Underwater Robotics

by

Mohd Fakhrul Amin bin Abd Razak

A project dissertation submitted in partial fulfilment of
the requirements for the Degree
Bachelor of Engineering (Hons)
(Electrical and Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Assoc. Prof. Dr Mohd Noh Karsiti)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
Mei 2011

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.

MOHD FAKHRUL AMIN BIN ABD RAZAK

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ABSTRACT

Underwater Robotics or Remotely Operated Vehicle (ROV) is a project that involves research and implement of the robots prototype. ROV are commonly used in oil and gas industries for pipeline inspection and maintenance which involve dangerous task and high risk environment. Besides that it also used for underwater exploration and research for marine scientist. Due to that, research and development on ROV is important in order to improve and extend the capabilities of the ROV. The scope of study for this project is to design and build a fully working prototype of ROV which involve testing the prototype designed, circuit design and simulation, waterproofing components and programming the hardware. The capability and feasibility of the designed prototype is tested using several methods, for example testing the buoyancy of the ROV by applying the Archimedes principles. The focus of this project is to design build a small working prototype which capable of manoeuvring under the water and do monitoring task using a less degree of complex technologies and with a cheaper cost. The ROV also will be able to send any data to the computer via UART protocol while under the water.

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ABBREVIATION AND NOMENCLATURES

FYP	Final Year Project
ROV	Remotely Operated Vehicle
PVC	Polyvinyl Chloride
I/O	Input Output
Micro-c	Microcontroller
PCB	Printed Circuit Board
HMI	Human Machine interface
Amp	Ampere

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CHAPTER1

INTRODUCTION

1.1 Background of Study

Underwater robotics or Remotely Operated Vehicle (ROV) is a tethered underwater robot which operates manually. They are common in deepwater industries such oil and gas extraction industries. They are usually used to do underwater work such as construction and surveying the underwater pipeline and also involve in oil and gas exploration for oil well. Besides ROV, human also are able to do the same but it only limited to some extent. The reasons of using ROV are because it is cheaper than paying a diver and ROV can go deeper underwater. Besides those, ROVs can works longer than diver could do. ROVs are unoccupied, highly manoeuvrable and operated by a person above water. In industries the ROV usually are linked to ship by a tether, which is a group of cables that carry electrical power, video and data signals for communication between operators and the robots for 2 ways interaction. Most ROVs are equipped with at least a video camera and lights which is used just for surveying purpose. They also have additional devices such as hydraulic arm, metal cutters, sonar sensors and many more.

1.2 Problem Statement

Underwater Robotics is a very general application robot that is used for various in industries. The robots usually do maintenance job such as welding and inspection which is very important for the company to make sure that the plant is always on tip-top condition. Besides that, underwater exploration for scientific research and oil well search is also important for the continuity of the companies' wealth. However when it come to the underwater jobs, it becomes complicated and less effective because it deals with flammable material and chemicals (exp: welding the gas and crude oil pipeline), high water pressure environment, limitation of oxygen gas for human worker, limitation of energy and working time, and unknown potential of underwater hazardous that may occur. So due to these reasons the underwater job is not physically and economically feasible when using human labour. So the most effective solution is used underwater robotics or ROV which is more physically and economically feasible for underwater job especially in oil and gas industries. The more dangerous and the high risk the job is, the more we need to use the underwater robotics. For this project we focus more on completing the prototype and using several method to test the feasibility of the design like applying the Archimedes principle for the determining the buoyancy capability of the designed ROV.

1.3 Objective

Main objective of underwater robotics project is to create a working prototype of ROVs which at least able to do monitoring task under the water and can send any data to the computer and receive any data from computer while under the water. For this project the data will be taken from the accelerometer mounted in the ROV.

1.4 Scope of Study

In this final year project, the project scope is limited to several aspects:

1. Creating a small working prototype of the underwater robots, which at least able to be sink under the water without a water leakage inside the system.
2. Using a cheaper and more commercially available sensors, devices or instruments as part of the robot's system.
3. Making a water proof casing for the instruments and devices of the robots that involved underwater.
4. Putting the entire parts together.

CHAPTER 2

LITERATURE REVIEW

2.1 Underwater Robotics

Underwater robotics and ROV is already been made using various method and technologies for replacing human to do the tedious and hazardous job under the sea. Even though it is already been made, underwater robotics is still on research in order to overcome the problem and weaknesses occurred when using underwater robotics. For example research idea by R. Peter Bonasso [1] says that in order to move and transit, to avoid obstacles, the robot must carry out a set of sensing behaviours which related to the task and it automatically react according instruction, sets using programming. Others are research by Biomimetic Underwater Robot Program [2]. This research is to develop a robot that used neuro-technology, based on the neurophysiology and behaviour of animal models. For example, 8-legged ambulatory vehicle that is based on the lobster and is intended for autonomous remote-sensing operations in rivers and/or the littoral zone ocean bottom with robust adaptations to irregular bottom contours, current and surge. There is also research on pipeline inspection method by using Gamma Ray System Operated by Robots for Underwater Pipeline Inspection [3]. However, all of these development and research ideas involve robots with very high degree of complexity and utilizing the latest technology that is not available to everyone and also expansive. As such, this project proposes doing a similar project without using expensive, high end materials and high technologies.

The underwater robotics development is very crucial nowadays since the needing of underwater technology these days is very significant because of high demand hydrocarbon fuel in oil and gas industries. These technologies now is needed to cover all aspect, which is not just for safety and gain profit but also on emergency and environmental issue like what happen on BP's oil rig recently this year. According to news by allvoices.com, 'On the 20^{th} of April 2010 the BP's horizontal offshore oil rig has been exploded due to human error which cause a billion pounds lost due to a billion dollar oil rig burn to ashes and four million barrels of oil gushing into the Gulf of Mexico, it is becoming the worst oil spill in US history' [4]. Besides that according to magazine article form IEEE Spectrum; 'a dozens of robot have been descended into the Gulf of Mexico' [5] in order to stop the oil spill. From the aftermath of the explosion, the robots have been push to its limit to do whatever it takes to stop the oil from gushing to the seas. Various ideas, techniques and technologies has been put together to put the oil spill to stop. From this phenomenon we can conclude that the research and development of underwater robotics or ROVs is very essential for the future used in any field especially in oil and gas industries.

2.2 Theory of Underwater Robotics

ROV is consisting of two major parts which is the tether management system and the ROV itself. For this project we are focusing more on the ROV.

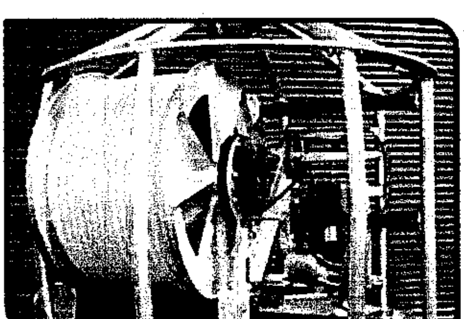


Figure 1: Tether

Figure 2: ROV

ROVs may be large or quite small, depending upon the jobs they are expected to do, but they all have some systems in common [6]:

- Framework on which other components are mounted;
- Flotation so that the ROV is neutrally buoyant (or nearly neutral; this means it doesn't rise or sink when in the water);
- Ballast to keep the robot from rolling over;
- Power to operate motors, video cameras, and other equipment;
- Propulsion to move the robot up and down, side to side, and backward and forward;
- Control to cause the robot to perform certain tasks
- Navigation to keep track of the robot

The most important concept that we need to understand when developing ROV is buoyancy force. Buoyancy force can be explained from the Archimedes Principles which is "Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object" [7].

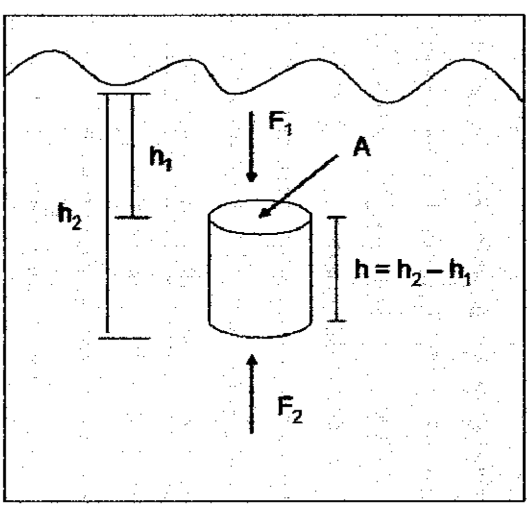


Figure 3: Fully submerge object

Weight of water = Lift Force($F_2 = \rho V g$)
(Displaced)

$\rho V g > M g = (+ve) positive\ bouyancy$
$\rho V g < M g = (-ve) negative\ bouyancy$
$\rho V g = M g = (0) zero\ bouyancy$

$$F = \rho V g - M g \text{ [8]}$$

F_1(Force due to Pressure Head) is ignored for this prototype since it is only designed to descendent not so deep.

Buoyancy Force (Net Force) = F
Mass of ROV in the air = M
Density of liquid = ρ
Gravitational Acceleration = g
Volume of ROV submerge = V

CHAPTER 3
METHODOLOGY

As stated in the previously, the objective of this project is to make a fully working prototype of ROV which at least able to do monitoring job under the water. So for this project the most important concept which is needed to be tested is the buoyancy capability of the designed robot. Comparing method approach is used to test the buoyancy of the ROV. For this project, 2 prototypes have been made to test the buoyancy of the designed ROV. The testing is applying the scientific concept which is Archimedes principle within a controlled simple experiment.

Besides buoyancy other important test also must be done such as water proofing test, safety issues on the ROV, manoeuvrability, complexity of the design, and power usage. The design specification of the prototype is shown on the next sub section.

3.1 Design specification

3. 2.1. Testing prototype "Gen1"

First prototype for testing is called "Gen1" has been made for testing purposes. This prototype is using only 4 dc motor to control the manoeuvrability of the robot. The reason of using dc motors is because dc motors is easy to handle and used only low cost motor driver circuit to control its direction and speed and it is a hope that with dc motor we can get a higher manoeuvrability with low cost. This prototype has been test but it uses the direct connection simple joystick just to test the robot above the water and under the water.

. The system will only consist of body, simple controller and a power supply.

4.3.1. Body

The robot will be using PVC as the structure of the robots body. The reason of using these materials is because these materials are light and easy to construct for the robots structure, it is also strong to withstand a water pressure. The structure has to be light as possible so that the overall density of the robot is low as possible in order to create high net buoyancy (up lift net force of water dispersion) when it is submerge under the water. The body must have a mounting place for the motors and other devices and all the system to be mounted on the body as shown in Figure 4 and Figure 5.

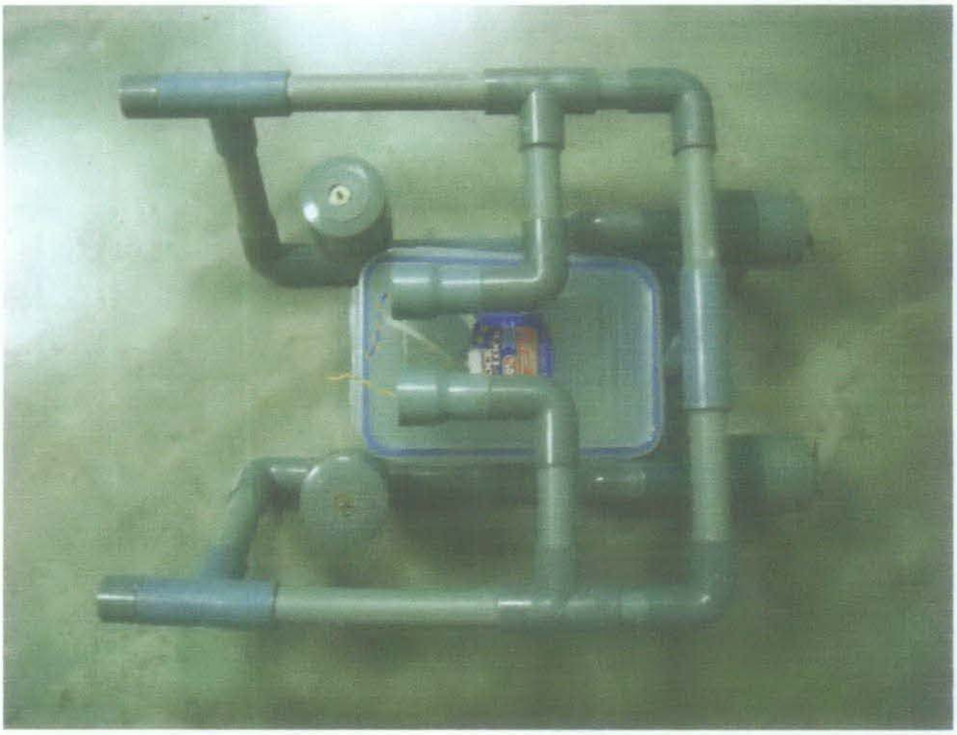


Figure 4: Top view of Gen1 Prototype

Minimum mass M of Gen1 = 3.03kg Actual Volume of Gen1 = to be determine using the Archimedes principle Raft Dimension = Length (42cm) x width (31cm) x high (15cm)

Figure 5: Side and rear view of Gen1 Prototype

3.1.1.2 Output Devices (DC Motors)

The four 24Watt DC motors will be output devices. The motor which attached with propeller will be act as the thrusters for robots to move in 3 dimensions. 2 motors will be attached for horizontal thrusters while the other 2 for horizontal thrusters as shown in Figure 6.

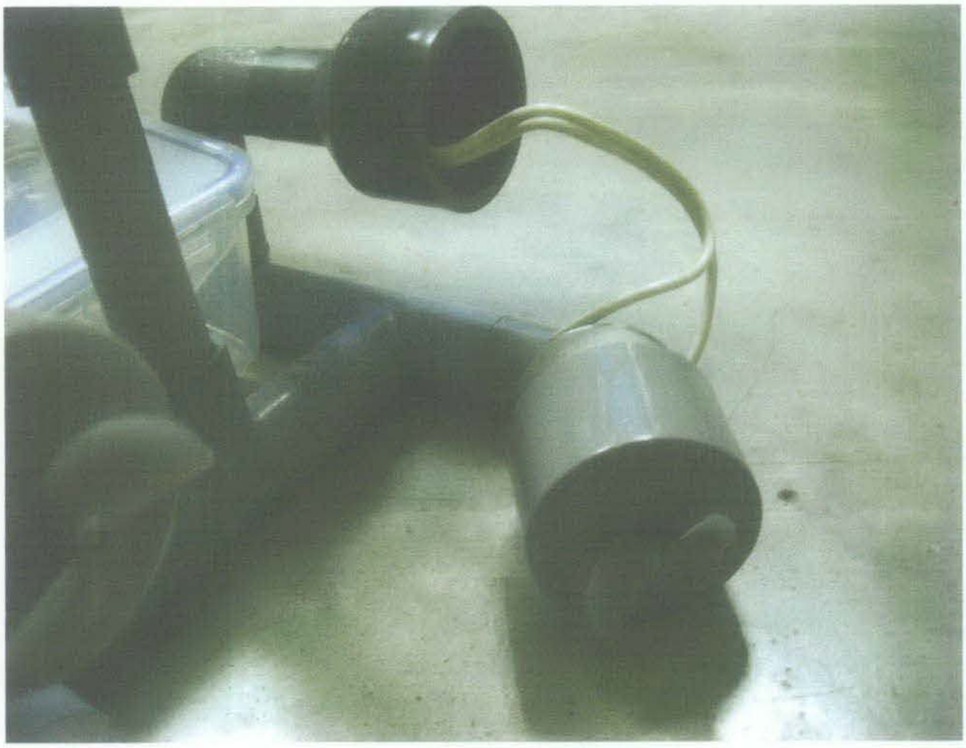


Figure 6: DC Motors for Thrusters

3.1.1.3 Power Supply

The power supply for the board will be optimally 5v dc voltage while the power supply for the motor will be optimally 12v dc voltage. The main source of the power will come from 2 types, first are from the standard house hold ac plug (240V-AC) which than converted to 12v dc for motors and 5v dc voltage for main board using adapters. Second is from the dry cell exp: 12v lead acid battery for motors and 9v battery for main board. The power supply also will be transmitted through suitable cable.

3. 2.2. Testing prototype "Gen2"

The second prototype is called "Gen2" and also has been made for testing purposes, which used different motors as propulsions system. The motors used is AC aquarium pump motors, and is obtain from the lab for the testing purpose only but not for the completion of a prototype. The reason of using AC aquarium pump is because the motors it's self is being design for submersible purpose. The major drawback of this motor is that it is impossible to control the direction and speed of AC motors with a simple motor driver circuit. The motor driver for controlling it will be very expensive and complex to be made. So the feasible way of controlling it is just by ON/OFF the motors without speed controlling and even without the direction controlling using joystick. So due to that we have to used a lot of motors to provide a thrust for each direction in balance which is 2 motors for forward thrust, 2 for backward thrust, 1 for upward thrust and 1 for downward thrust. For this design the motor used is many, bigger and a bit heavier compared to DC motors from Gen1. So due to that a different body has been made in order to suite the motors.

The **detail of the Gen2** testing prototype robots is shown below. The system will only consist of body, simple controller and a power supply.

3.1.2.1 Body

The design of the second prototype "Gen2" is different from Gen1; this is because the shape of the motors is bigger and the mounting is different. So the design should accommodate all motors to be fit with the robots. The numbers of motors used is also increase, so the size of the body should be bigger in order to fit all 6 motors. The robot also is equipped with 2 PVC buoyancy tank to give the robots a low overall density. This is because the buoyancy tank increase the volume of the robots greatly whiles little increase in mass. This is proven with the equation Density = Mass/Volume. The body of the robots with AC motors mounted is shown in Figure 7 and Figure 8.

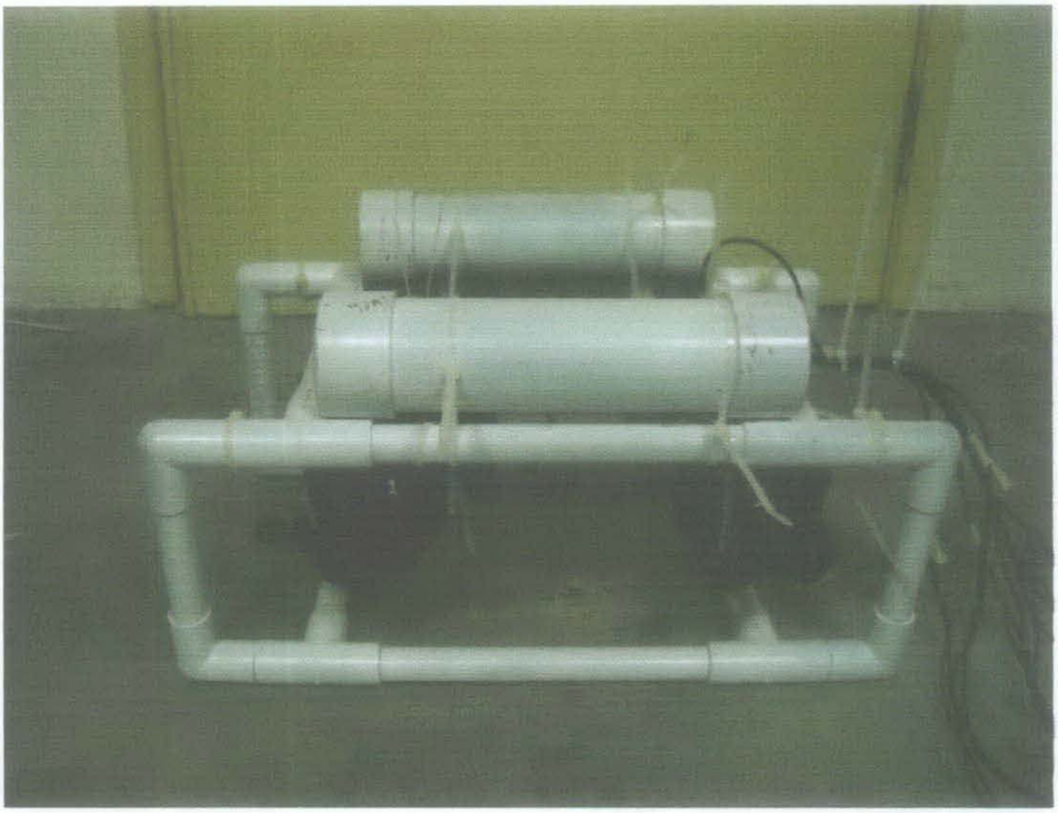


Figure 7: Side View of Gen2 Prototype

Minimum mass M of Gen2 = 6.02kg

Actual Volume of Gen2 = to be determine using the Archimedes principle

Raft Dimension = Length (55cm) x width (31cm) x high (19cm)

Figure 8: Gen2 Prototype with Tether

3.1.2.2 *Output Devices (AC Aquarium pump motors)*

For the output devices will be AC pump motors shown in Figure 10 instead of DC motors. The main reason of using AC pumps motor because it is absolutely water proof. The function of the pump is similar as the DC motor which is used to produce vertical or horizontal thrust for the robots to move. For this prototype we used 6 dc motors which is 4 for horizontal thrust and 2 for vertical thrust.

Specification: Power: 35Watt Typical Voltages: 12V

Figure 9: AC Aquarium Pump

3.1.2.3 *Power Supply*

For this prototype definitely it will used AC power supplied which is directly from the plug. The main concern is the current draw might be too high if the load is too much on the robots. But the fuse will be burned before anything happen.

3.2 The testing of Gen1 and Gen2 prototype

3. 2.1. Buoyancy test

To test the buoyancy of both ROV, first we have to determine the volume of the ROV. The volume can be determined using the Archimedes principle. As stated in the Archimedes principle the volume of water disperse is equal to the volume of the object submerge under the water. For this testing procedure:

- First the ROV is submerging into a small size aquarium Length (0.6m) x width (0.4m) x high (0.4m); the ROV must be fully submerged so that the dispersed volume of water is equal to the actual volume of the ROV.
- Secondly the dispersed water high is than measured.
- Thirdly the measured high will be multiplied with the width and length of the aquarium, the result of the multiplication is the volume of the water dispersed when the ROV is fully submerged. So the obtained volume of dispersed water is the volume of the ROV.
- This steps is repeated for Gen2 prototype

When the volume is obtain we can than calculate the buoyancy force of the designed ROV using the formula stated in the literature review. The result of buoyancy test will be shown and discussed in Chapter 2.

3. 2.2. Water proofing test for motors

For gen1 prototype, it uses a general DC motor which is mainly not designed to use under the water. So this experiment is to confirm that whether DC motor can work underwater without proper waterproofing or not. In this simple experiment setup, 4 naked motors attached with propeller (no water proof casing at all) used for the ROV is putted under the water and the motor is being powered directly from the AC-DC (12v) adapter. For gen2 prototype it uses 6 AC aquarium pump motors. Since the motor is designed for water proofing, so it is expected that it will turn on perfectly under the water. The result of motors water proofing test for both ROV will be shown and discussed in Chapter 2.

3. 2.3. Manoeuvrability test

For manoeuvrability test, both ROV will be test to move under the water. A simple on and off control circuit interfaced with relay is developed just to control the movement of both ROV. The result of manoeuvrability test will be shown and discussed in Chapter 2.

3. 2.4. Power consumption test

For Gen1, 2 types of power supply are also being compared. The 2 power supplied used for Gen1 is adapter 240VAC-12VDC and dry cell. For Gen2, since it uses AC aquarium pump motor, so it will use a direct 240v power supply form the household plug. The power consumption can be calculated easily using P=IV formula.

3.3 Procedure Identification

In ensuring the smoothness of project execution, all required procedures are identified. The procedures are listed below:

1. Do research and study on the project

   A lot of information and fact is needed to obtain before we do any work on the ROV. An extensive research on the internet and journals should be enough in order to grab a basic understanding on how to make a prototype of ROV. Besides that a research on the material need to be used and are available nearby, is also crucial so that those items can be obtained easily.

2. Construction

   Construction work should be done on the basic parts first such as the body of the robot and the I/O devices which need to be attached to the robot. All the devices attached must be made or readily waterproof so that it can work perfectly under the water. After the basic part, we than can continue to the more complex part which is the controlling part (circuit board) and interfacing of the I/O devices and communication system.

3. Testing

   After the basic construction complete the system should be tested by parts for example we could test the buoyancy of the body first before we can test the other parts such as controlling. If the testing is failed we should repeat step 1 or step 2 or both until we get a desired result. The desired result is supposed to meet the objective such as able to manoeuvre under the water.

3.4 Procedure Flowchart

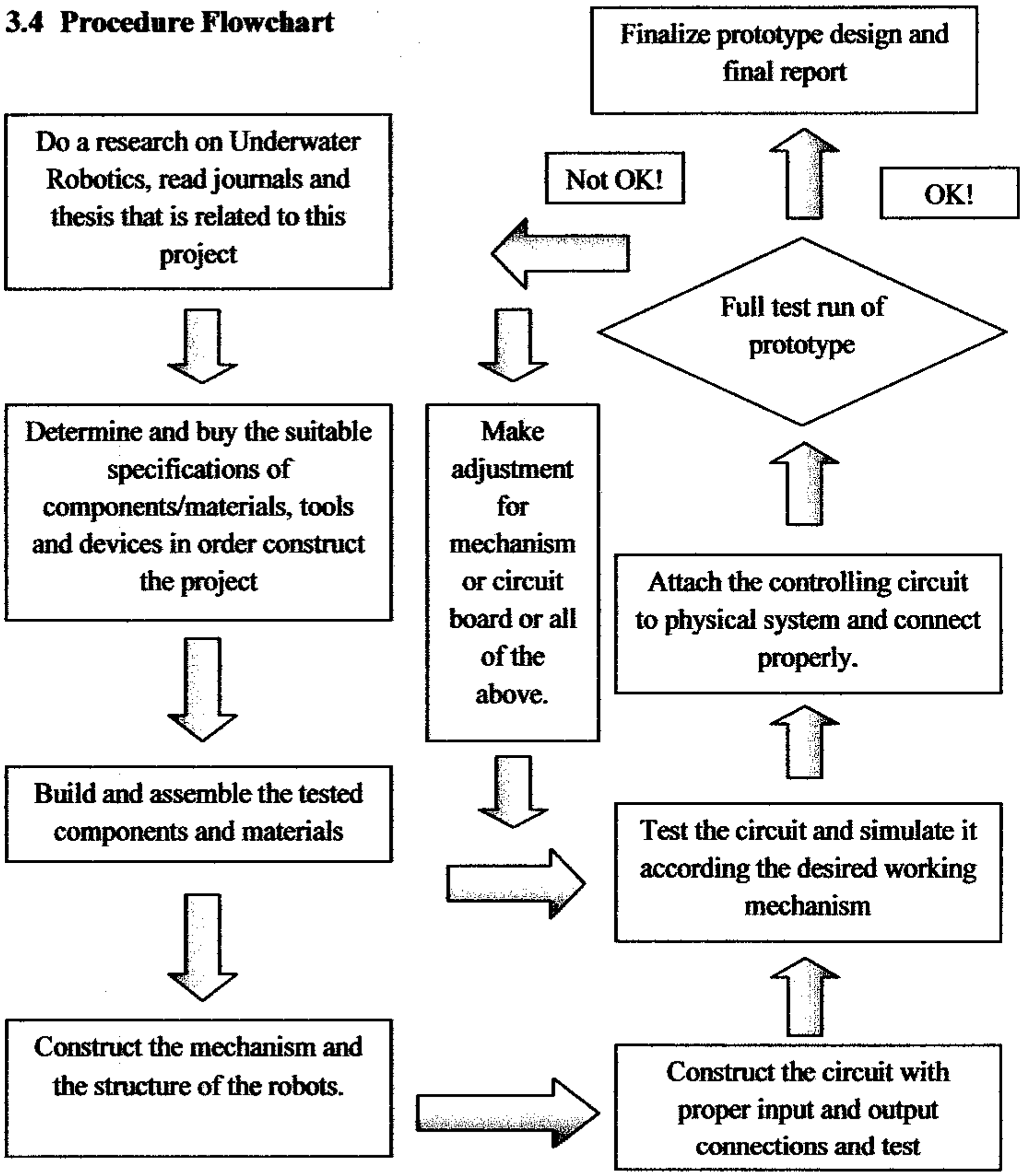


Figure 10: Flow Chart of Project

3.5 Tools and Equipment Used

3. 2.1. Tools used

1. Multi-Meter

   Used to check the connection, signals and voltage of supplied to the robot.

2. Solder gun and soldering iron

   Used to make connection between I/O devices and the electrical network in the robot

3. Small size aquarium

   Used to obtain the volume of ROV

3. 2.2. Software Used

1. MPLAB IDE (C, asssambly), PCW C Compiler IDE(C), Arduino Alpha (C)

   This software is used to program the microcontroller PIC chip and Atmel Mega chip.

2. PICKit2, WinPICProg

   This software is used to download the compiled hex file from IDE software to microcontroller.

3. Proteus ISIS & ARES

   ISIS is used to design the main board circuit and motor driver circuit and then simulate it. Than ARES is use for design a PCB routing of the designed board, either using auto routing or manual routing.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Findings:

On the first semester a lots of research and testing has been done in order to get a general idea of working prototype with a good manoeuvrable capability and also high buoyancy as possible. So on the first semester until now there a few prototypes have been done in order to test the best possible design and ROV system that fits the criteria below:

- **Cost**: Should be as cheap as possible
- **Size and weight**: Should be small and light as possible for higher buoyancy
- **Functionality**: Efficient and reliable in manoeuvring
- **Material availability**: Should be available, easy, and not too costly to get.
- **Robust system**: Fast responses, and high durability

4.2 Testing Result "Gen1":

After the simple experiment is done, the result is noted and analyze in this section. Besides that there are few unexpected problem has been indentify which also will be analyze.

4.2.2 Buoyancy test result

Buoyancy Force for Gen1:
The Buoyancy force of a submerged object lowered through wave zone is:

$$F = \rho V g - Mg$$

Buoyancy Force = F
Mass of ROV in the air = M
Density of liquid = ρ
Gravitational Acceleration = g
Volume of ROV submerge under water = V

Minimum mass M of Gen1 = 3.03kg

Density (ρ) of tap water at 27°C = 998.2 kg/m^3 or 0.9982g/cm^3

g = 9.81 m/s^2

Volume of Gen2 = 0.00334m^3

$$F = \rho V g - Mg$$

$$F = 998.2(0.00334)(9.81) - 3.03(9.81)$$

$$F = 2.9452N$$

4.2.3 Water proofing test results for motors

As a result of motors water proofing test, the motor is actually moved without a problem and it gives a quite amount of thrust from the spinning of the propeller. So from here we can conclude that the motor doesn't have any problem when working underwater without proper waterproofing, and this is actually a major finding on deciding what the best prototype design is.

4.2.4 Manoeuvrability test result

For gen1 prototype, the manoeuvrability is good. This is because this prototype is light and small in volume compared to Gen2, so this will lessen the inertia and water drag effect of the ROV, which result in good manoeuvrability. Besides that since it uses 4 motors only, but still give a good manoeuvrability so it is a very efficient design in controlling the movement of the robots. The problem of the robot is it has less balance in the design. For this problem it can be overcome by adding the buoyancy tank for balancing it left or right, or front or rear.

4.2.5 Power consumption test result

- For adapter 240VAC-12VDC:
  - The power supplied by adapter is high and can coup with the demand of the loads of the motors such as increasing load will increase the current demand of the motor if motor speed is constant. This actually will give a high range of maximum thrust force for the ROV. The maximum possible supplied current is very high form the adapter which is up to 8A compared to dry cell, so it will be dangerous to the devices if the load is too high, and also dangerous of leakage current.

- For dry cell:
  - The power supplied by battery is not that high and the max current supplied is very limited to the current rating of the battery which is 4.5AH as an example of lead acid battery. So using a battery is much safer for the surrounding and the motor driver circuit, since maximum current can supplied is much lower. The typical current needed to move a motor under the water is 2.12A and it is actually enough to produce a thrust but the maximum thrust possible will be low. Besides that for ROV the movement speed of ROV is not really important, what more important is the manoeuvrability of the ROV which can also achieve even though with low movement speed and the safety of the surrounding system. Since maximum motor used is 4 than:

$$I = 2.12\,Amp \times 4$$

$$I = 8.48 Amp$$

4.3 Testing Result "Gen2":

After the simple experiment is done, the result is noted and analyze in this section. The result will be compared to the Gen1 result to determine what is the best design.

4.3.1. Buoyancy test result

Buoyancy Force for Gen2:
The Buoyancy force of a submerged object lowered through wave zone is:

$$F = \rho V g - Mg$$

Buoyancy Force = F
Mass of ROV in the air = M
Density of liquid = ρ
Gravitational Acceleration = g
Volume of ROV submerge under water = V

Minimum mass M of Gen2 = 6.02kg

Density (ρ) of tap water at 27°C = 998.2 kg/m^3 or 0.9982g/cm^3

g = 9.81 m/s^2

Volume of Gen2 = 0.00630m^3

$$F = \rho V g - Mg$$

$$F = 998.2(0.0063)(9.81) - 6.02(9.81)$$

$$F = 2.6355N$$

4.3.2. Water proofing test results for motors

Good water proofing for the propulsion system, this is because, by using the AC aquarium pump the water leakage to the motors is nothing to worry about since the pump is made for submersible purpose.

4.3.3. Manoeuvrability test result

The manoeuvrability is bad mostly due to the weight of the robot. The buoyancy is not a problem since we can add stuff to add the volume. But for the manoeuvrability it is a bit slow especially when turning due to its inertia properties and size which increases the water drag or resistance.

4.3.4. Power consumption result

Power consumption is high for this prototype. This is because it used lots of motor which is six motors for controlling the movement direction.

Specification:
Power: 35Watt
Typical Voltages: 12V

$P = IV$

So the typical current which needs to be supplied is:

$$I = \frac{P}{V}$$

$$I = \frac{35W}{12V}$$

$$I = 2.9167Amp$$

Since, the maximum motors that will be ON simultaneously for manoeuvring is 5 so it Max current would be:

$$I = 2.9167\ Amp \times 5$$

$$I = 14.58333\ Amp$$

And besides that since the motor can controlled for ON/OFF only and not the speed and direction so the motors will use a maximum power possible when it is ON. Since the this prototype used AC current so it is very big and when it's ON especially when 3 motors are ON at the same time it will used maximum power since we cannot control the speed. Due to all this factors it shows that it is really not a feasible design and not efficient on power usage for the ROV. Since it uses 6 AC aquarium pumps so it will be more expansive than using four DC motors. One AC aquarium pump is already more expensive than a single DC motors. So it is really not economically feasible.

4.4 Comparison result, "Gen1" VS "Gen2"

From the result obtain in part 4.2 and 4.3 we can make comparison between this two testing prototypes which is "Gen1" and "Gen2". The comparison is shown in the table below

Gen1	**<< Prototype >>** **Categories**	Gen2
Not a perfect water proof casing for the motors but can still work underwater	**Water proofing casing for thrusters**	Very good water proof motor casing
Small and light, so less inertia and water resistance	**Size and weight**	Big and heavier, so high inertia and water resistance
High buoyancy (High net upward force)	**Buoyancy**	Slightly lower than Gen1 but can be improve easily
Low cost in raft estimation	**Material Cost**	High cost in raft estimation
Good power usage efficiency	**Efficiency**	Bad power usage efficiency
4 controllable speed and direction motors	**Manoeuvrability**	6 controllable ON/OFF only motors
Safer because it uses dry cell as source of power	**A safe system?**	Not safe, since using an AC current which has a very high leakage current
Considering all categories it is a highly feasible design of ROV	**Feasibilities**	Considering all categories it is a low feasible design of ROV

Table 1: "Gen1" VS "Gen2"

So from the comparison it is concluded that the "Gen1" design is very feasible and a good choice for making ROV.

4.5 Circuit Modelling

4.5.1 Main Board / Micro Controller Unit (MCU) / Receiver Circuit Design

The main board is design to act as an interface between Microcontrollers (Micro-c) and other interface circuit or simple I/O devices. The microcontroller will act like a brain which control the robots according to our program burned in the microcontroller. The 5v supplied for the main board are obtain from the UART communication line or from the 9V battery through LM7805 voltage regulator or both.

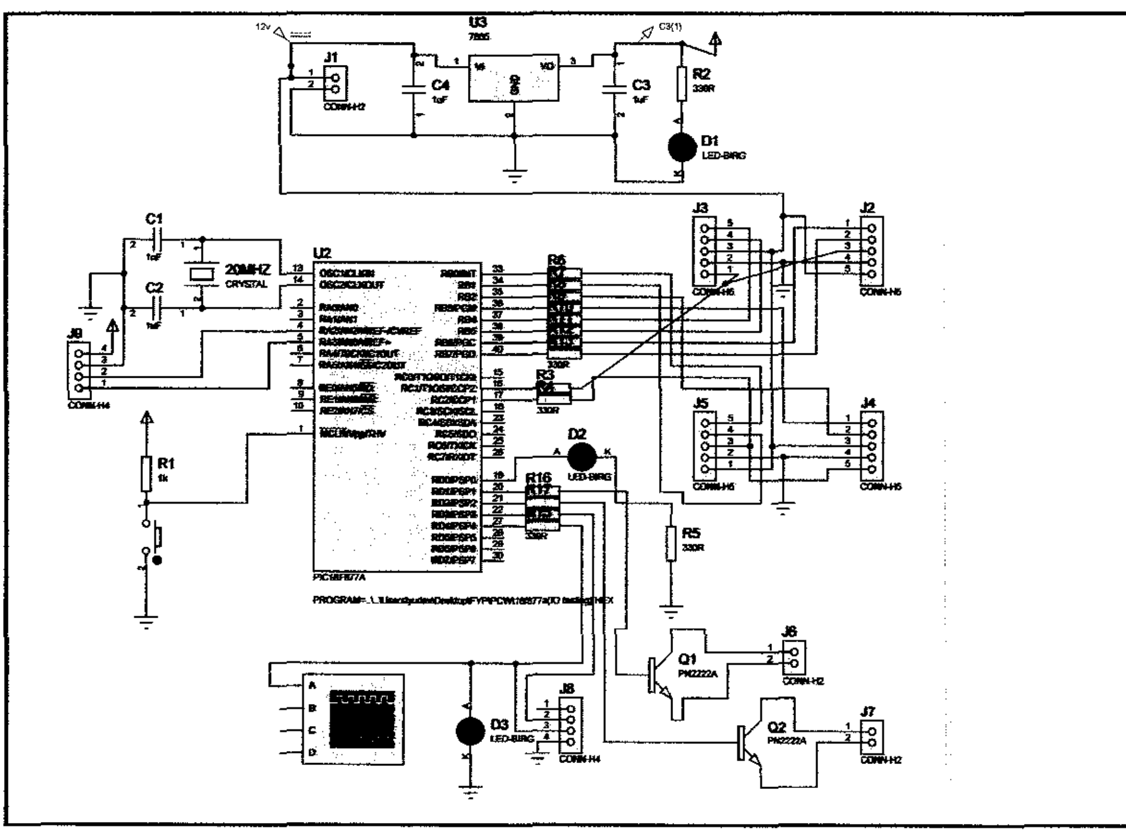


Figure 11: Microcontroller Unit (MCU) design and simulation

The circuit is design and simulated using Proteus ISIS V7.0. Simulation is very important to ensure that the circuit design is working according to the design specification. To simulate the circuit, the microcontroller must be programmed first using PCW CCH compiler programming software to create the source code. The circuit design must be inserted with the programming source code in order to work accordingly. Figure 9 below shows the snapshots of source code development for the simulation.

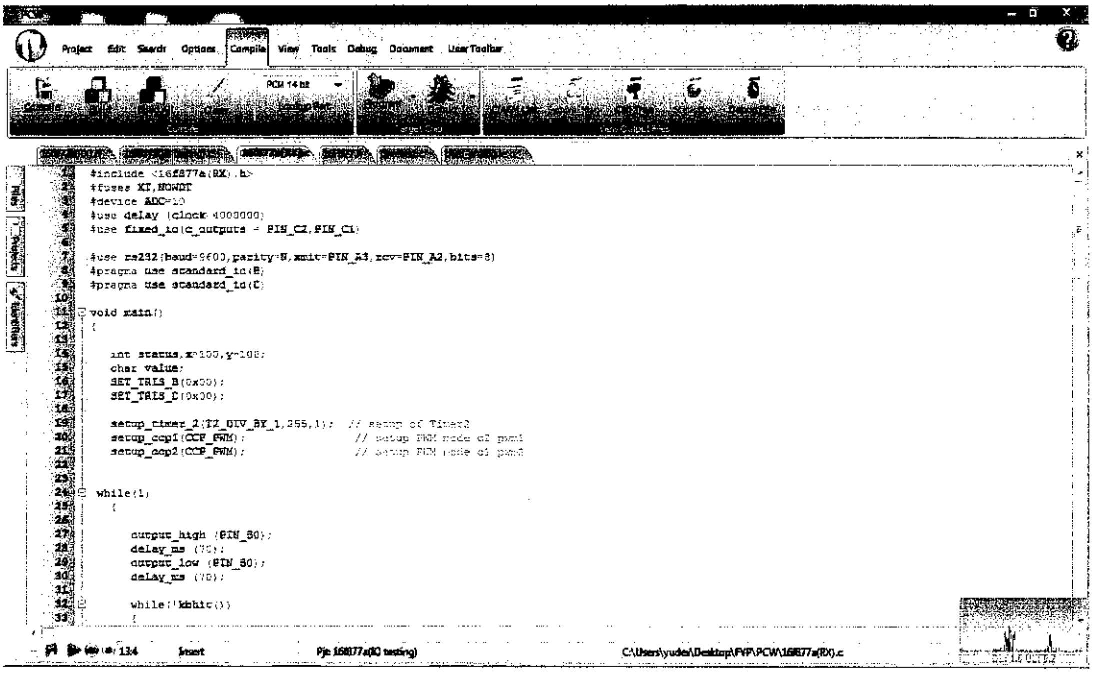


Figure 12: PCW CCH Compiler programming software

4.5.2 Motor Driver Design

Motor driver is a circuit which act as an interface between the MCU and the motors for controlling the speed or direction or both. The important factors which need to be considered before designing a motor driver is:

- The maximum current which the motor driver needs to handle
- The amount of motors need to be control for a single motor driver
- The typical voltage supply for the motor driver and motors which need to be control
- Numbers of input which need to be feed to the drivers from Micro-c.

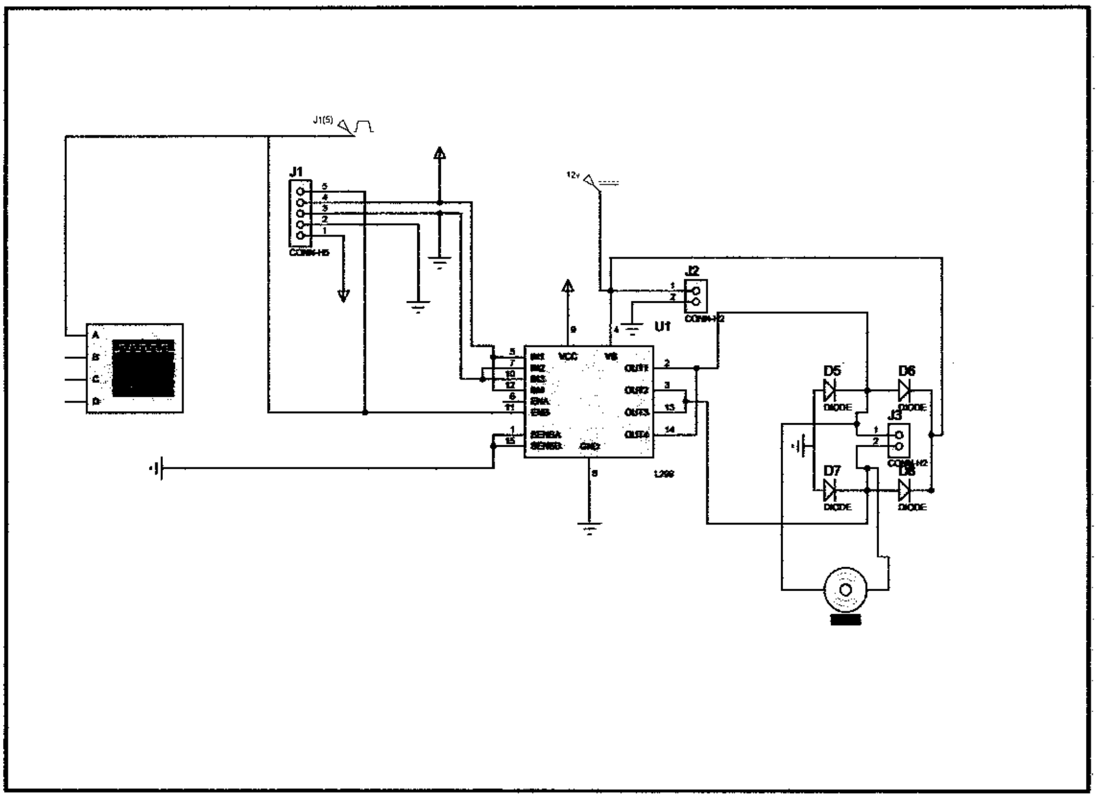


Figure 13: Motor driver circuit design and simulation

For this motor driver the specification is:

- 4A maximum current rating that the motor driver can handle
- Handle only one 12V DC brushed motor for each motor driver
- Interfaces the microcontroller for controlling both direction and speed
- Typical voltage supplied for motors is 12V and motor driver is 5V
- The input signal from the MCU will be PWM, RUN1 and RUN2. But the signal will need a common ground for reference of voltage signal so add one more ground pin and 5v pin for power up the motor driver circuit.

4.5.3 PCB design

After all circuit design are done and simulation are successful accordingly then the board must be constructed in printed circuit board (PCB) format. The PCB is design using Proteus ARES V7.0.

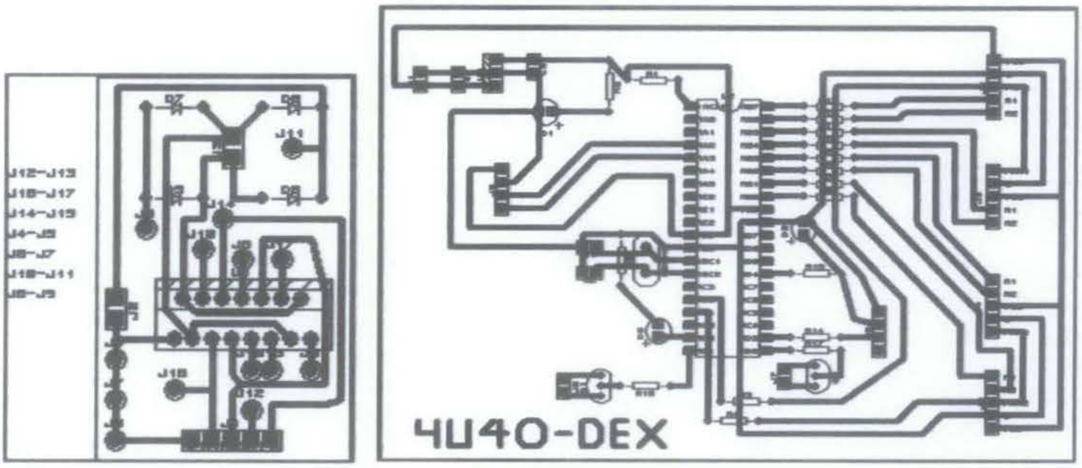


Figure 14: PCB design for motor driver and MCU

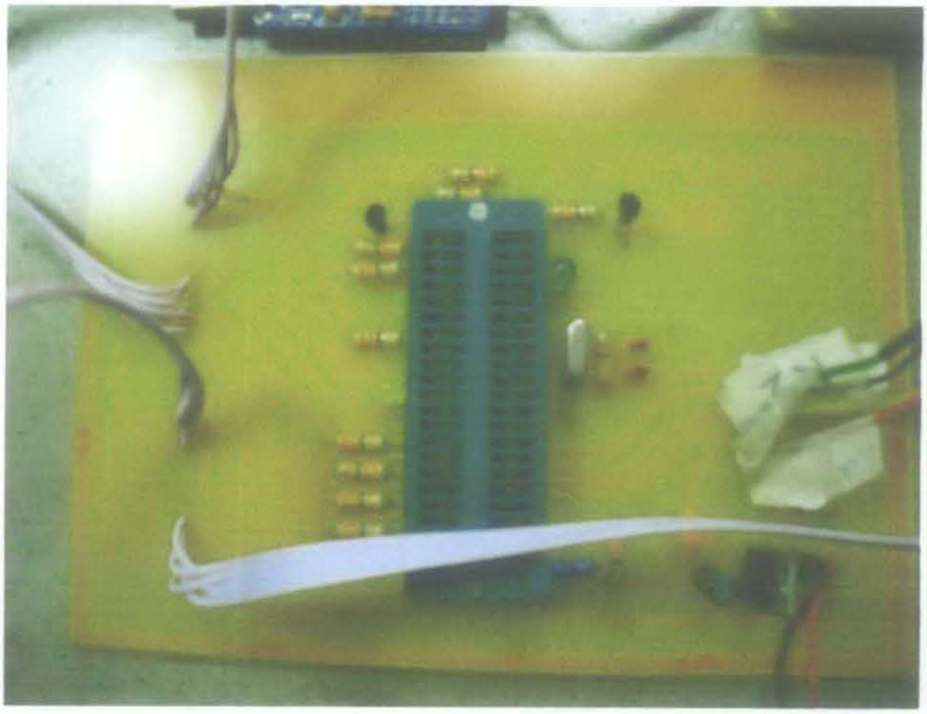


Figure 15: Completed MCU PCB design

4.6 The Programs

The language used for programming the microcontroller is C. The program shown is used for the testing purpose of the prototype system. This program must include header file for example "#include <16f877 (RX).h>" which is must generated earlier or obtain from the libraries before generating the main program shown below.

```
#include <16f877(RX).h>
#fuses XT,NOWDT
#device ADC=10
#use delay (clock=4000000)
#use fixed_io(c_outputs = PIN_C2,PIN_C1)

#use rs232(baud=9600,parity=N,xmit=PIN_A3,rcv=PIN_A2,bits=8)
#pragma use standard_io(B)
#pragma use standard_io(D)

void main()
{
  int status,x=100,y=100;
  char value;
  SET_TRIS_B(0x00);
  SET_TRIS_D(0x00);

  setup_timer_2(T2_DIV_BY_1,255,1); // setup of Timer2
  setup_ccp1(CCP_PWM);              // setup PWM mode c2 pwm1
  setup_ccp2(CCP_PWM);              // setup PWM mode c1 pwm2

 while(1)
  {
    output_high (PIN_B0);
    delay_ms (70);
    output_low (PIN_B0);
    delay_ms (70);

    while(!kbhit())
    {
    do
    {
      value=getc();
      if (value=='1')
      {
```

```
    while(value=='1')
    {
    x=x-2;
    output_high (PIN_B4);
    delay_ms (x);
    output_low (PIN_B4);
    delay_ms (x);
    //value=getc();
    set_pwm1_duty(50);       // adjust duty cycle
    value=0;
    }
  }
  else if (value=='2')
  {
    while(value=='2')
    {
    y=y-2;
    output_high (PIN_B5);
    delay_ms (y);
    output_low (PIN_B5);
    delay_ms (y);
    //value=getc();
    set_pwm1_duty(100);       // adjust duty cycle
    value=0;
    }
  }
  else if (value=='3')
  {
    while(value=='3')
    {
    output_high (PIN_B6);
    delay_ms (100);
    output_low (PIN_B6);
    delay_ms (100);
    //value=getc();
    set_pwm1_duty(150);       // adjust duty cycle
    value=0;
    }
  }
  else if (value=='4')
  {
    while(value=='4')
    {
    output_high (PIN_B7);
    delay_ms (100);
```

```
        output_low (PIN_B7);
        delay_ms (100);
        //value=getc();
        set_pwm1_duty(200);      // adjust duty cycle
        value=0;
        }
      }
      else if (value=='5')
      {
        while(value=='5')
        {
        output_high (PIN_B7);
        delay_ms (100);
        output_low (PIN_B7);
        delay_ms (100);
        //value=getc();
        set_pwm1_duty(255);      // adjust duty cycle
        value=0;
        }
      }

      else
      {
      value=0;
      output_high (PIN_D1);
      delay_ms (100);
      output_low (PIN_B1);
      delay_ms (100);
      x=100;
      y=100;
      }


    } while (0); //RS232_ERRORS will be 0 when there is a timeout
    }
  }
  }
```

4.7 The Final design "Aqua Drone"

Figure 16: Aqua Drone

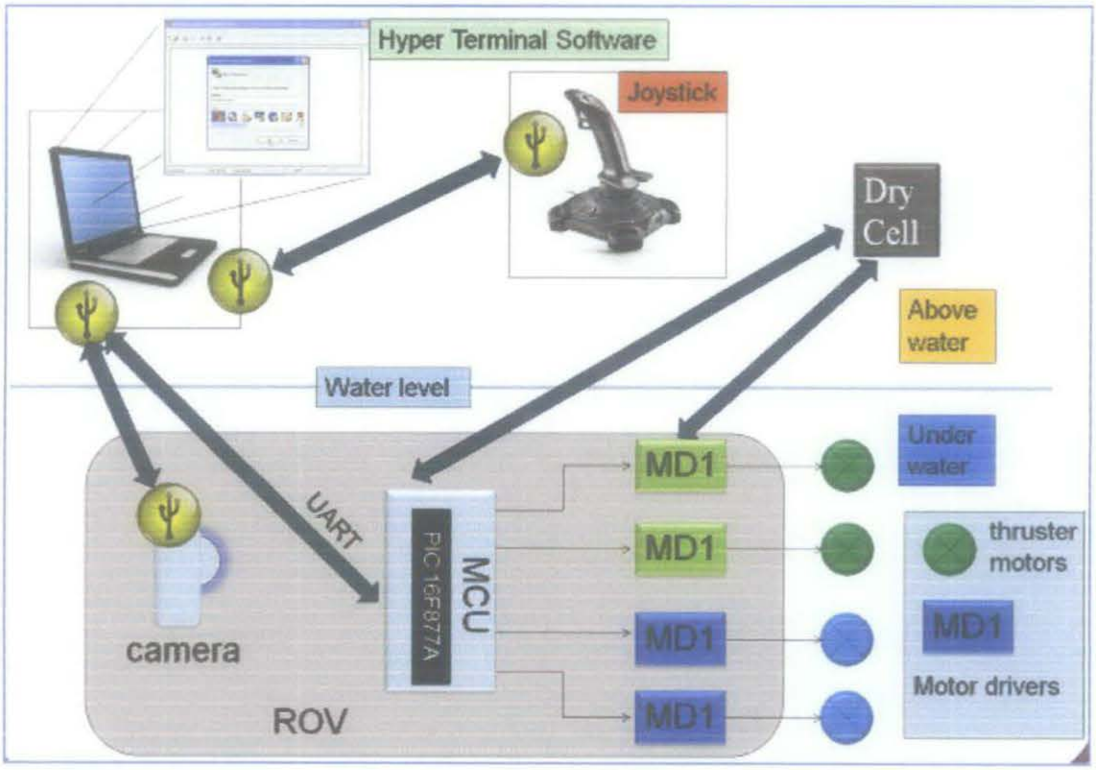


Figure 17: Basic System Environment, of "Aqua Drone"

4.7.1. *Body of Aqua Drone*

For the final prototype "Aqua Drone" it is decided to use the "Gen 1" prototype as the base. The buoyancy tank and the available weighing are added to adjust the buoyancy until it is slightly positive.

Buoyancy Force for Aqua Drone:
The Buoyancy force of a submerged object lowered through wave zone is:
(Using the same formula)

$$F = \rho V g - M g$$

Minimum mass M of Aqua Drone = 5.13kg

Density (ρ) of tap water at 27°C = 998.2 kg/m^3 or 0.9982g/cm^3

g = 9.81 m/s^2

Volume of Gen2 = 0.00537m^3

$$F = \rho V g - M g$$

$$F = 998.2(0.00537)(9.81) - 5.13(9.81)$$

$$F = 2.2377N$$

4.7.2. *Output Devices*

For the output devices, it will be four 24 Watt DC motors and two torches light. 2 motors are used for horizontal thrusting and other 2 for vertical thrusting. The torch light is used for lighting the front area to ease the camera to take picture and video.

4.7.3. Input Device

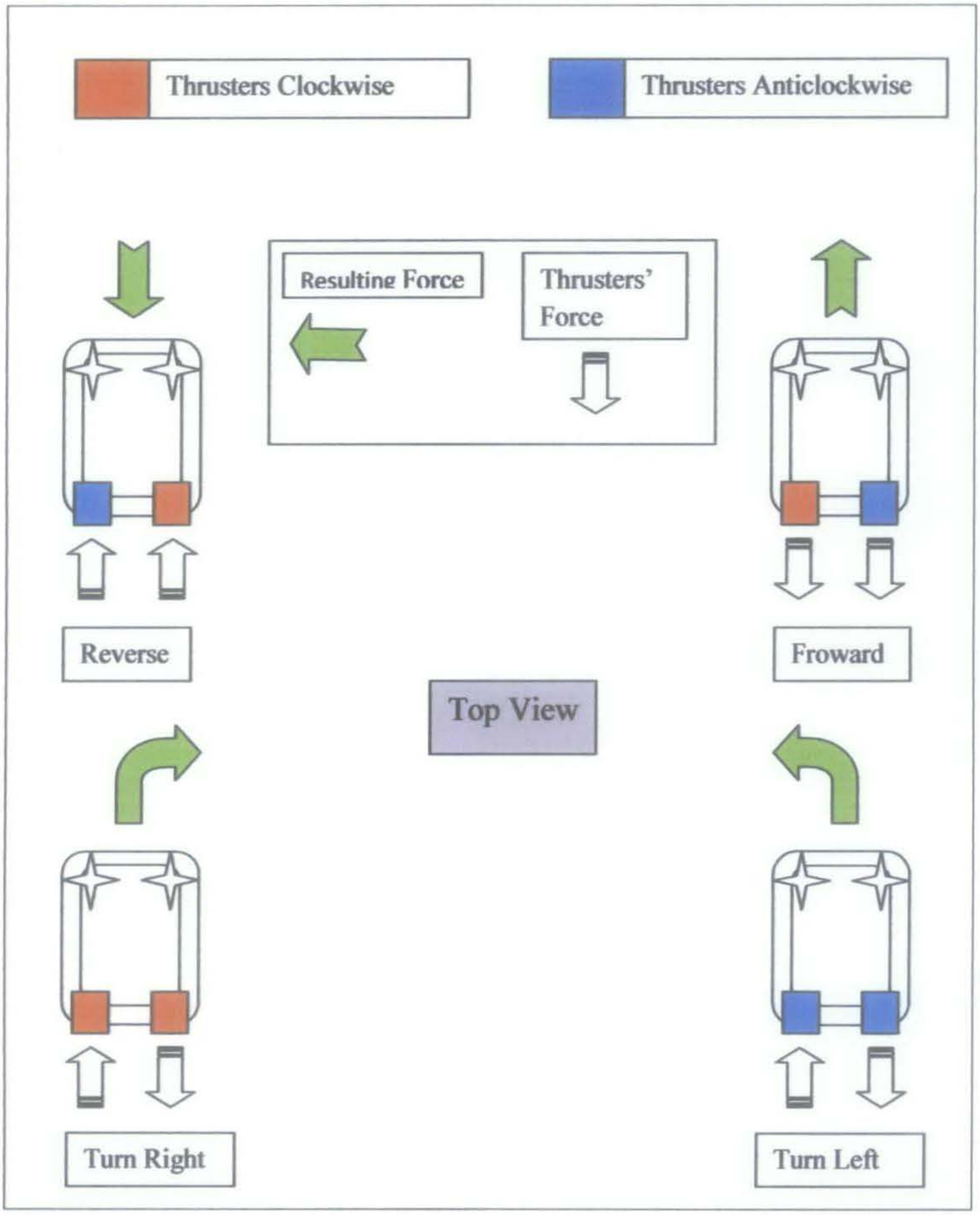
For the input devices, it will be small video camera and accelerometer. The webcam will act as eyes for the operator in order to navigate the ROV. The accelerometer is used to obtain the acceleration data of the ROV when moved.

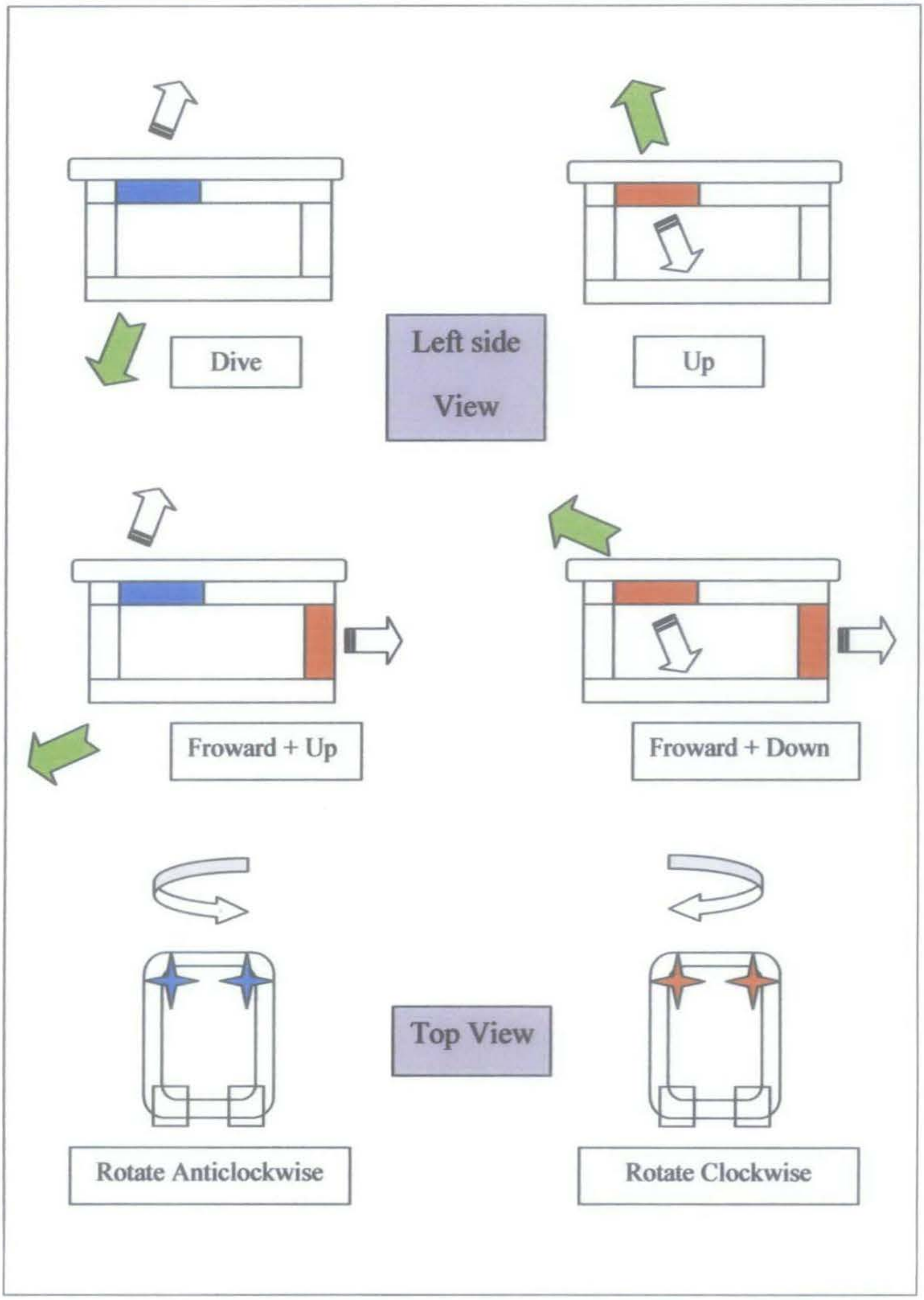
Figure 18: Web Camera

Figure 19: Accelerometer

4.8 Motion Algorithm design for Aqua Drone

A different combination of thrusters' movement will create balance and steady manoeuvrability of the ROV. The rotation of thrusters depends on the orientation of the blade.




Dive
Left side View
Up
Froward + Up
Froward + Down
Top View
Rotate Anticlockwise
Rotate Clockwise

4.9 Data mapping and acquisition

The accelerometer gives analogue voltage signal from 0 – 5v. Since the raw count is 8 bit there are 256 characters, so the resolution that we can get is:

$$Resolution = \frac{5v}{256} = 0.019 \approx 0.02v/raw\ count$$ (For simplicity)

256 raw counts give a low resolution of 0.02v/raw count; this will give a small error to the measured acceleration. For example when the measured value of accelerometer voltage signal is 0.029v then it will read as 0 raw count (as mapped to 0.02v), which give error of -0.009v, when the measured value is 3.916v then it will read as 201 (as mapped to 3.92v) which give error +0.004v.

From this small error, a significant error will occurred when this data is being cumulated. This is because when accumulating a data the error will be sum up due to each data with its error. This significant error due to accumulation is called "cumulative error".

$$cumulative\ (data\ signal_n + significant\ error_n)$$
$$= (data\ signal_1 + error_1) + \cdots + (data\ signal_n + error_n)$$

For this accelerometer the value of zero reference is differs in varied ambient temperature. So we need to choose the value carefully so that the data won't have zero offset. Besides that data acquisition also depends on the speed of the microcontroller. Speed of microcontroller is depends of the crystal clock used it its clock cycle. For this ROV the microcontroller used 20Mhz crystal clock and need for clock cycle to complete one instruction cycle, so max speed is20Mhz/4 = 5mhz. Simple experiment is conducted for testing the sensitivity and data acquisition of the accelerometer. The data is show next page.

4.10 Data collected, for accelerometer sensitivity and data acquisition testing

The data collected is from a simple experiment to test the sensitivity of the accelerometer. The experiment is conducted by lowering the robot into the water in the wave tank, let it stop on the surface of the wave tank for a while and then pull it up again. The data is than tabulated in the Microsoft excel and plotted using the excel function. The original graph from a raw data is shown below. The vertical axis is the 8 bit ADC value or 256 raw count value computed from the accelerometer while the horizontal axis, is time along the experiment.

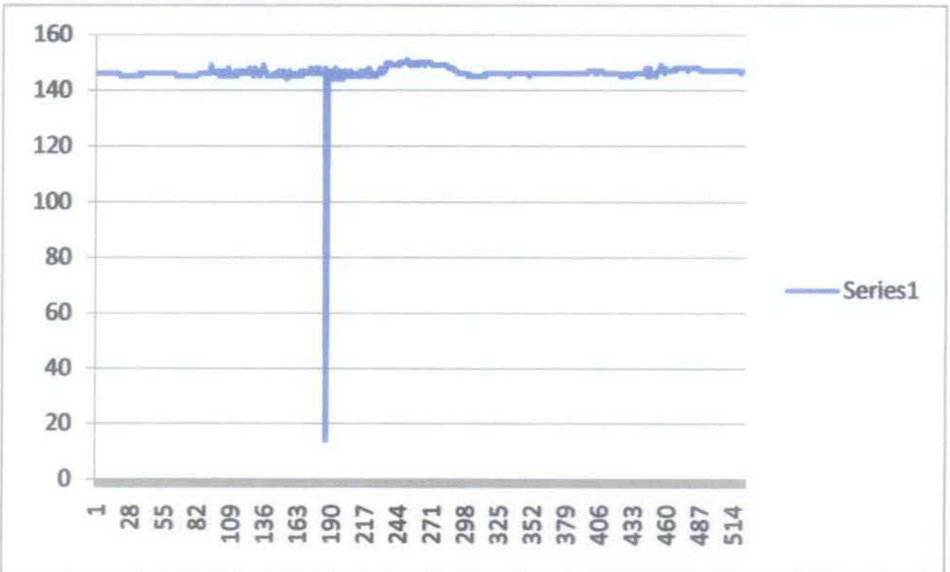


Figure 20: Original graph from a raw data of acceleration

Form the graph above the zero value of acceleration is 146; this raw data is then computed using formula formulated in the excel,

$$Raw\ count\ Acceleration = Raw\ data - 146$$

The graph shown below is the computed graph form the original data. Positive value is when the accelerometer is accelerating parallel to the gravitational magnitude vector (downward). Negative value is when the accelerometer is accelerating opposite to the gravitational magnitude vector (upward).

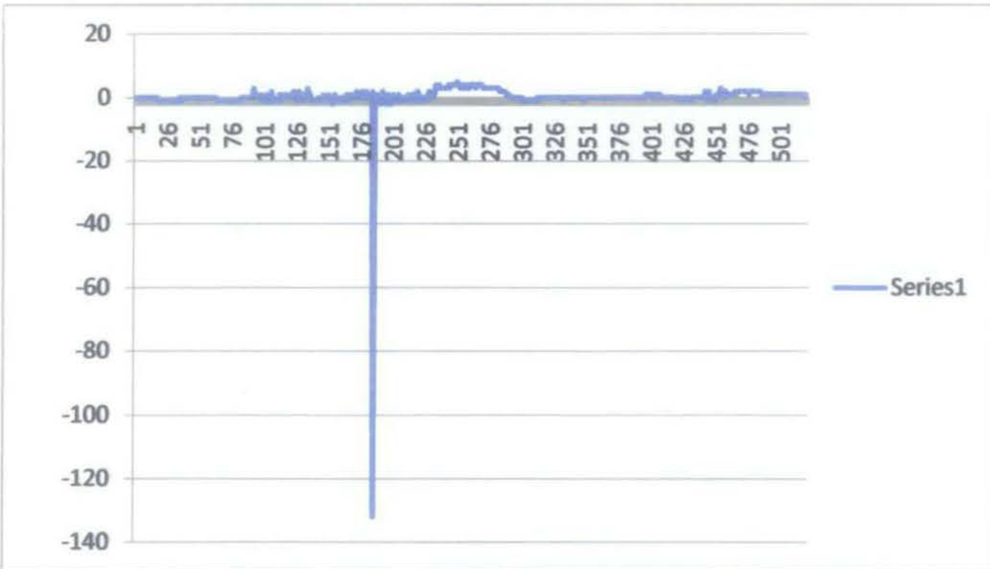


Figure 21: Computed Acceleration graph

From the graph we can see that the "-132" value is when the acceleration is negative, which mean the ROV accelerate to goes down from static position. The graph next shows the velocity of the ROV over time. The velocity value is obtained by accumulating of the computed acceleration data.

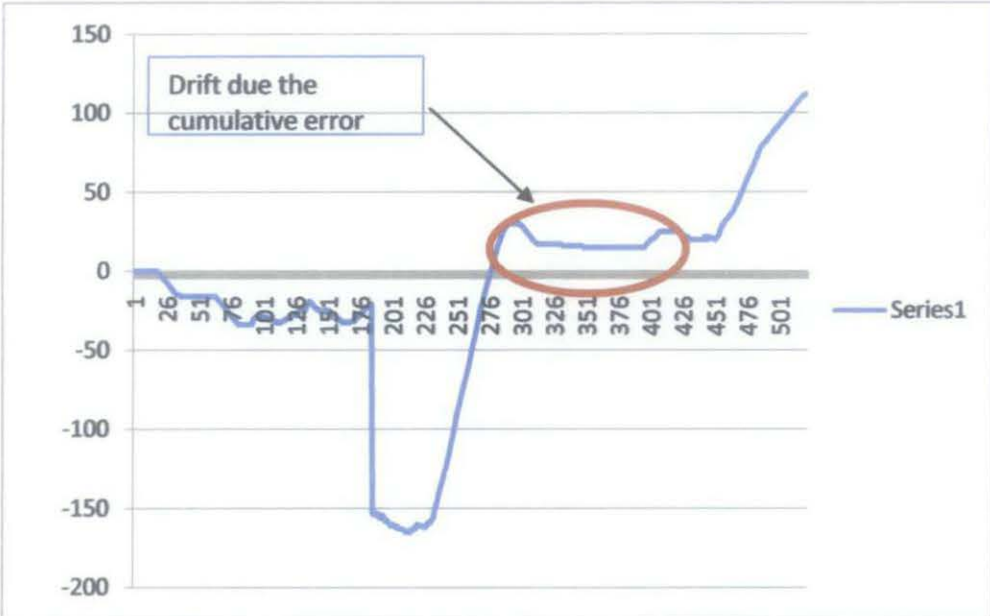
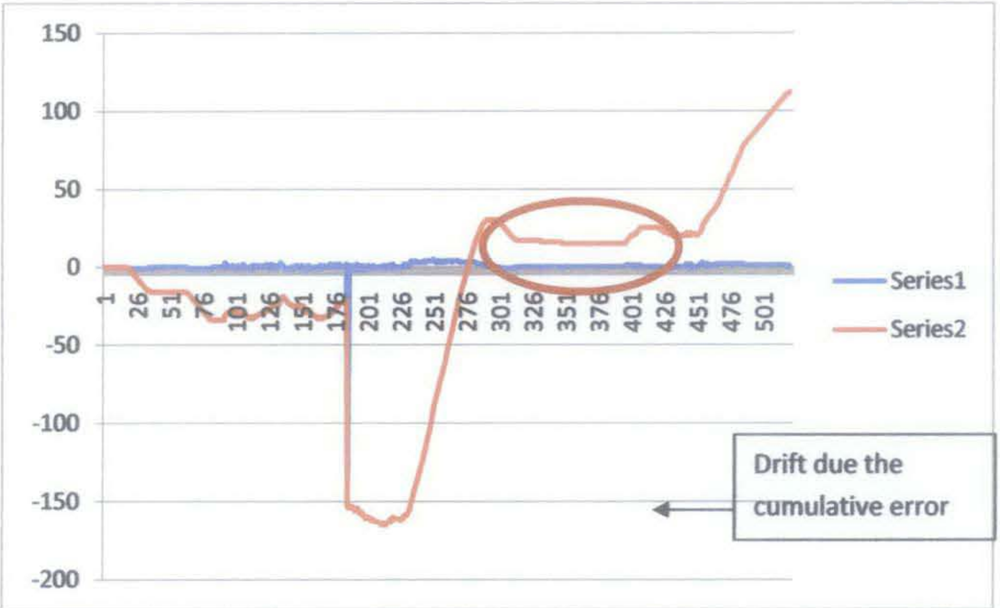


Figure 22: Computed velocity graph

Form the graph the initial position velocity measured is zero, and also at the 314th data, the value should also be zero, since the ROV rest on the surface at that time, but there is offset. This offset is due to the "cumulative error". Cumulative error happens when all the "data signal + error" is added, and it has become very significant offset or drifts in the graph. The computed displacement graph with computed acceleration + computed velocity is shown next. The displacement value is obtained by accumulating the computed velocity data.



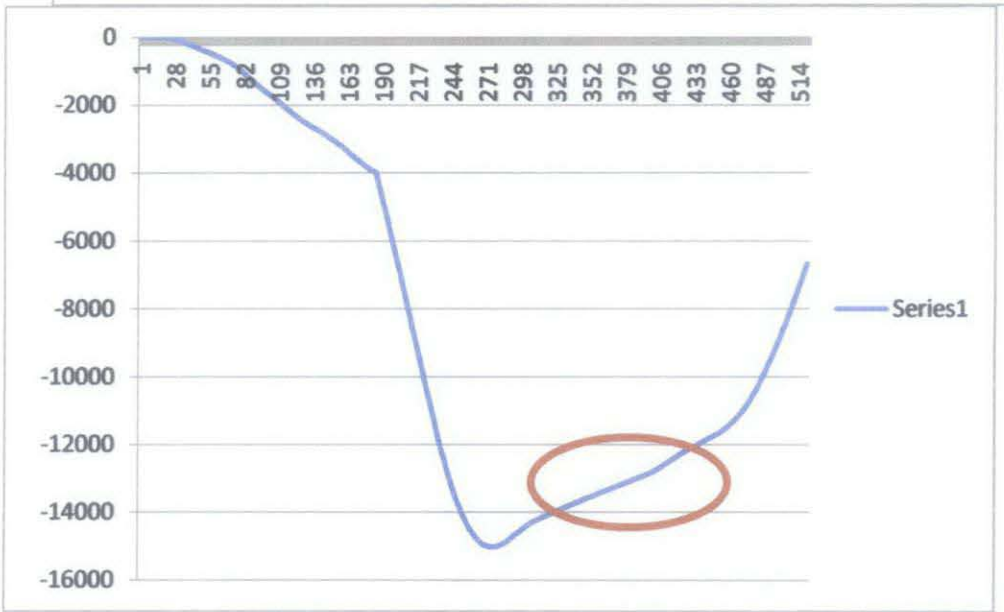


Figure 23: Computed displacement graph and computed velocity + acceleration

Form the graph we can see that the position of the ROV is always under the water, and there are supposed to be constant displacement at the last displacements value but it's not. As discussed earlier this is due to the cumulative error. The error becomes grater when the data is cumulated for the second time.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The minimum objective of this project is finally achieve which is to design and build an ROV which able to manoeuvre under the water, do a monitoring task and can take any kind of data and send it to the computer while under the water via UART communication. The successful of this project and the findings can help people to save cost and avoid danger working environment for human under the water as the robot can take over the job of monitoring, research, mapping and inspection routine 24 hours a day. Besides that is a hope for this project, that the ROV prototype designed could be used for next generation research whereby they can do a lot of study base on this ROV like modelling a transfer function for this ROV since it has equipped with accelerometer and other studies.

5.2 Recommendations

Throughout this project I can see there are few things that can be suggested when resuming this project for the next semester. First of all the AC aquarium pump for now can only be controlled by ON and OFF the pump. It will be better if the speed of the pump motors can be controlled using special motor drivers for the AC motors, but to do that a further research can be done by other FYP student for the next semester so that the prototype is not a waste. Other recommendation would be increasing the funding for the (Final Year Project) FYP and give the funding earlier. This is because the money given for the FYP somehow is not on par with the high expectation of FYP progress and results. So it is batter if the funding is according to complexity and expectation of the project.

Besides that underwater robotics, is a very vast project and research. The projects, task can be divided into 2 main disciplines which is the electrical & electronics engineering and mechanical engineering. This is because a robot basically has 2 different main parts which is the mechanism/structure part and the electronics control part. So due to that I propose that it is batter for this project to be divided into both disciplines so that ones can focus on the mechanism while the other can focus on the electronics control part.

This is a very good division because lots of research and project could be completed according to both disciplines like, do a very sophisticated semi-autonomous system design for the robotics, Human Machine Interface (HMI) design for the ROV (Software interaction) and many more ingenious idea. For the mechanical part they could focus more on the tether management system, manipulator arm design, and much more innovative idea. This proposal can only be achieve successfully when the both disciplines are working together.

For this final design of Aqua drone, a HMI can be develop for this prototype so that more sophisticated software and tools can be used to control the ROV as well as collecting as much data as possible and store automatically in the computer's memory. The HMI design can be developed using Visual Basic software as it has the capability to develop a software that can accessing the computers com port. Besides that from the accelerometer we can get the acceleration data of the ROV when we give an input. Form this capabilities we can module the ROVs transfer function.

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[2] Joseph Ayers. *8/27/2009 "Biomemetic Underwater Robot Program"* <http://www.neurotechnology.neu.edu/ >.

[3] Ricardo TADEU, Henrique ROCHA, *"Gamma Ray System Operated by Robots for Underwater Pipeline Inspection"* Journal paper Rio de Janeiro Federal University. 2006.

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[5] Magazine Article: The Gulf Spill's Lesson for Robotics. *August, 2010, IEEE Spectrum.*

[6] Magazine Article: Build an Underwater Robotics. *July, 2010, National Oceanic and Atmospheric Administration (NOAA).*

[7] Article: Buoyancy. *May 2009* <http://en.wikipedia.org/wiki/Buoyancy#Beyond_Archimedes.27_principle>.

[8] Magnus Valen *"Launch and recovery of ROV: Investigation of operational limit from DNV Recommended Practices and time domain simulations in SIMO"*, Master Thesis of Norwegian University of Science and Technology, Department of Marine Technology.

APPENDIX A

Milestone for the Final Year Project Part I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary Research Work														
3	Submission of Preliminary Report														
4	Seminar 1 (optional)														
5	Project Work														
6	Submission of Progress Report														
7	Seminar 2 (compulsory)														
8	Project work continues														
9	Submission of Interim Report Final Draft														
10	Oral Presentation														

Suggested milestone

Process

Milestone for the Final Year Project Part II

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Decides the best design														
2	Build the body of ROV														
3	Design Circuit diagram and simulate it														
4	Design PCB and produce the PCB board														
5	Program the board for testing it														
6	Submission of Progress report														
7	Do analysis and full test run on the ROV's systems capabilities														
8	Pre EDX preparation														
9	EDX														
10	Submission of Technical Report														
11	Oral Presentation														

DUAL FULL-BRIDGE DRIVER

- OPERATING SUPPLY VOLTAGE UP TO 46 V
- TOTAL DC CURRENT UP TO 4 A
- LOW SATURATION VOLTAGE
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)

Multiwatt15

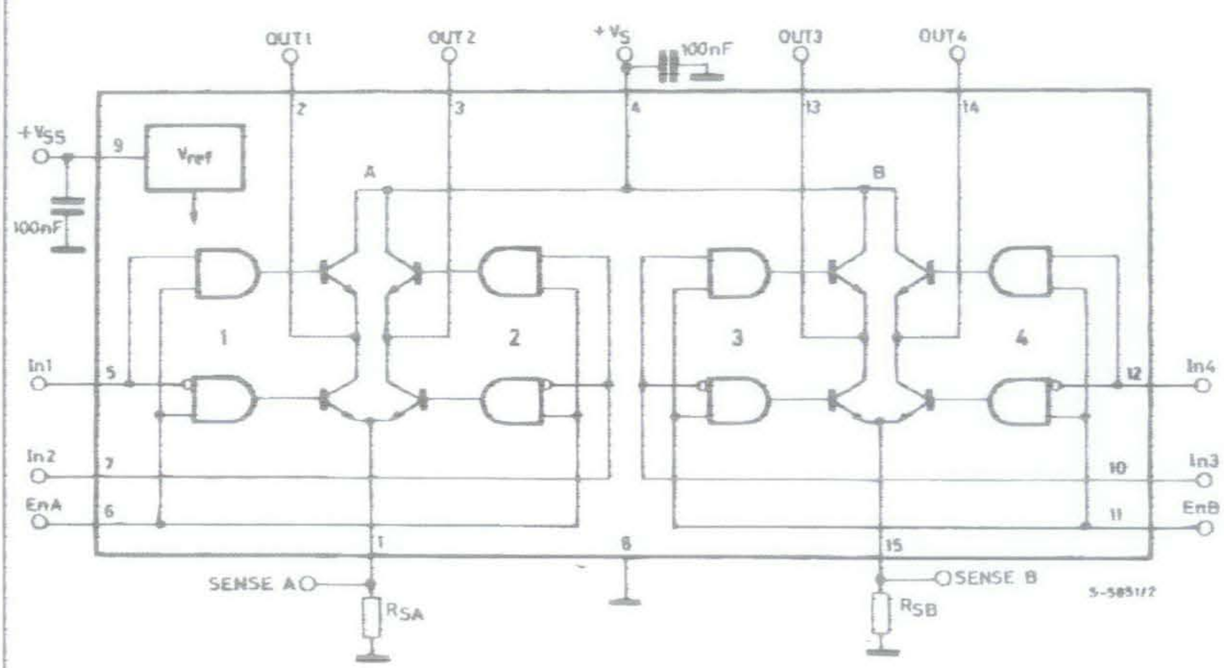
PowerSO20

ORDERING NUMBERS : L298N (Multiwatt Vert.)
L298HN (Multiwatt Horiz.)
L298P (PowerSO20)

DESCRIPTION

The L298 is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

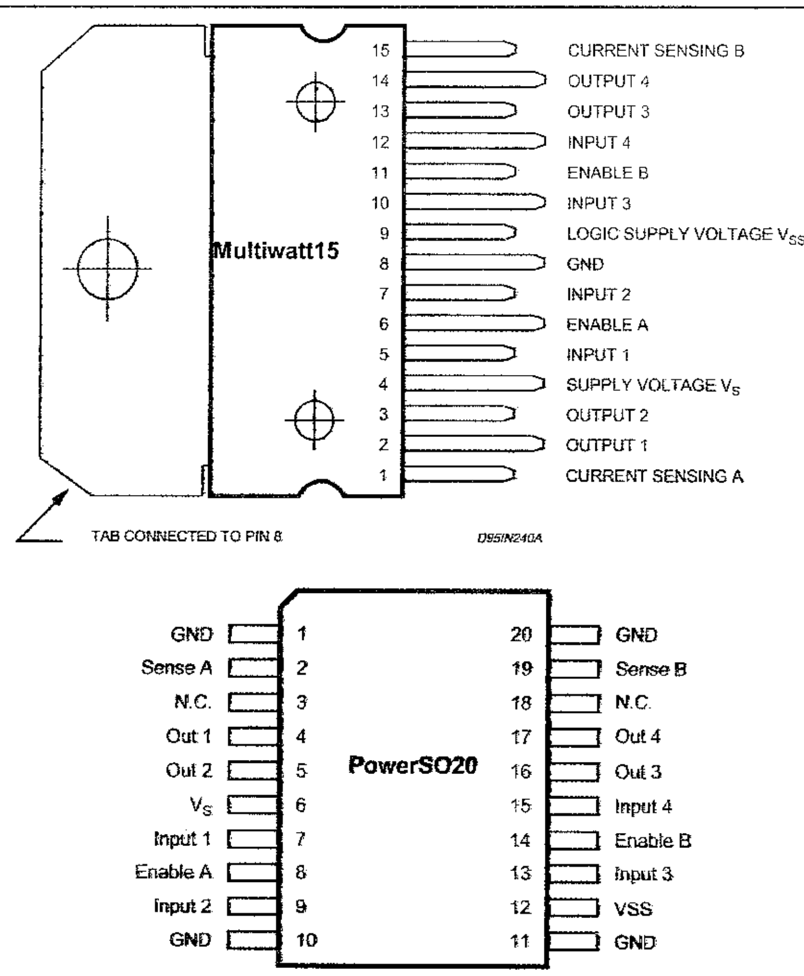
BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_S	Power Supply	50	V
V_{SS}	Logic Supply Voltage	7	V
V_I, V_{en}	Input and Enable Voltage	–0.3 to 7	V
I_O	Peak Output Current (each Channel) – Non Repetitive (t = 100μs) –Repetitive (80% on –20% off; t_{on} = 10ms) –DC Operation	 3 2.5 2	 A A A
V_{sens}	Sensing Voltage	–1 to 2.3	V
P_{tot}	Total Power Dissipation (T_{case} = 75°C)	25	W
T_{op}	Junction Operating Temperature	–25 to 130	°C
T_{stg}, T_j	Storage and Junction Temperature	–40 to 150	°C

PIN CONNECTIONS (top view)



THERMAL DATA

Symbol	Parameter		PowerSO20	Multiwatt15	Unit
$R_{th\ j\text{-}case}$	Thermal Resistance Junction-case	Max.	–	3	°C/W
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction-ambient	Max.	13 (*)	35	°C/W

(*) Mounted on aluminum substrate

PIN FUNCTIONS (refer to the block diagram)

MW.15	PowerSO	Name	Function
1;15	2;19	Sense A; Sense B	Between this pin and ground is connected the sense resistor to control the current of the load.
2;3	4;5	Out 1; Out 2	Outputs of the Bridge A; the current that flows through the load connected between these two pins is monitored at pin 1.
4	6	V_S	Supply Voltage for the Power Output Stages. A non-inductive 100nF capacitor must be connected between this pin and ground.
5;7	7;9	Input 1; Input 2	TTL Compatible Inputs of the Bridge A.
6;11	8;14	Enable A; Enable B	TTL Compatible Enable Input: the L state disables the bridge A (enable A) and/or the bridge B (enable B).
8	1,10,11,20	GND	Ground.
9	12	VSS	Supply Voltage for the Logic Blocks. A100nF capacitor must be connected between this pin and ground.
10; 12	13;15	Input 3; Input 4	TTL Compatible Inputs of the Bridge B.
13; 14	16;17	Out 3; Out 4	Outputs of the Bridge B. The current that flows through the load connected between these two pins is monitored at pin 15.
–	3;18	N.C.	Not Connected

ELECTRICAL CHARACTERISTICS (V_S = 42V; V_{SS} = 5V, T_j = 25°C; unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_S	Supply Voltage (pin 4)	Operative Condition	V_{IH} +2.5		46	V
V_{SS}	Logic Supply Voltage (pin 9)		4.5	5	7	V
I_S	Quiescent Supply Current (pin 4)	V_{en} = H; I_L = 0 V_i = L V_i = H		13 50	22 70	mA mA
		V_{en} = L V_i = X			4	mA
I_{SS}	Quiescent Current from V_{SS} (pin 9)	V_{en} = H; I_L = 0 V_i = L V_i = H		24 7	36 12	mA mA
		V_{en} = L V_i = X			6	mA
V_{iL}	Input Low Voltage (pins 5, 7, 10, 12)		–0.3		1.5	V
V_{iH}	Input High Voltage (pins 5, 7, 10, 12)		2.3		VSS	V
I_{iL}	Low Voltage Input Current (pins 5, 7, 10, 12)	V_i = L			–10	µA
I_{iH}	High Voltage Input Current (pins 5, 7, 10, 12)	Vi = H ≤ V_{SS} –0.6V		30	100	µA
V_{en} = L	Enable Low Voltage (pins 6, 11)		–0.3		1.5	V
V_{en} = H	Enable High Voltage (pins 6, 11)		2.3		V_{SS}	V
I_{en} = L	Low Voltage Enable Current (pins 6, 11)	V_{en} = L			–10	µA
I_{en} = H	High Voltage Enable Current (pins 6, 11)	V_{en} = H ≤ V_{SS} –0.6V		30	100	µA
$V_{CEsat(H)}$	Source Saturation Voltage	I_L = 1A I_L = 2A	0.95	1.35 2	1.7 2.7	V V
$V_{CEsat(L)}$	Sink Saturation Voltage	I_L = 1A (5) I_L = 2A (5)	0.85	1.2 1.7	1.6 2.3	V V
V_{CEsat}	Total Drop	I_L = 1A (5) I_L = 2A (5)	1.80		3.2 4.9	V V
V_{sens}	Sensing Voltage (pins 1, 15)		–1 (1)		2	V

ELECTRICAL CHARACTERISTICS *(continued)*

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
T_1 (V_i)	Source Current Turn-off Delay	0.5 V_i to 0.9 I_L (2); (4)		1.5		μs
T_2 (V_i)	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		0.2		μs
T_3 (V_i)	Source Current Turn-on Delay	0.5 V_i to 0.1 I_L (2); (4)		2		μs
T_4 (V_i)	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.7		μs
T_5 (V_i)	Sink Current Turn-off Delay	0.5 V_i to 0.9 I_L (3); (4)		0.7		μs
T_6 (V_i)	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.25		μs
T_7 (V_i)	Sink Current Turn-on Delay	0.5 V_i to 0.9 I_L (3); (4)		1.6		μs
T_8 (V_i)	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.2		μs
fc (V_i)	Commutation Frequency	I_L = 2A		25	40	KHz
T_1 (V_{en})	Source Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (2); (4)		3		μs
T_2 (V_{en})	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		1		μs
T_3 (V_{en})	Source Current Turn-on Delay	0.5 V_{en} to 0.1 I_L (2); (4)		0.3		μs
T_4 (V_{en})	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.4		μs
T_5 (V_{en})	Sink Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (3); (4)		2.2		μs
T_6 (V_{en})	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.35		μs
T_7 (V_{en})	Sink Current Turn-on Delay	0.5 V_{en} to 0.9 I_L (3); (4)		0.25		μs
T_8 (V_{en})	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.1		μs

1) 1)Sensing voltage can be –1 V for t ≤ 50 μsec; in steady state V_{sens} min ≥ – 0.5 V.
2) See fig. 2.
3) See fig. 4.
4) The load must be a pure resistor.

Figure 1 : Typical Saturation Voltage vs. Output Current.

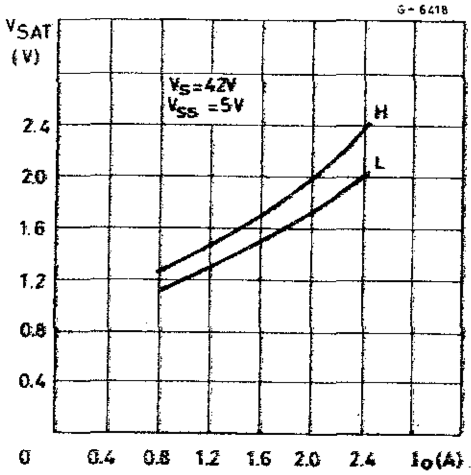
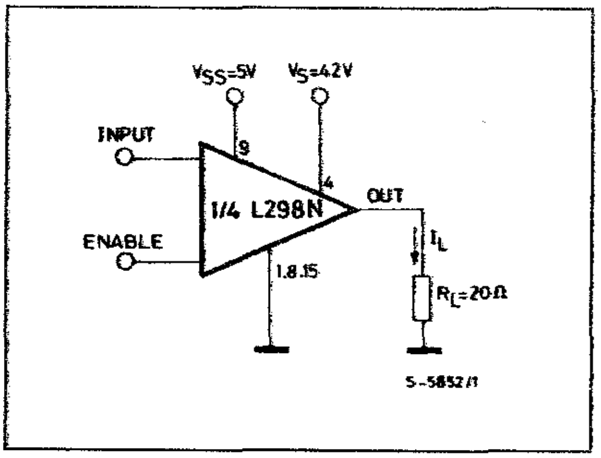


Figure 2 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = H

Figure 3 : Source Current Delay Times vs. Input or Enable Switching.

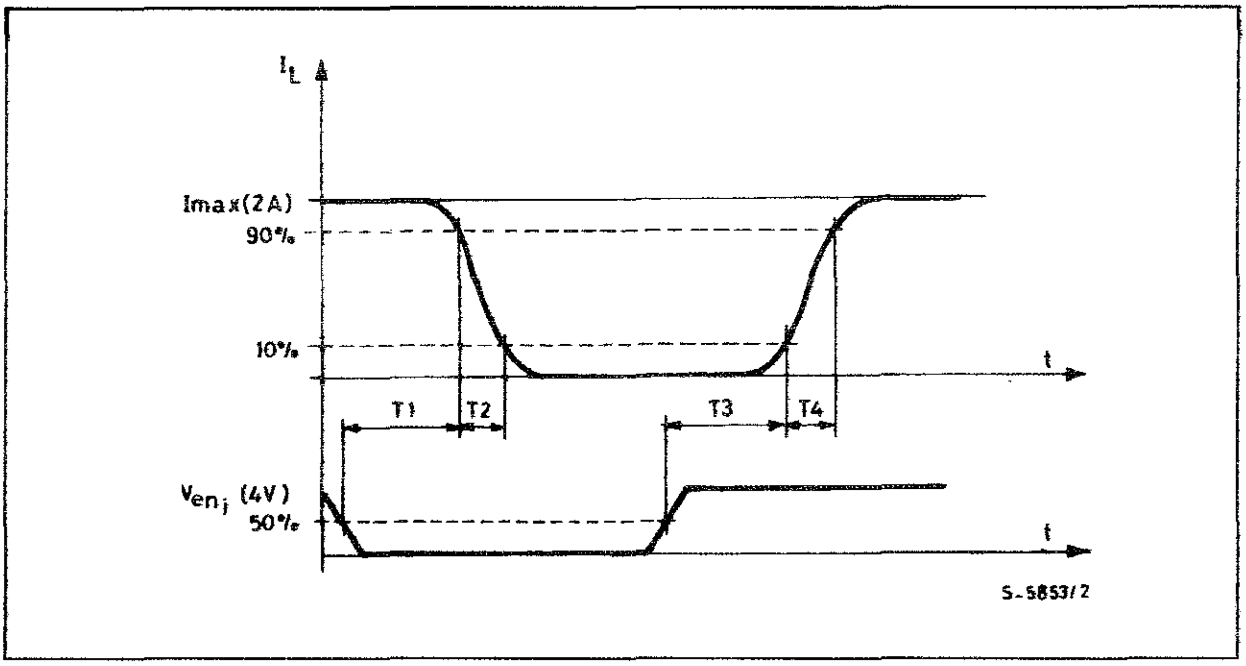
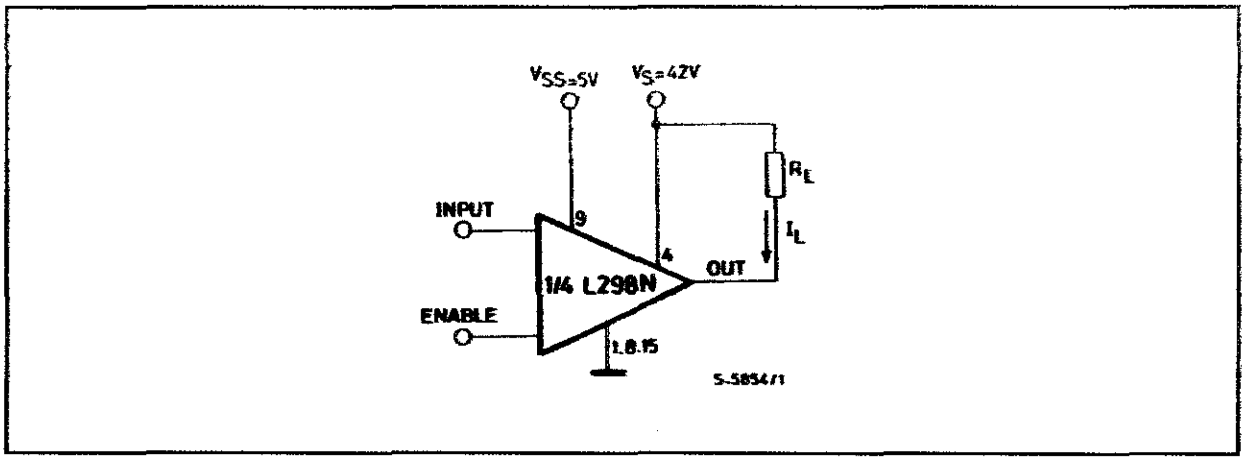


Figure 4 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = L

Figure 5 : Sink Current Delay Times vs. Input 0 V Enable Switching.

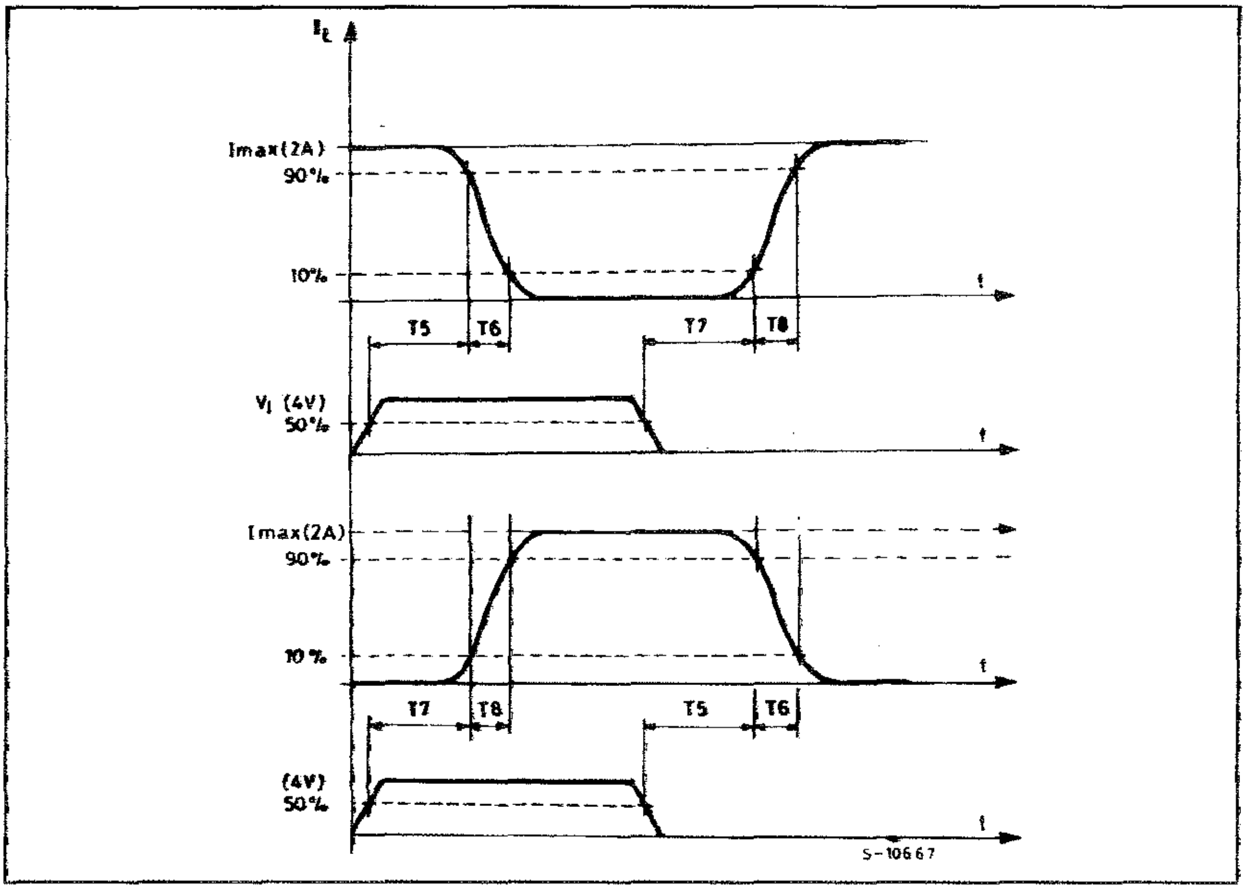
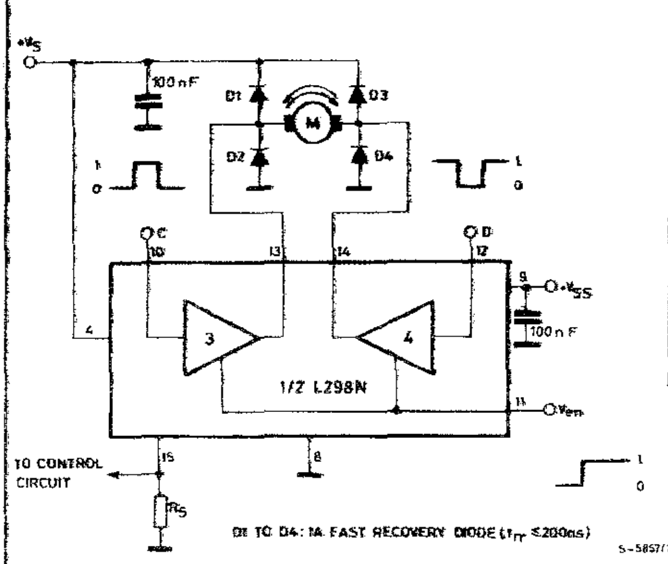


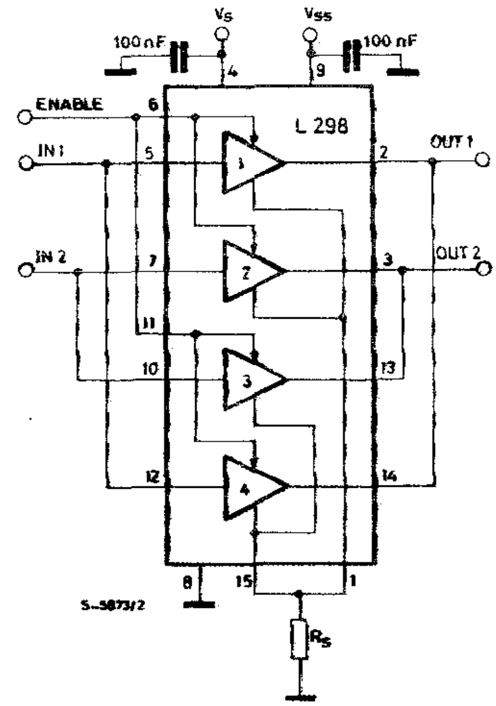
Figure 6 : Bidirectional DC Motor Control.



Inputs		Function
V_{en} = H	C = H ; D = L	Forward
	C = L ; D = H	Reverse
	C = D	Fast Motor Stop
V_{en} = L	C = X ; D = X	Free Running Motor Stop

L = Low H = High X = Don't care

Figure 7 : For higher currents, outputs can be paralleled. Take care to parallel channel 1 with channel 4 and channel 2 with channel 3.



APPLICATION INFORMATION (Refer to the block diagram)

1.1. POWER OUTPUT STAGE

The L298 integrates two power output stages (A ; B). The power output stage is a bridge configuration and its outputs can drive an inductive load in common or differenzial mode, depending on the state of the inputs. The current that flows through the load comes out from the bridge at the sense output : an external resistor (R_{SA} ; R_{SB}.) allows to detect the intensity of this current.

1.2. INPUT STAGE

Each bridge is driven by means of four gates the input of which are In1 ; In2 ; EnA and In3 ; In4 ; EnB. The In inputs set the bridge state when The En input is high ; a low state of the En input inhibits the bridge. All the inputs are TTL compatible.

2. SUGGESTIONS

A non inductive capacitor, usually of 100 nF, must be foreseen between both Vs and Vss, to ground, as near as possible to GND pin. When the large capacitor of the power supply is too far from the IC, a second smaller one must be foreseen near the L298.

The sense resistor, not of a wire wound type, must be grounded near the negative pole of Vs that must be near the GND pin of the I.C.

Each input must be connected to the source of the driving signals by means of a very short path.

Turn-On and Turn-Off : Before to Turn-ON the Supply Voltage and before to Turn it OFF, the Enable input must be driven to the Low state.

3. APPLICATIONS

Fig 6 shows a bidirectional DC motor control Schematic Diagram for which only one bridge is needed. The external bridge of diodes D1 to D4 is made by four fast recovery elements ($t_{rr} \leq 200$ nsec) that must be chosen of a VF as low as possible at the worst case of the load current.

The sense output voltage can be used to control the current amplitude by chopping the inputs, or to provide overcurrent protection by switching low the enable input.

The brake function (Fast motor stop) requires that the Absolute Maximum Rating of 2 Amps must never be overcome.

When the repetitive peak current needed from the load is higher than 2 Amps, a paralleled configuration can be chosen (See Fig.7).

An external bridge of diodes are required when inductive loads are driven and when the inputs of the IC are chopped ; Shottky diodes would be preferred.

This solution can drive until 3 Amps In DC operation and until 3.5 Amps of a repetitive peak current.

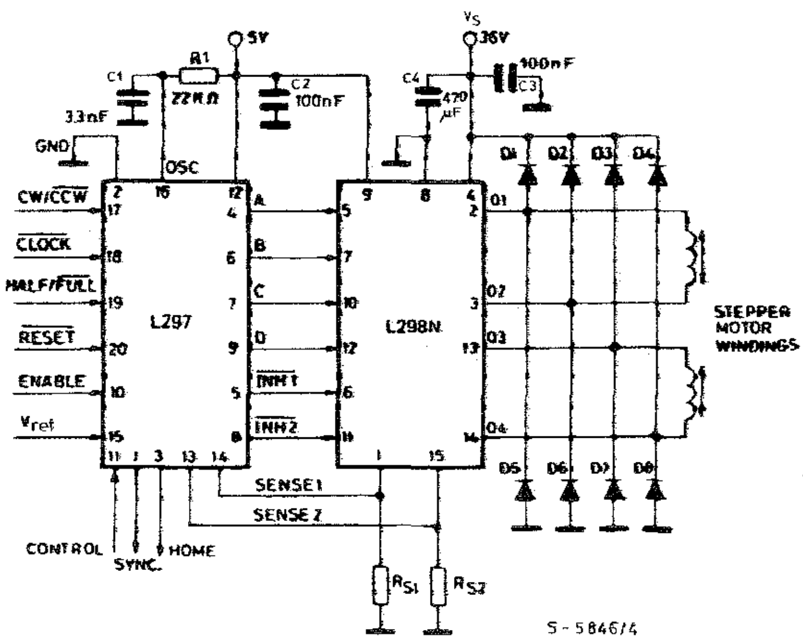
On Fig 8 it is shown the driving of a two phase bipolar stepper motor ; the needed signals to drive the inputs of the L298 are generated, in this example, from the IC L297.

Fig 9 shows an example of P.C.B. designed for the application of Fig 8.

Figure 8 : Two Phase Bipolar Stepper Motor Circuit.

Fig 10 shows a second two phase bipolar stepper motor control circuit where the current is controlled by the I.C. L6506.

This circuit drives bipolar stepper motors with winding currents up to 2 A. The diodes are fast 2 A types.



$R_{S1} = R_{S2} = 0.5\ \Omega$

D1 to D8 = 2 A Fast diodes $\left\{ \begin{array}{l} V_F \leq 1.2\ V\ @\ I = 2\ A \\ trr \leq 200\ ns \end{array} \right.$

Figure 9 : Suggested Printed Circuit Board Layout for the Circuit of fig. 8 (1:1 scale).

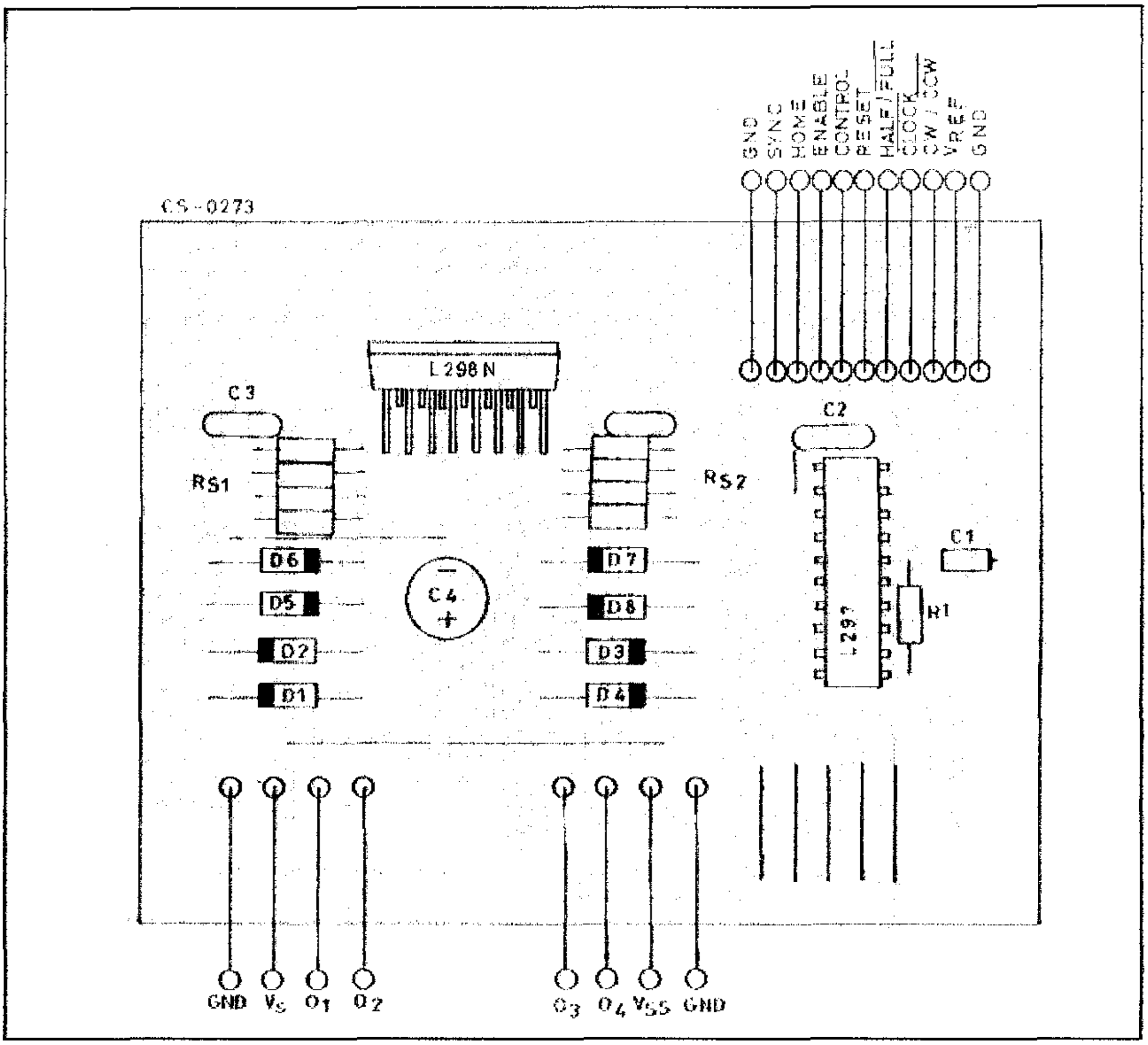
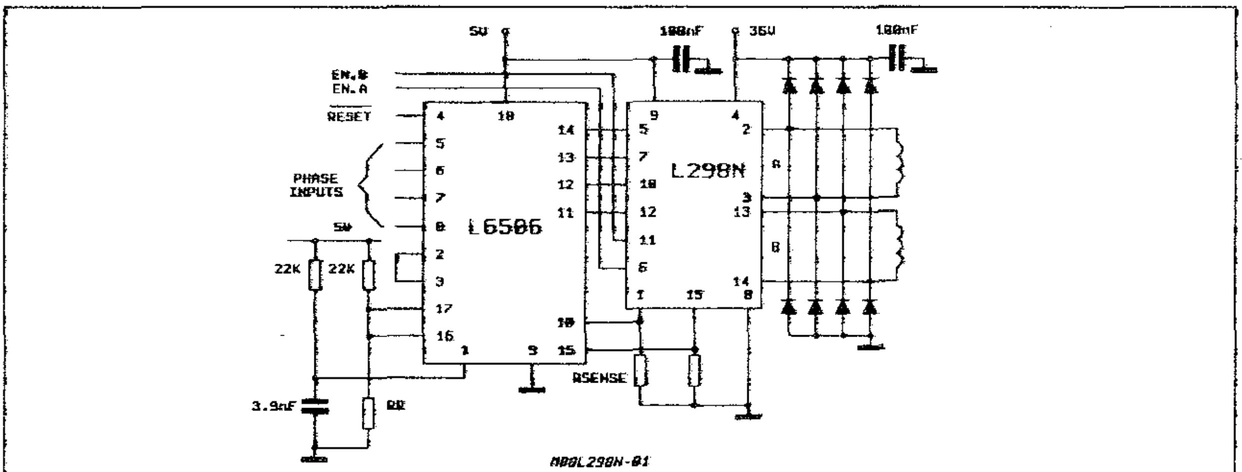


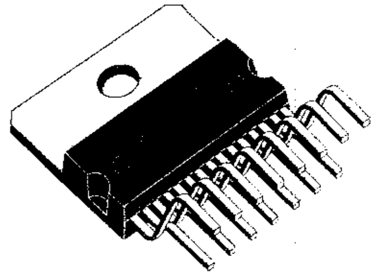
Figure 10 : Two Phase Bipolar Stepper Motor Control Circuit by Using the Current Controller L6506.



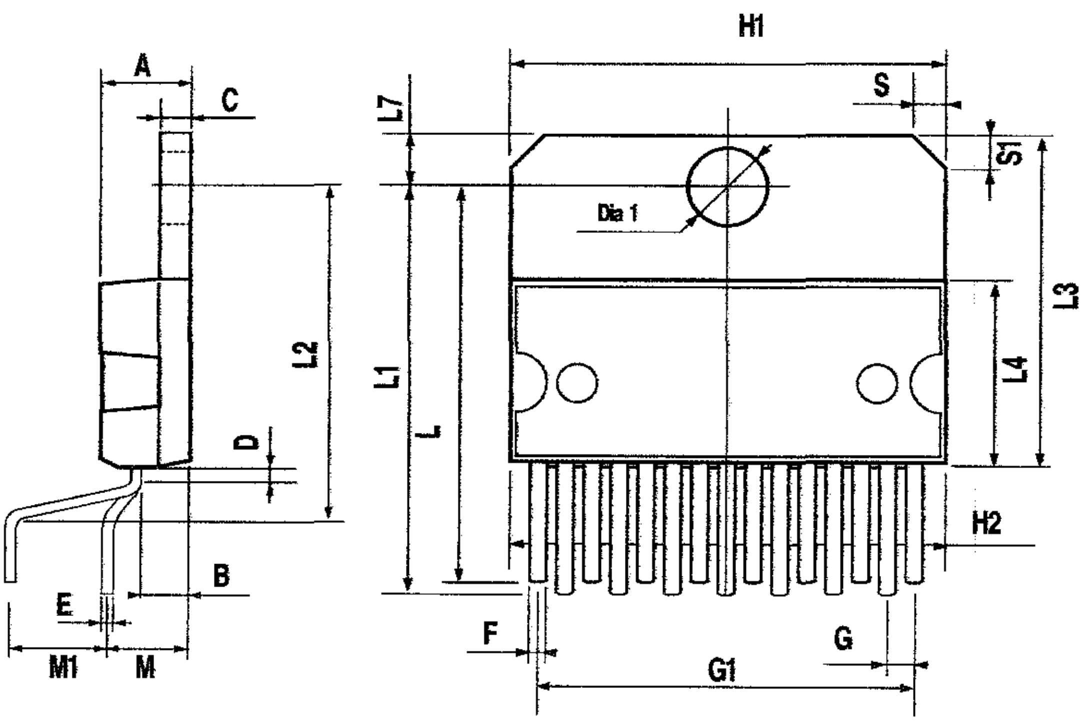
RR and Rsense depend from the load current

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			5			0.197
B			2.65			0.104
C			1.6			0.063
D		1			0.039	
E	0.49		0.55	0.019		0.022
F	0.66		0.75	0.026		0.030
G	1.02	1.27	1.52	0.040	0.050	0.060
G1	17.53	17.78	18.03	0.690	0.700	0.710
H1	19.6			0.772		
H2			20.2			0.795
L	21.9	22.2	22.5	0.862	0.874	0.886
L1	21.7	22.1	22.5	0.854	0.870	0.886
L2	17.65		18.1	0.695		0.713
L3	17.25	17.5	17.75	0.679	0.689	0.699
L4	10.3	10.7	10.9	0.406	0.421	0.429
L7	2.65		2.9	0.104		0.114
M	4.25	4.55	4.85	0.167	0.179	0.191
M1	4.63	5.08	5.53	0.182	0.200	0.218
S	1.9		2.6	0.075		0.102
S1	1.9		2.6	0.075		0.102
Dia1	3.65		3.85	0.144		0.152

OUTLINE AND MECHANICAL DATA

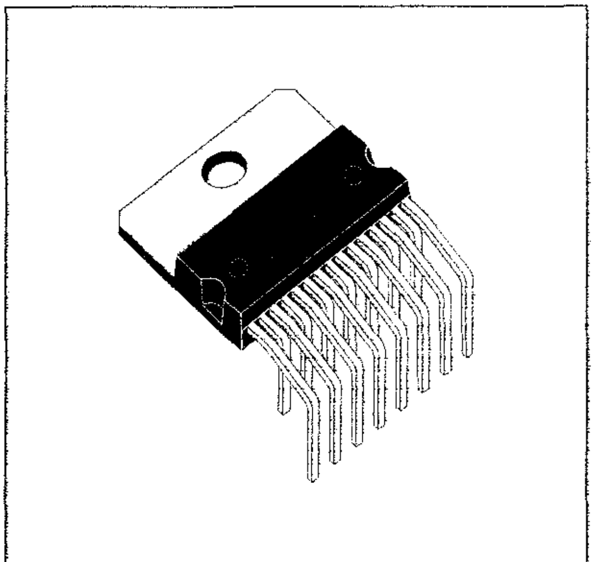


Multiwatt15 V

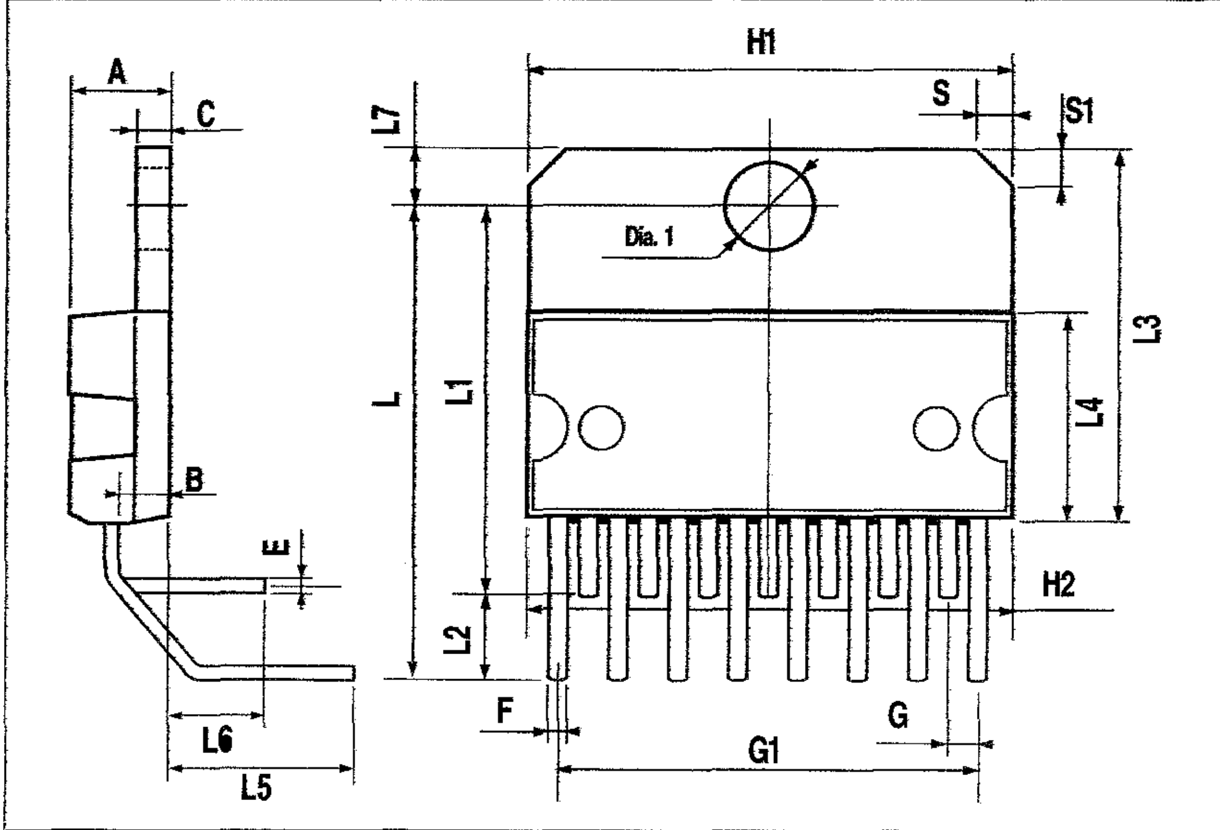


DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			5			0.197
B			2.65			0.104
C			1.6			0.063
E	0.49		0.55	0.019		0.022
F	0.66		0.75	0.026		0.030
G	1.14	1.27	1.4	0.045	0.050	0.055
G1	17.57	17.78	17.91	0.692	0.700	0.705
H1	19.6			0.772		
H2			20.2			0.795
L		20.57			0.810	
L1		18.03			0.710	
L2		2.54			0.100	
L3	17.25	17.5	17.75	0.679	0.689	0.699
L4	10.3	10.7	10.9	0.406	0.421	0.429
L5		5.28			0.208	
L6		2.38			0.094	
L7	2.65		2.9	0.104		0.114
S	1.9		2.6	0.075		0.102
S1	1.9		2.6	0.075		0.102
Dia1	3.65		3.85	0.144		0.152

OUTLINE AND MECHANICAL DATA



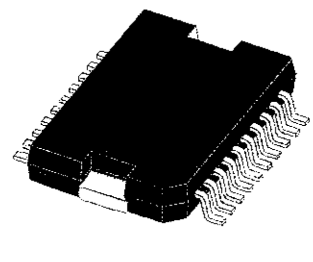
Multiwatt15 H



DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			3.6			0.142
a1	0.1		0.3	0.004		0.012
a2			3.3			0.130
a3	0		0.1	0.000		0.004
b	0.4		0.53	0.016		0.021
c	0.23		0.32	0.009		0.013
D (1)	15.8		16	0.622		0.630
D1	9.4		9.8	0.370		0.386
E	13.9		14.5	0.547		0.570
e		1.27			0.050	
e3		11.43			0.450	
E1 (1)	10.9		11.1	0.429		0.437
E2			2.9			0.114
E3	5.8		6.2	0.228		0.244
G	0		0.1	0.000		0.004
H	15.5		15.9	0.610		0.626
h			1.1			0.043
L	0.8		1.1	0.031		0.043
N	10° (max.)					
S	8° (max.)					
T		10			0.394	

(1) "D and F" do not include mold flash or protrusions.
- Mold flash or protrusions shall not exceed 0.15 mm (0.006").
- Critical dimensions: "E", "G" and "a3"

OUTLINE AND MECHANICAL DATA



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PowerSO20