller has been used as the impeller for this project. The size of the impeller must not too big because it will draw high current. Therefore, this 2 blade remote control motor boat impeller is the best option.

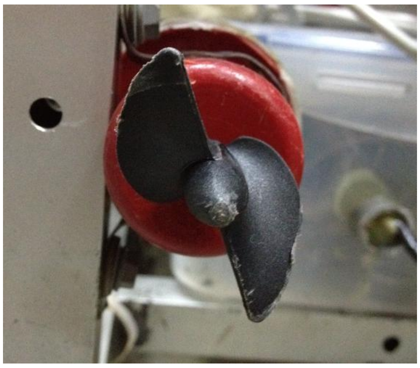

Figure 27 : 2 blade impeller

To manoeuvre the ROV, two thrusters were used simultaneously for horizontal movement while only one thruster will be used for vertical movement. For horizontal movement, both thrusters rotate in the opposite direction to the other to steer right or left. Table 5 shows the propeller rotation and its response:

Table 5 : Propeller rotation and response

Horizontal Right	**Horizontal Left**	**Vertical**	**Response**
Clockwise	Counter-clockwise		Steer left
Counter-clockwise	Clockwise		Steer right
Clockwise	Clockwise		Move forward
Counter-clockwise	Counter-clockwise		Move reverse
		Clockwise	Level up
		Counter-clockwise	Level down

4.4 Controller

The thrusters are being manipulated using the controller. This controller consists of two variable resistors and two push buttons. The variable resistors are for the horizontal thrusters. The speed and the rotation direction of the thrusters are being manipulated using these variable resistors. Another two push buttons are for vertical thrusters where one for level up the ROV and one for level down the ROV.

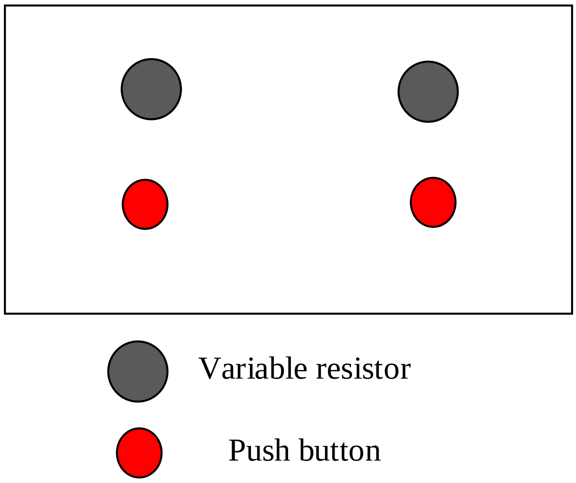

Figure 28 : Controller design

4.5 Tether

Tether is the physical connection between from the main controller to the ROV in the water. The responsibilities of tether are:

- Deliver instructions from the main controller to the ROV in the water.
- Deliver video up to the operator.

Two 10m Ethernet cable (Cat. 5) has been used as tether in this project. Each of this Ethernet cable consist of four pairs of wires. Three pairs of wires are used for manipulating the horizontal thrusters while two are used for the vertical thrusters. Three pairs of wires are unused but available for future use. The maximum depth the ROV can dive is only 10m since the tether length is only 10m. The main physical requirements for the tether are it must be as light and small as possible in order to minimize drag through the water and neutrally buoyant. A number of flotation devices are attached together with the Ethernet cable since the cable is not neutrally buoyant. In addition, epoxy has been applied at the end of the cable to avoid the water flows in the waterproof enclosure if the cable ripped.

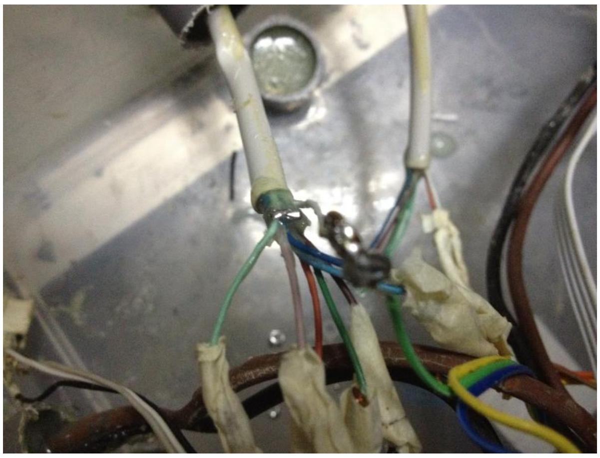

Figure 29 : Epoxy has been applied at the end of the Ethernet cable

4.6 Controller Circuit

Peripheral Interface Controller (PIC) has been used to control the movement of the ROV. PIC16F877A has been selected to control two horizontal thrusters and a vertical thruster. The reasons why PIC16F877A has been chosen over Arduino are as follows:

- PIC16F877A cheaper
- PIC16F877A easily available
- PIC16F877A required less jumper
- PIC16F877A flexible and powerful

For this project, three PIC16F877A has been used to control the three thrusters since each PIC16F877A only have two pins of PWM which is for clockwise and counter clockwise rotation. Three motor drivers are then being connected to the PIC16877A. These motor drivers receive the signals from the PIC16877A and drive the thrusters. The relay has been used to manipulate the rotation direction of the thrusters. Below is the schematic diagram of the motor driver :

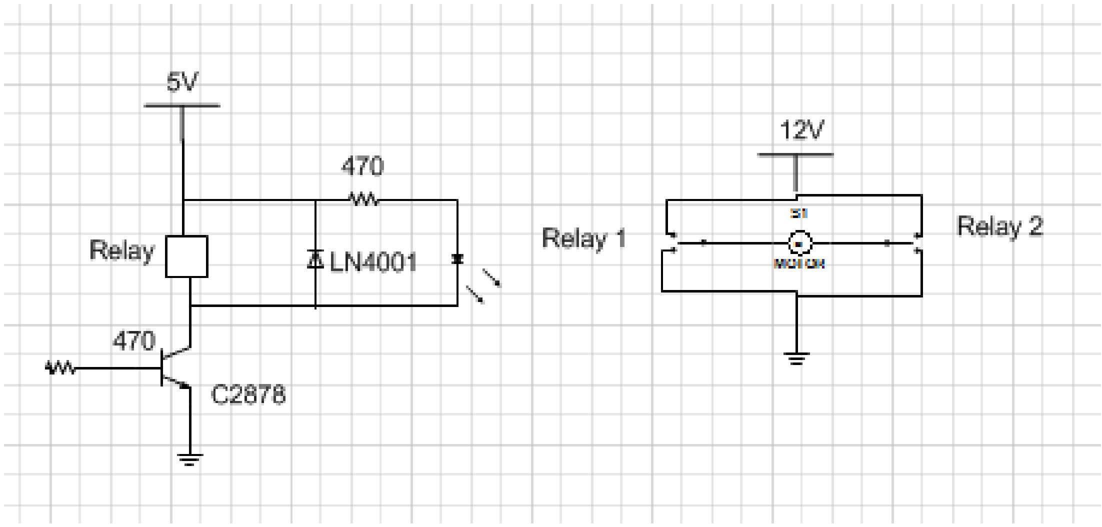

Figure 30 : Motor driver circuit

For the motor connection, H-bridge connection has been used to manipulate the rotation of the motor.

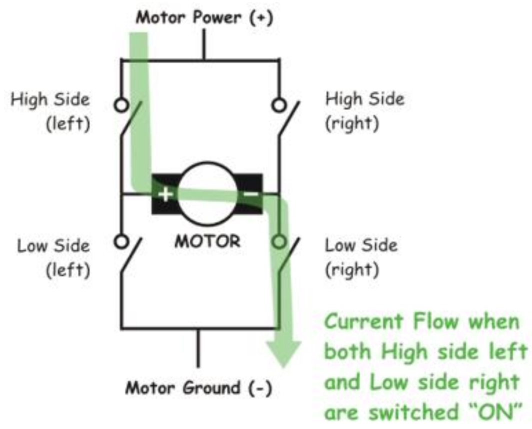

Figure 31 : H-bridge

High side for left and right are normally open while low side for left and right are normally closed. Table 6 shows the condition for the motor :

Table 6 : Motor condition

High Side Left	High Side Right	Low Side Left	Low Side Right	Description
On	Off	Off	On	Clockwise
Off	On	On	Off	Counter-clockwise

4.6.1 Pulse Width Modulation

Pulse Width Modulation is normally used to control certain devices such as DC motors and LED lights. PWM signal consists of high and low levels of pulse which it can be manipulated by varying the duty cycle. Duty cycle can be described as high level over a period of time. The main advantage of PWM signal is very low power loss in switching devices where there is almost no voltage drop across the switch when it is on. Therefore, by using PWM signal, the speed of motor can be controlled effectively.

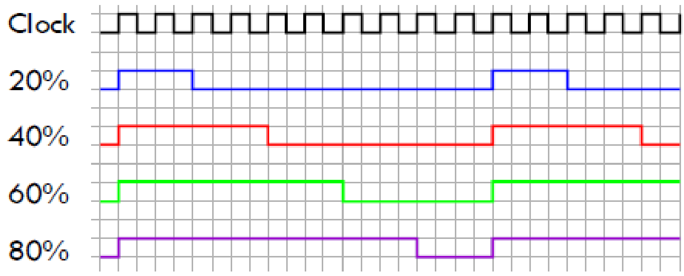

Figure 32 : PWM signal

As seen in Figure above, when the duty cycle is 20%, the effective average voltage is only 20% of the maximum output voltage. For example, if the maximum output voltage is 12V, then the effective average voltage is 2.40V. When the duty cycle is 80%, effective average voltage is 9.60V. By varying the duty cycle, many different effective average voltage can be obtained.

4.7 Power Supply

4.7.1 Power from Surface

Most of the ROVs are being powered from the surface, but there is a major problem using the surface power option. There will be voltage drop along the wire caused by the resistance of the wire and therefore the ROV is being underpowered. There is a way to solve this problem by using a larger gauge wire. However, this large gauge will increase the drag and buoyancy requirement since it is heavier than the normal tether. Table 7 shows the voltage drop of the ROV during testing :

Table 7 : Voltage drop

Supplied Voltage	Voltage Drop	Available Voltage
12 V	3.12 V	8.88 V
15 V	3.04 V	11.96 V

During prototype testing, the power supply that was used is 12V 7.2Ah battery. The thrusters only receive 5.2V during full speed. Since the voltage received by the thrusters is too low, the thrusters only rotate at a slow speed and therefore the ROV unable to manoeuvre smoothly. Besides, the current drawn by the thrusters also been measured as shown in Table 8:

Table 8 : Current drawn

Supplied voltage	Current
12V	0.3A
17V	0.6A

Figure 33 : Current drawn by thrusters

4.7.2 On Board Power

The third objectives of this project is to install on board power. There are few factors that need to considered in order to have on-board power :

- Voltage
- Size and weight
- Power capacity and energy density
- Cost

There are few different battery technology that available on market:

- Lead acid
- Nickel Cadmium
- Nickel Metal Hydride
- Lithium Polymer

Lead acid batteries normally used in automotives. They are too big, heavy and prone to leakage. Lithium Polymer (LIPO) batteries are the best option for ROV. They offer:

- Can be easily configured
- Light weight
- Greatest power capacity and energy density
- Reasonable cost

For this project, FullyMax 14.8V 3300mAH 4S 35C LIPO pack battery has been used as on board power. This battery consists of four cells which is 3.7V each connected in series. This battery can be charged up to 15.6V using LiPro Balance Charger. The 35C rating of the battery indicates the maximum continuous discharge current the battery can deliver without overheating and damaging the battery.

$$Maximum\ discharge\ current = capacity\ (Amp\ hours) x\ C\ rating \quad \text{Equation 4}$$

$$Maximum\ continous\ discharge\ current = 3.3\ A\ x\ 35 \quad \text{Equation 5}$$

$$Maximum\ continous\ discharge\ current = 115.5\ Amps \quad \text{Equation 6}$$

Based on the Equation 4,5 and 6, this battery is more than suitable that can be used for the ROV since the ROV does not draw more than 2-3 Amps at any time. This LIPO battery can give a typical run-time of around 20 minutes. To extend the run-time, another LIPO battery can be added by connecting it in parallel.

Figure 34: FullyMax 14.8V 3300mAH 4S 35C LIPO

Figure 35: LiPro Balance Charger

4.8 Video Camera

There are few considerations that have been made in choosing the right video camera. The considerations are:

- Cost
- Ease of application
- Image type and quality

The video camera that has been used in diving is easily available but it is very expensive. Since the main aim in choosing the video camera is the cost, this diving camera is not suitable for the project. Therefore, a sewer inspection camera has been chosen to be the video camera for this project. This camera is small, waterproof, average image quality and uses USB cable. Since this video camera uses USB cable, no additional power source is needed because this camera will be powered using the

USB cable. In addition, this video camera has build in adjustable lights. Table 9 shows the specifications of the video camera :

Table 9 : Video camera specifications

Specifications	Details
Waterproof Level	IP67
Camera head outer diameter	14.55mm
Resolution	640x480
Sensor	$\frac{1}{6}$ CMOS Image Sensor
Pixels	300k
Wide visual view angel	62°
Light	4 adjustable led switch
Colour	24 colours

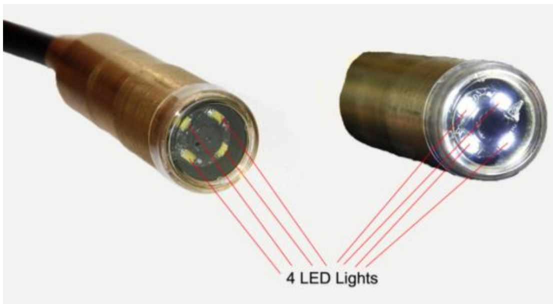

Figure 36 : Video camera

4.9 Depth Sensor

MPX 4250 gauge pressure sensor has been used in this project. This pressure sensor is very important in order to keep the ROV at the desired level. The ROV may be pushed up and down by underwater sea current and therefore it is very difficult for the operator to keep maintain at the desired level. With this pressure, the level of the ROV can be maintained automatically. Table 10 the specifications of the pressure sensor :

Table 10 : MPX4250 specifications

Specifications	Details
Accuracy	±1.4%
Analogue Output	4.9V
Housing Material	Epoxy
Maximum Operating Temperature	+125°C
Minimum Operating Temperature	-40°C
Maximum Pressure Reading	250kPa
Pressure Reading Type	Gauge

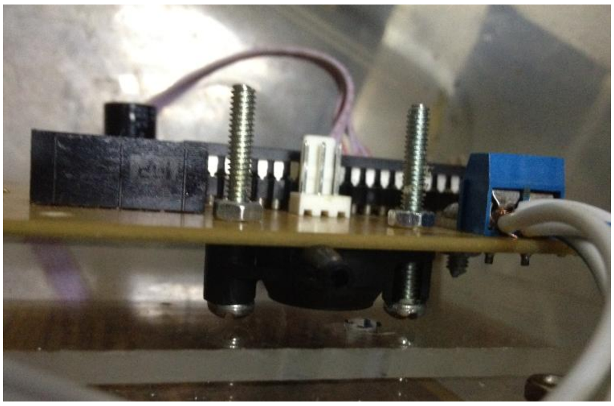

Figure 37 : MPX4250 gauge pressure sensor

4.10 Prototype Testing

Several prototype testing has been done to test the operational capabilities of the ROV. The testing has been done at two different places which are UTP swimming pool and lake. From the first test, it is observed that the ROV has negative buoyancy where it sinks in the pool after few minutes. By removing some of the washers that attached at the ROV, the problem is solved.

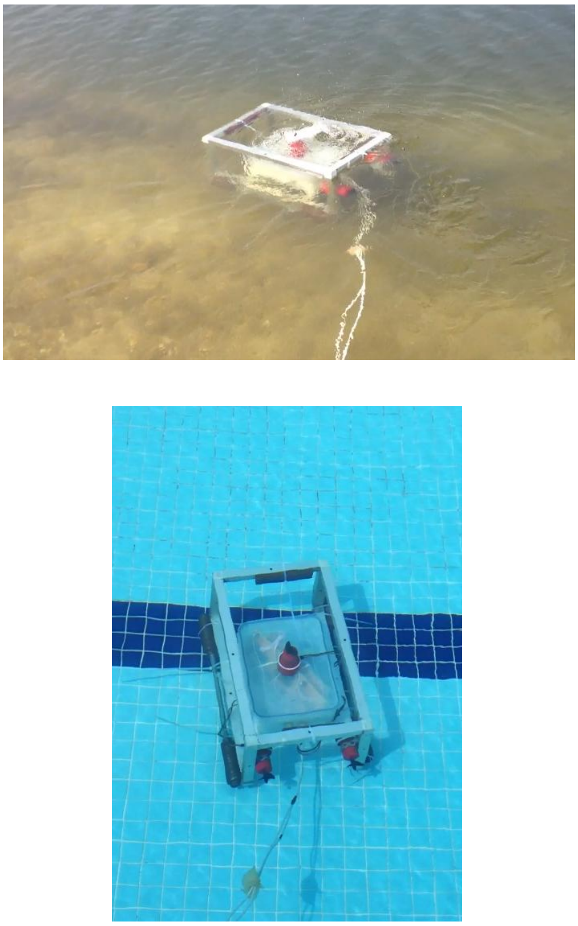

Figure 38 : Prototype testing

RECOMMENDATIONS AND CONCLUSION

5.1 Conclusion

The development of ROV grew rapidly since it was first development by Dimitri Rebikoff. ROV has been involved in so many operations such as recovering Titanic and rescuing Gulf of Mexico oil well. Therefore, there are so many improvements that can be made at in ROV to make it powerful and wiser.

Upon completion of this project, all three objectives are met, which are design and construct ROV prototype, installing auto depth function and installing on board power. By having this features, this ROV prototype is a step ahead compared to other observation class ROV. There is no more issue for the ROV operator to maintain the ROV at certain level since the auto depth function will solve the problem. Besides, thick wires for power source are no longer needed since the ROV has on board power.

5.2 Recommendations

5.2.1 Leak Detector

A leak system detector is required to ensure that the water-proof enclosure is always dry. This leak system detector will give warning if any leaks may occur inside the water proof enclosure. This system consists of a small section of copper-coated-strip board with the connecting wires attached to adjoining tracks. If water presents inside the waterproof enclosure, it will signal by light up an LED.

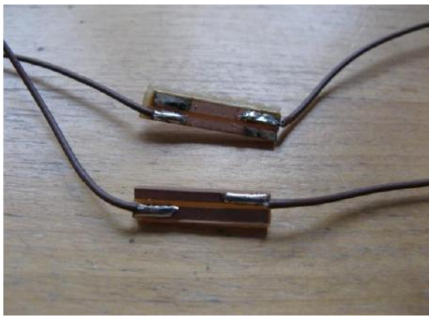

Figure 39: Leak detector

5.2.2 Auto Ballast System

When the leak detector detects water inside the waterproof enclosure, this auto ballast system will be automatically activated. The main function of this auto ballast system is for safety purpose, where it will change the buoyancy of the ROV to positive buoyancy by forcing the water out from the ballast tank using valve or pump whenever there is water inside the waterproof enclosure. Moreover, all the controller circuit will be shut off when this system is activated.

Figure 40 : Auto ballast system

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APPENDICES

APPENDIX A - Gantt Chart Final Year Project 1

No	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Topic selection														
2.	Preliminary research work														
3.	Submission of Extended Proposal														
4.	Project Work: Designing electrical part														
5.	Proposal defence														
5.	Project Work: Troubleshooting electrical part														
6.	Project Work: Testing electrical part														
7.	Drafting interim report														
8.	Submission of interim report														

APPENDIX B - Gantt Chart Final Year Project 2

No	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Troubleshooting electrical and mechanical part.														
2.	Progress report														
3.	Further improvement of the prototype														
4.	Pre-EDX														
5.	Draft Report														
6.	Final Report														
7.	Viva														

Appendix C - Programming Code for Horizontal Thruster

```
                LIST P=16F877a

                ERRORLEVEL      -302
                ERRORLEVEL      -305

                #INCLUDE <P16F877a.INC>

                __CONFIG        0X3F32

;=======================MACRO ================================

BANK0       MACRO                               ;CHANGE TO BANK 0
                BCF             STATUS,RP0
                BCF             STATUS,RP1
                ENDM

BANK1       MACRO                               ;CHANGE TO BANK 1
                BSF             STATUS,RP0
                BCF             STATUS,RP1
                ENDM

BANK2       MACRO                               ;CHANGE TO BANK 2
                BCF             STATUS,RP0
                BSF             STATUS,RP1
                ENDM
```

```
BANK3           MACRO                                   ;CHANGE TO BANK 3
                        BSF             STATUS,RP0

                        BSF             STATUS,RP1
                        ENDM

status  equu            03h
ADCon0  equ     1fh
ADCon1  equ     9fh

                cblock  0x20
cnt500u         ;500usec counter Address
cnt1m           ;1msec counter Address
cnt100m         ;100msec counter Address
cnt500m         ;500msec counter Address
cnt1s                   ;1sec counter Address
tmr10
addrcnt3
addrcnt3x
addrcnt3y
buff1
buff2
buff3
buff4
ton
toff
polarflag
sppolar
inpwm
```

```
            endc
pwmindex equu        d'50'    ;pwm cycle
;========== VARIABLE ===========================================
;DATA MEMORY ADDRESS =20h - 7Fh (BANK0)
;                                      A0h - EFh (BANK1)
;                                      110h - 16Fh (BANK2)
;                                      190h - 1EFh      (BANK3)

;========== RESET VECTOR =======================================


                     ORG         00

RESET       GOTO     INIT
;========== INTERRUPT VECTOR ===================================


                     ORG         04

INT                  GOTO     INIT
;========== INITIALIAZATION ====================================

                     ORG         05

INIT        BANK0
                     clrf     PORTA
                     CLRF     PORTB
                     CLRF     PORTC
                     CLRF     PORTD
                     CLRF     PORTE
```

```
        BANK1

        movlw   b'00000000'        ;PORTA analog
        movwf   ADCON1             ;ADC all digital input
        movlw   b'00111111'
        movwf   TRISA              ;PORTA AS INPUT
        movlw   b'00000111'
        movwf   TRISE
        clrf    TRISB
        movlw   b'10110000'        ;PORTC AS INPUT
        movwf   TRISC
        clrf    TRISD              ;PORTD AS INPUT N OUTPUT

;input
;re1        = propeller dir and speed
;output
;portB      = analog value
;rd4        = reverse
;rd5        = forward
;rd6        = speed control
datum
        BANK0
        CLRF    PORTB              ;clear output
        clrf    PORTC
        clrf    PORTD
        clrf    PORTE
main
        call    stanalog1
        btfsc   polarflag,00
```

```
                goto    toforth
                goto    toreverse

toforth
                call    forward
                goto    kkk
toreverse
                call    reverse
                goto    kkk

kkk
                goto    main
;*******************************************************
;rd4            = reverse
;rd5            = forward
;rd6            = speed control
forward
                bsf             PORTD,04                ;motor forward
                bcf             PORTD,05
                bsf             PORTD,06

                call    mainspeed

                return
reverse
                bcf             PORTD,04
                bsf             PORTD,05                ;motor reverse
                bsf             PORTD,06

                call    mainspeed
```

```
        return
;********************************************************
mainspeed
        movlw   pwmindex
        movwf   inpwm
        movlw   d'10'
        subwf   buff1,w
        btfss   STATUS,00
        goto    off                     ;minimum speed
reload
        movfw   buff1                   ;reload counter to ghost location
        movwf   ton
        movfw   buff2
        movwf   toff
on
        bsf             PORTD,06
onwait
        nop
        nop
        nop
        nop
        nop
        nop
        decfsz  ton,1                   ;on time delay

        goto    onwait
off
        bcf             PORTD,06
offwait
```

```
                nop
                nop
                nop
                nop
                nop
                nop
                decfsz  toff,1                      ;off time delay
                goto    offwait
                decfsz  inpwm,1
                goto    reload
                return
;*******************************************************
stanalog1
        movlw   B'01110001'     ;Fosc/8 [7-6], A/D ch0 [5-3], a/d on [0]
        movwf   ADCon0
        bsf     ADCon0,GO               ;Start A/D conversion
Wait1
        btfsc   ADCon0,GO               ;Wait for conversion to complete
        goto    Wait1
        movf    ADRESH,W                ;write A/D result to temporary location
        movwf   buff4                   ;copy value
        movwf   PORTB


        movfw   buff4
        sublw   d'154'
        btfss   STATUS,02               ;z=1 if zero (buff4 = 154)
        goto    nextsp

        goto    displax                 ;do nothing
```

```
nextsp
        movfw   buff4
        sublw   d'154'
        btfss   STATUS,00               ;c=1 if +ve (buff4 < 154)
        goto    advance
        goto    backward
advance
        movlw   b'11111111'
        movwf   polarflag
        movlw   d'154'
        subwf   buff4,w
        movwf   buff3                   ;buff3 containing speed index
        movwf   buff1
        goto    lagi
backward
        movlw   b'00000000'
        movwf   polarflag
        movfw   buff4
        sublw   d'154'
        movwf   buff3                   ;buff3 containing speed index
        movwf   buff1
lagi
                movlw   d'0'
                xorwf   buff3,w
                btfsc   STATUS,02
                goto    displax
                decfsz  buff3,f
                goto    zzz
zzz
                goto    lagi
```

```
displax

                movfw     buff1                        ;buff1 containing on time index

                sublw     d'154'

                movwf     buff2                        ;buff1 containing off time index


                return
;*******************************************************
;         Analog Stuff
;*******************************************************


;************* 1msec Timer Subroutine *****************
t1m     movlw   d'2'          ;(1)      Set loop cnt1
        movwf   cnt1m         ;(1)      Save loop cnt1
tm1lp1  movlw   d'249'        ;(1)*2    Set loop cnt2
        movwf   cnt500u       ;(1)*2    Save loop cnt2
tm1lp2  nop                   ;(1)*249*2 Time adjust
        nop                   ;(1)*249*2 Time adjust
                decfsz  cnt500u,f     ;(1)*249*2 cnt500u-1=0 ?
        goto    tm1lp2        ;(2)*248*2 No, continue
        decfsz  cnt1m,f       ;(1)*2    cnt1m-1=0 ?
        goto    tm1lp1        ;(2)      No. Continue
        return                ;(2)      Yes. Cnt end
                              ;Total 2501*0.4usec=1msec
;************* 10msec Timer Subroutine *****************
t10m    movlw   d'10'         ;(1)      Set loop cnt1
        movwf           tmr10
loopt10
                call            t1m
                decfsz          tmr10,1
```

```
                goto        loopt10
                return
;************* 100msec Timer Subroutine ***************
t100m   movlw   d'50'       ;Set loop counter
        movwf   cnt100m     ;Save loop counter
tm2lp   call    t1m         ;1msec subroutine
        decfsz  cnt100m,f   ;cnt100m - 1 = 0 ?
        goto    tm2lp       ;No. Continue
        return              ;Yes. Count end
;************* 500msec Timer Subroutine ***************
t500m   movlw   d'5'        ;Set loop counter
        movwf   cnt500m     ;Save loop counter
tm3lp   call    t100m       ;100msec subroutine
        decfsz  cnt500m,f   ;cnt500m - 1 = 0 ?
        goto    tm3lp       ;No. Continue
        return              ;Yes. Count end
;************** 1sec Timer Subroutine *****************
t1s     movlw   d'2'        ;Set loop counter
        movwf   cnt1s       ;Save loop counter
tm4lp   call    t500m       ;500msec subroutine
        decfsz  cnt1s,f     ;cnt1s - 1 = 0 ?
        goto    tm4lp       ;No. Continue
        return              ;Yes. Count end
                END
```

APPENDIX D - Programming Code for Vertical Thruster

```
                        LIST P=16F877a

                        ERRORLEVEL      -302
                        ERRORLEVEL      -305

                        #INCLUDE <P16F877a.INC>

                        __CONFIG        0X3F32

;========================MACRO =================================

BANK0       MACRO                               ;CHANGE TO BANK 0
                        BCF             STATUS,RP0
                        BCF             STATUS,RP1
                        ENDM

BANK1       MACRO                               ;CHANGE TO BANK 1
                        BSF             STATUS,RP0
                        BCF             STATUS,RP1
                        ENDM

BANK2       MACRO                               ;CHANGE TO BANK 2
                        BCF             STATUS,RP0
                        BSF             STATUS,RP1
                        ENDM

BANK3       MACRO                               ;CHANGE TO BANK 3
```

```
			BSF		STATUS,RP0


			BSF		STATUS,RP1

			ENDM


status	equ		03h

ADCon0	equ	1fh

ADCon1	equ	9fh


		cblock	0x20

cnt500u		;500usec counter Address

cnt1m		;1msec counter Address

cnt100m		;100msec counter Address

cnt500m		;500msec counter Address

cnt1s			;1sec counter Address

tmr10


buff1

buff2

buff3

buff4


ton

toff


speedid


inpwm
```

```
                endc

;========== VARIABLE ===========================================
;DATA MEMORY ADDRESS = 20h - 7Fh (BANK0)
;                                A0h - EFh (BANK1)
;                                110h - 16Fh (BANK2)
;                                190h - 1EFh       (BANK3)

;========== RESET VECTOR =======================================

                        ORG             00

RESET           GOTO    INIT

;========== INTERRUPT VECTOR ===================================

                        ORG             04

INT                     GOTO    INIT

;========== INITIALIAZATION ====================================

                        ORG             05

INIT            BANK0
                        clrf    PORTA
```

```
        CLRF    PORTB
        CLRF    PORTC
        CLRF    PORTD
        CLRF    PORTE

        BANK1

        movlw   b'00000000'             ;PORTA analog
        movwf   ADCON1                  ;ADC all digital input
        movlw   b'00111111'
        movwf   TRISA                   ;PORTA AS INPUT
        movlw   b'00000111'
        movwf   TRISE
        clrf    TRISB
        movlw   b'10110000'             ;PORTC AS INPUT
        movwf   TRISC
        movlw   b'00001111'
        movwf   TRISD                   ;PORTD AS INPUT N OUTPUT

;input
;re1            = spare analog

;output
;portB          = analog value
;rd3            = fastup
;rc4            = slowdive
;rd2            = fastdive

;rd4            = reverse
;rd5            = forward
```

```
;rd6            = speed control

datum
                BANK0
                CLRF    PORTB           ;clear output
                clrf    PORTC
                clrf    PORTD
                clrf    PORTE

buttonscan
                btfsc   PORTD,03
                goto    up100
                btfsc   PORTC,04
                goto    dive50
                btfsc   PORTD,02
                goto    dive100
                call    normalise
                goto    buttonscan

normalise
                bcf             PORTD,04
                bcf             PORTD,05
                bcf             PORTD,06
                nop
                nop
                return
;rd4            = reverse
;rd5            = forward
;rd6            = speed control
up100
```

```
        bsf         PORTD,04
        bsf         PORTD,06
        nop
        movlw   d'1'
        movwf   speedid
        goto    pwming

dive50
        bsf         PORTD,05
        nop
        movlw   d'2'
        movwf   speedid
        goto    pwming

dive100
        bsf         PORTD,05
        bsf         PORTD,06
        nop
        movlw   d'3'
        movwf   speedid
        goto    pwming

pwming
        movlw   d'10'
        movwf   inpwm
        movlw   d'1'
        xorwf   speedid,w
        btfsc   STATUS,02
        goto    buttonscan
        movlw   d'2'
```

```
                xorwf   speedid,w
                btfsc   STATUS,02
                goto    pwm
                goto    buttonscan

pwm             bsf             PORTD,06
                call    t10m
                bcf             PORTD,06
                call    t10m
                decfsz  inpwm
                goto    pwm
                goto    buttonscan
```

```
;       Analog Stuff
;*******************************************************
stanalog1
        movlw   B'01110001'     ;Fosc/8 [7-6], A/D ch0 [5-3], a/d on [0]
        movwf   ADCon0
        bsf     ADCon0,GO               ;Start A/D conversion
Wait1
        btfsc   ADCon0,GO               ;Wait for conversion to complete
        goto    Wait1
        movf    ADRESH,W                ;write A/D result to temporary location
        movwf   buff4                   ;copy value
        movwf   PORTB
```

```
;************* 1msec Timer Subroutine *****************

t1m     movlw   d'2'          ;(1)       Set loop cnt1

        movwf   cnt1m         ;(1)       Save loop cnt1

tm1lp1  movlw   d'249'        ;(1)*2     Set loop cnt2

        movwf   cnt500u       ;(1)*2     Save loop cnt2

tm1lp2  nop                   ;(1)*249*2 Time adjust

        nop                   ;(1)*249*2 Time adjust

                decfsz  cnt500u,f     ;(1)*249*2 cnt500u-1=0 ?

        goto    tm1lp2        ;(2)*248*2 No, continue

        decfsz  cnt1m,f       ;(1)*2     cnt1m-1=0 ?

        goto    tm1lp1        ;(2)       No. Continue

        return                ;(2)       Yes. Cnt end

                              ;Total 2501*0.4usec=1msec


;************* 10msec Timer Subroutine *****************

t10m    movlw   d'10'         ;(1)       Set loop cnt1

        movwf           tmr10

loopt10

                call            t1m

                decfsz          tmr10,1

                goto            loopt10

                return

;************* 100msec Timer Subroutine ***************

t100m   movlw   d'50'         ;Set loop counter

        movwf   cnt100m       ;Save loop counter

tm2lp   call    t1m           ;1msec subroutine

        decfsz  cnt100m,f     ;cnt100m - 1 = 0 ?

        goto    tm2lp         ;No. Continue

        return                ;Yes. Count end

;************* 500msec Timer Subroutine ***************
```

```
t500m   movlw   d'5'           ;Set loop counter

        movwf   cnt500m        ;Save loop counter

tm3lp   call    t100m          ;100msec subroutine

        decfsz  cnt500m,f      ;cnt500m - 1 = 0 ?

        goto    tm3lp          ;No. Continue

        return                 ;Yes. Count end

;************** 1sec Timer Subroutine *****************

t1s     movlw   d'2'           ;Set loop counter

        movwf   cnt1s          ;Save loop counter

tm4lp   call    t500m          ;500msec subroutine

        decfsz  cnt1s,f        ;cnt1s - 1 = 0 ?

        goto    tm4lp          ;No. Continue

        return                 ;Yes. Count end

                END
```

APPENDIX E - MPX4250 Datasheet

Pressure

Freescale Semiconductor

MPX4250
Rev 7, 1/2009

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4250 Series

0 to 250 kPa (0 to 36.3 psi)
0.2 to 4.9 V Output

The MPX4250 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure. The small form factor and high reliability of on-chip integration make the Freescale sensor a logical and economical choice for the automotive system engineer.

Application Examples

- Ideally Suited for Microprocessor or Microcontroller-Based Systems

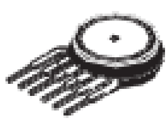
Features

- Differential and Gauge Applications Available
- 1.4% Maximum Error Over 0° to 85°C
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over −40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element

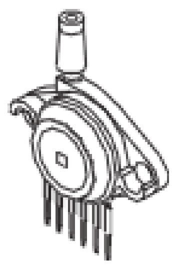
ORDERING INFORMATION

Device Name	Package Options	Case No.	# of Ports			Pressure Type			Device Marking
			None	Single	Dual	Gauge	Differential	Absolute	
Unibody Package (MPX4250 Series)									
MPX4250D	Tray	867	•				•		MPX4250D
MPX4250GP	Tray	867B		•		•			MPX4250GP
MPX4250DP	Tray	867C			•		•		MPX4250DP

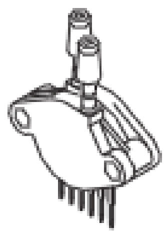
UNIBODY PACKAGES



MPX4250D
CASE 867



MPX4250GP
CASE 867B



MPX4250DP
CASE 867C

freescale semiconductor

Operating Characteristics

Table 1. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	250	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.139	0.204	0.269	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.844	4.909	4.974	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.705	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.4	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	18.8	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
TcSpan:	Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.

7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Maximum Ratings

Table 2. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

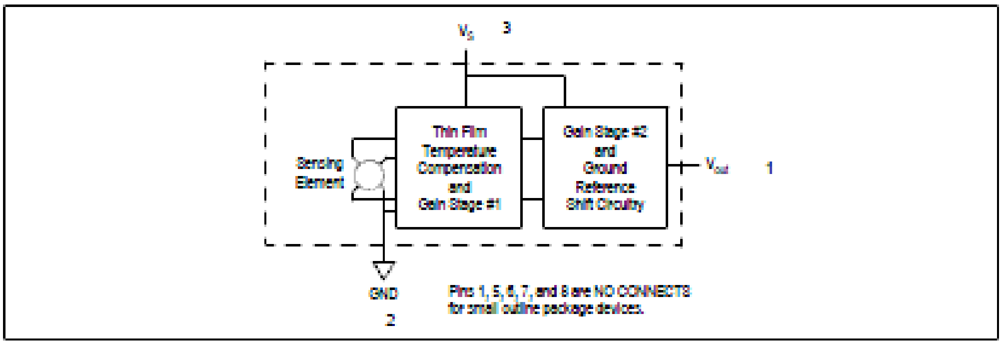


Figure 1. Fully Integrated Pressure Sensor Schematic

On-chip Temperature Compensation and Calibration

Figure 2 illustrates the differential/gauge pressure sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4250 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range

.

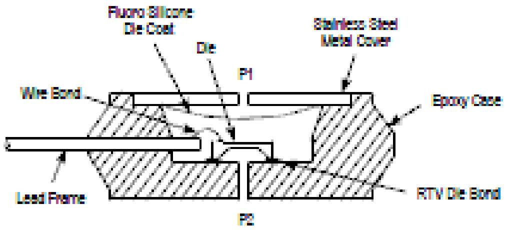


Figure 2. Cross Sectional Diagram (not to scale)

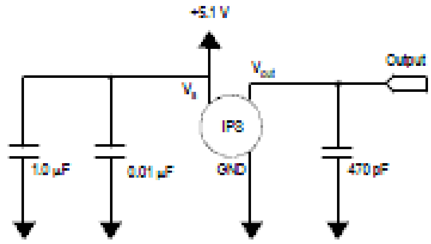


Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1535)

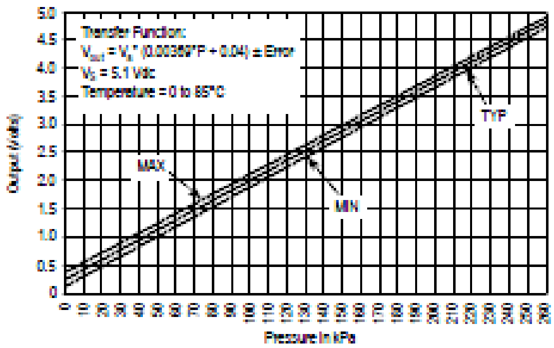
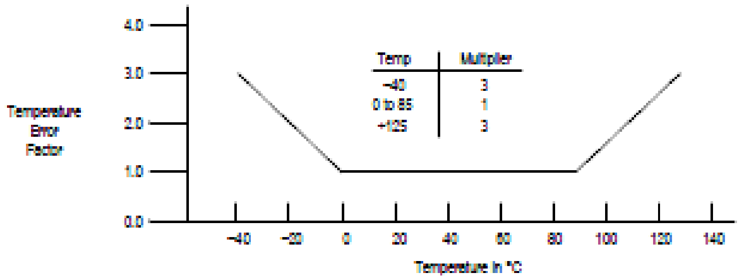


Figure 4. Output versus Absolute Pressure

Transfer Function (MPX4250)

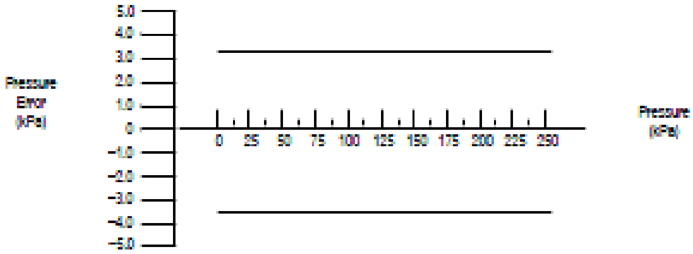
Nominal Transfer Value: $V_{out} = V_S \times (0.00369 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.00369 x V_S)
$V_S = 5.1 \pm 0.25$ Vdc

Temperature Error Band



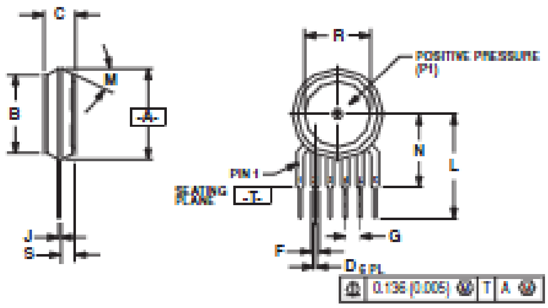
NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 250 kPa	±3.45 kPa

PACKAGE DIMENSIONS



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

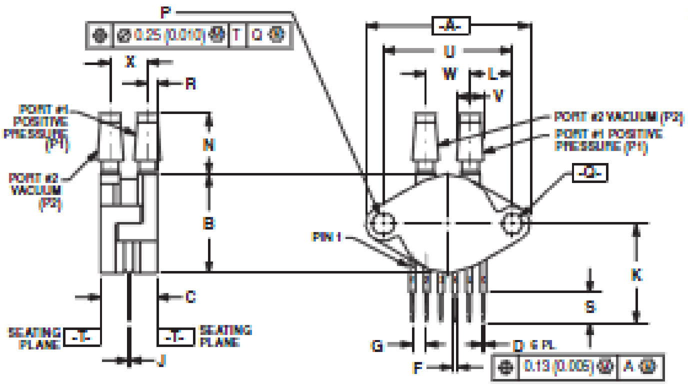
DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
S	0.090	0.105	2.29	2.66

STYLE 1:
PIN 1. VOUT
2. GROUND
3. VCC
4. V1
5. V2
6. VEX

STYLE 2:
PIN 1. OPEN
2. GROUND
3. -VOUT
4. VSUPPLY
5. +VOUT
6. OPEN

STYLE 3:
PIN 1. OPEN
2. GROUND
3. +VOUT
4. +VSUPPLY
5. -VOUT
6. OPEN

BASIC ELEMENT (D)
CASE 867-08
ISSUE N



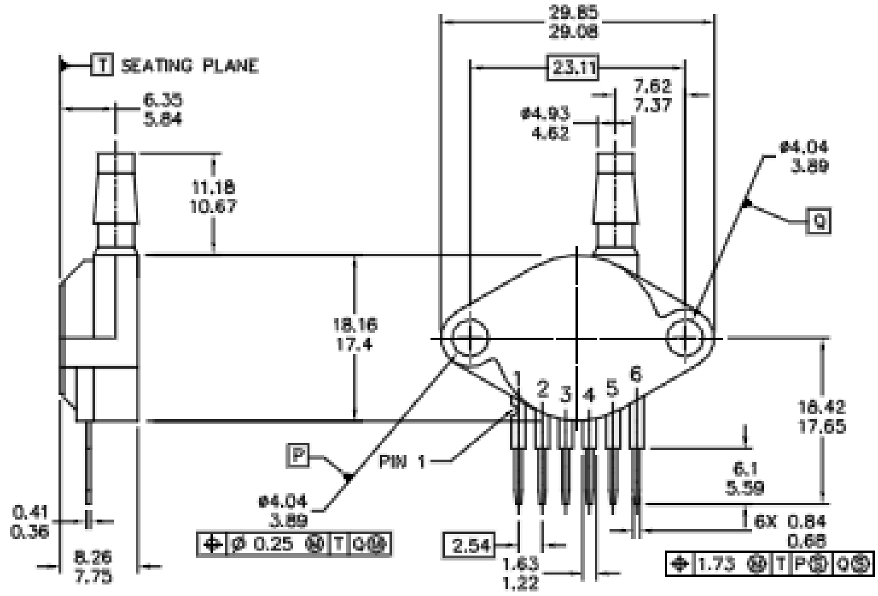
NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.182	0.194	4.62	4.93
W	0.310	0.330	7.87	8.38
X	0.248	0.278	6.30	7.06

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

PRESSURE AND VACUUM SIDE DUAL PORTED (DP)
CASE 867C-05
ISSUE F

PACKAGE DIMENSIONS



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TITLE: SENSOR, 6 LEAD UNIBODY CELL, AP & GP 01ASB09087B	DOCUMENT NO: 98ASB42796B		REV: G
	CASE NUMBER: 867B-04		28 JUL 2005
	STANDARD: NON-JEDEC		

PAGE 1 OF 2

PRESSURE SIDE PORTED (GP)
CASE 867B-04
ISSUE G

PACKAGE DIMENSIONS

NOTES:

1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. 867B–01 THRU –3 OBSOLETE, NEW STANDARD 867B–04.

STYLE 1:

PIN 1: V OUT
2: GROUND
3: VCC
4: V1
5: V2
6: V EX

	MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE
TITLE: SENSOR, 6 LEAD UNIBODY CELL, AP & GP 01ASB09087B	DOCUMENT NO: 98ASB42796B	REV: G
	CASE NUMBER: 867B–04	28 JUL 2005
	STANDARD: NON–JEDEC	

PAGE 2 OF 2

PRESSURE SIDE PORTED (GP)
CASE 867B-04
ISSUE G

APPENDIX F - Motor Driver Relay

HRS4 Series

PCB Power Relays

multicomp

Features:

- SPCO contacts.
- Sealed to allow washing after flow soldering.

Specifications:

Coil Data:

Nominal Voltage	: 3V dc to 48V dc.
Nominal Power Consumption	: 360 to 450 mW.

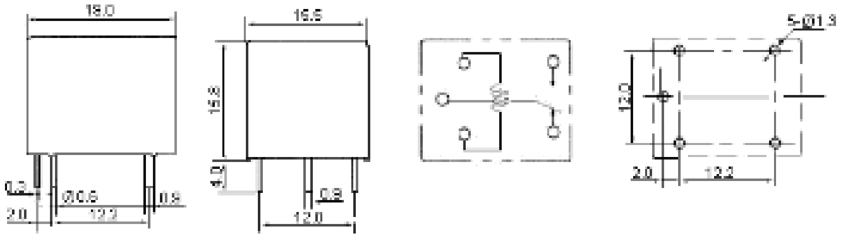
Contact Data:

Contact Arrangement	: 1 Form A , 1 Form C.
Contact Material	: AgCdo.
Contact Rating	: 10A 120V ac/24V dc (1C). 15A 120V ac/24V dc (1A).
Maximum Switching Voltage	: 110V dc/240V ac.
Maximum Switching Current	: 15A.
Maximum Switching Power	: 1800VA , 360W.
Contact Resistance (Initial)	: 50mΩ at 6V dc 1A.
Life Expectancy Electrical	: 100,000 operations at nominal load
Mechanical	: 10,000,000 operations.

General Data:

Minimum Insulation Resistance	: 100MΩ at 500V dc.
Dielectric Strength	: 750V ac , 1 minute between open contacts 1,500V ac , 1 minute between contacts and coil.
Maximum Operate Time	: 8ms.
Maximum Release Time	: 5ms.
Operating Temperature Range	: -30°C to +85°C.
Shock Resistance	: 10G.
Vibration Resistance	: 10 - 55Hz , Amplitude 1.5mm.

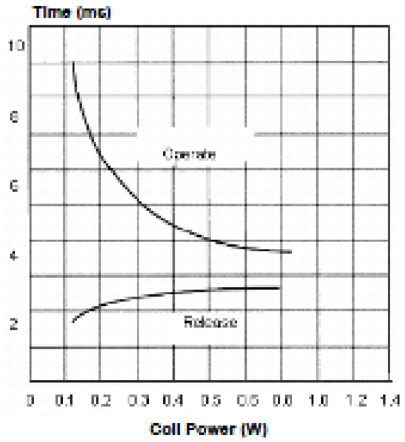
Dimensions



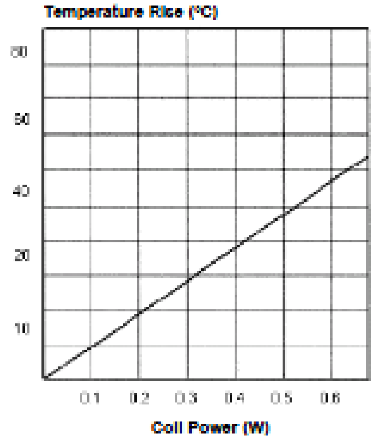
Dimensions : Millimetres

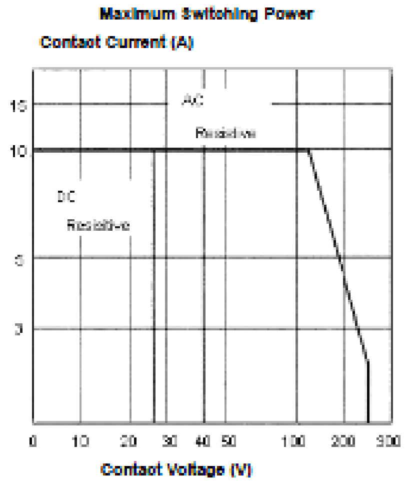
HRS4 Characteristic Data

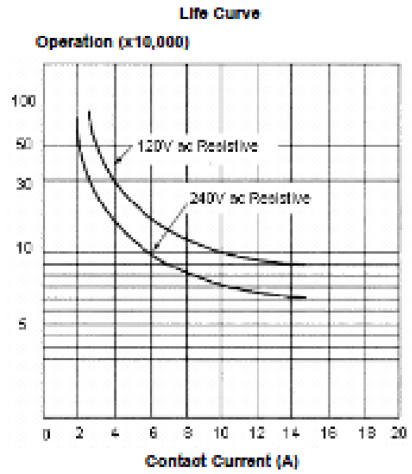
Timing



Coil Temperature Rise







Specification Table

Type	Coil Nominal (V dc)	Coil Resistance (Ω) ±10%	Operate Voltage (V dc)	Release Voltage (V dc)	Coil Nominal (mW)	Part Number
SPCO	5	50	3.75	0.50	450	HRS4-S DC5V
	12	320	9.00	1.20		HRS4-S DC12V
	24	820	18.00	2.40		HRS4-S DC24V

Part Number Explanation

HRS4 - S DC5V

Type | Enclosure | Nominal Voltage

Enclosure : S = Washable.

Nominal Voltage : DC5V = 5V, DC12V = 12V, DC24V = 24V.

Notes:

International Sales Offices:

AUSTRALIA – Farnell InOne	Tel No: ++ 61 2 9645 8888	Fax No: ++ 61 2 9644 7988
AUSTRIA – Farnell InOne	Tel No: ++ 43 662 2180 680	Fax No: ++ 43 662 2180 670
BELGIUM – Farnell InOne	Tel No: ++ 32 3 475 2810	Fax No: ++ 32 3 227 3648
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SPAIN – Farnell InOne	Tel No: ++ 34 93 475 8803	Fax No: ++ 34 93 474 5107
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SWITZERLAND – Farnell InOne	Tel No: ++ 41 1 204 64 64	Fax No: ++ 41 1 204 64 54
UK – Farnell InOne	Tel No: ++ 44 8701 200 200	Fax No: ++ 44 8701 200 201
UK – Buck&Hickman InOne	++ 44 8450 510 150	++ 44 8450 510 150
UK – CPC	++ 44 8701 202 530	++ 44 8701 202 527
[illegible]	Tel No: ++ 44 8701 200 208	Fax No: ++ 44 8701 200 209

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