# DEVELOPMENT OF REMOTELY OPERATED UNDERWATER VEHICLE

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# DEVELOPMENT OF REMOTELY OPERATED UNDERWATER VEHICLE

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Report submitted in fulfillment of the requirements
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**JUDUL:** **LANDMARK DETECTION FOR VISION BASED OF AUTONOMOUS GUIDED VEHICLE**

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**Dedicated to my Parents**

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# ABSTRACT

Underwater Vehicle (UV) contributes in numerous applications in our daily life. Several problems in UV is commonly related to the control system of the vehicle as its application in real life is unpredictable due to changes and effects on or by the vehicle. Throughout this thesis, it will be focus on developing Remotely Operated Underwater Vehicle (ROV), design and apply control system to test the actual behavior of the vehicle. Method used to test the vehicle was by autonomous control, where image processing was applied to observe the vehicle movements. Two types of test was conducted to observe the surge and yaw behavior, therefore overshoot percentage was concluded and compared with simulation. With the design of control system actual behavior was observable and able to be compared with simulation.

# ABSTRAK

Kenderaanbawah air telahmenyumbangkepadabanaykpenggunaanyadidalamkehidupanharian. Beberapamasalahuntukkenderaaninikebiasaanyaberkaitrapartdengansistemkawalankenderaankeranaaplikasidalamkehidupansebenartidakbolehdiramalkeranaperubahandankesan kepadaataudaripadakenderaan. Sepanjangtesisini, fokusakandiberikanuntukmembangunkankenderaanbawah air, merekadanmenggunakansistemkawalanuntukmelihatkelakuankenderaantersebut.Kaedah yang telahdigunapakaiuntukmengujikenderaanadalahmenggunakankawalantanpapemamdu, di manapemprosesangambar di gunapakaiuntukmelihatpergerakankenderaan. Duajenisujiantelahdilakukanuntukmelihatkelakuan surge dan yaw, di sampinglebihanperatustelah di simpulkandan di bandingkandengansimulasi. Denganmerekasistemkawalankeadaansebenardapat di lihatdanboleh di bandingkandengan simulasi.

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# CHAPTER 1

# INTRODUCTION

## 1.1 ROVs

Deep water industry or task is constantly evolving, and provides greater challenge as its depth of operation increase. This sort of activities requires not only accuracy, but ability to work in harsh condition that is dangerous and risky to be performed by human diver. To overcome this, researches has came up with the idea of underwater vehicle (UV), either remotely operated or autonomous, to replace divers in performing those task. UV nowadays has been develop by many companies, and with the advancement of technology, implementation of sensors and other hardware as well as software has been introduced to increase the capability of the UV. This enables more input information to be analyze, thus provides the UV users with rich information on what is happening underneath the sea surface.

Autonomous underwater vehicle (AUV) is designed to be able to perform on its own, without the need of connected to any controllers on surface. The AUV is preprogrammed with specific instruction before release into the sea, and its ability to avoid obstacles making it suitable to be use commercially and in military application as well (Bui, 2006). AUV also capable of controlling its own motion and adapt to the change of external disturbances, and at the same time maintaining its accuracy and reliability during task performing (Leonard, 1995).

Remotely operated underwater vehicle or simply called as ROV is an unoccupied and maneuverable vehicle, controlled by some sort of remote control by a person and usually from onboard of a boat. Signals are transferred back and forth by umbilical cable that act as the life line for the ROV, controlling thrusters and enabling live time viewing to the user via onboard camera. Common umbilical cable usually consists of power supply and communication where it is essential to operate the ROV (Lygouras, 1995).

## 1.2 PROJECT BACKGROUND

Underwater vehicle had been around since the early 1950s where its application is widely use around the globe forvarious underwater operations. Under harsh and risky condition, sending divers to completethose tasks is extremely dangerous and risky, and it can cause lost of life. Underwater operations such as repairing underwater pipes or probably in military spying task consume a lot of working hours, thus implementation of UV in completing those task enables not just long working hours, but capable of doing continuous work without fatigue. Advancement of technology nowadays allows UV developers to design and fabricate according to customers demand, which mainly focus on its application.

Various types of sensors was introduced to enable a more sophisticated UV, such as the lateral-line sensors capable of detecting change on local water velocity caused by object at its surrounding (Martiny, et al., 2009). This enable the UV to detect any object on its surrounding even during milky water condition where other sensors might unable to detect, thus avoiding any collision from its surrounding object. Although with the capability of lateral-line sensors, most ROVs require vision based navigation such as an onboard camera not only for sending image to the pilot, but as well as to enable image processing to stabilize the vehicle (Amat, et al., 1999). Tethered UV enable pilot to control the direction of the vehicle, with the help of onboard camera to see where it is going. Various control technique has been introduce such as the use of proportional and derivative action that are proved to be working (Guo, et al., 2003).

## 1.3 PROBLEM STATEMENT

Underwater task proposed great challenge to researchers as the condition deep down inside the ocean can be dangerous. Sending divers to repair leakage on pipes or to collect some samples for biology research can be fatal to them as the deeper it gets, pressure is growing higher and at the right amount it can easily crush the human body. Although with the help of UV, there is still one major problem associated with it, which is the cost. Most underwater equipments is expensive and developing UV with limited cost is difficult.Especially to ensure its ability to go deeper without having to bottleneck the capability of its onboard equipments. Therefore, it is important to calculate the right amount of cost to be spend. It is highly related to what type of application and task the UV will go through.

Ability of existing ROV to be control using both remotely and autonomously control proposed a great challenge and every aspect in designing and allocating important electronics component need to be taken into consideration. Light source is also needed and important in order to produce enough light intensity while the ROV performing autonomous control, so that object can be easily recognized. Roborealm software will be used to process the image from webcam, which enable object to be track and sending the signals to respective electronics component to move the ROV.

## 1.4 PROJECT OBJECTIVE

The objectives of this project are :

a) To develop and maneuver existing underwater vehicle and perform basic movements
b) To developcontrol systemof the vehicle
c) To test the control system of the vehicle and observe its behavior

## 1.5 PROJECT SCOPE

The scope of this project is to develop the existing ROV and implement both control method which are remotely controlled and autonomous. This will be done by implementing two ways of control method, which are remotely controlled and autonomously controlled. Remotely controlled enable the UV to be control via gamepad, while for autonomous control webcam will be use to capture image and process using software before sending the signals to respective motor driver.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 UNDERWATER VEHICLES

### 2.1.1 Autonomous underwater vehicle

AUVs are controlled by various means of ways usually involved artificial intelligence system (Blidberg,1991), such as by using an indirect adaptive control method based on an extended Kalman filter (Mohan, 2012). Other than that, open-loop control and close-loop control are also being implement in UV controllers, in which both has its own pros and cons depends on the purpose and application (Leonard, 1995).An ongoing research project on artificial lateral-line flow sensor has been managed to replace the existing vision sensor, taking it to a high new level of underwater vehicle application (Martiny, 2009). Giving the underwater vehicle the sense of fish, lateral-line sensor measures local water velocities around the vehicle, enabling navigation during poor visual conditions of the water such as in murky condition. An example of underwater vehicle that uses this type of sensor is the Snookie that used hot-thermistor anemometry to measure water velocities and had been proven successful (Franosch, et al. 2010).

### 2.1.2 Remotely operated underwater vehicle

Application of ROV ranging from oil pipe inspection in an offshore gas and oil facilities to exploration of ocean floor discovering new habitat or species of fish. One of the motivations of ROV development is the high cost of human divers, and the harsh condition of working under water. Some ROV capable of performing predefined operation without the need to be control, which was done with the help of autonomous control (Amat, 1999). This function is important to be able to perform long observations operation, where no attention is needed from the operator. ROV requires an operator to control and maneuver the vehicle, connected by umbilical cable that consist of power supply cables and communication which is usually for information transmit and monitoring (Lygouras,1995).Vision sensor served as the eye for operator, providing a real time view on the front camera of the vehicle for ROV, or surrounding view that uses ultrasonic sound to emit a short burst of sound to detect objects in its surrounding that is commonly apply in AUV (Khalid, 2010).

## 2.2 ROV SPECIFICATION

The existing ROV has length, width and height of 0.4m, 0.5m, and 0.57m respectively. The overall total mass is around 22.5 kg, including the five thrusters which are the power window. The total overall weight excludes electronics system, which is assumed to contribute about 0.5 kg to the overall total mass and battery packs consist of six 12V 1.2AH maintenance-free rechargeable sealed lead acid batteries.

It has five thrusters, two mounted at the back, one at each side of left and right, and another in front of the ROV. This enables it to move in five degree of freedom (DOF) which are: surge, heave, roll, pitch and yaw. No thrusters mounted to enable sway movement which is about y-axis.

A webcam and illuminating system is placed inside of the main compartment. Webcam will be use to capture images, enabling autonomous control of the ROV. Illuminating is important as to ensure consistent light intensity in order for image processing purpose and as well as for the pilot to see when remote control method is enable.

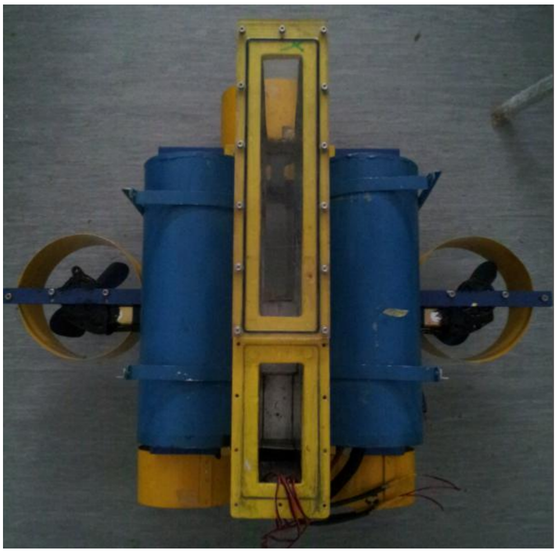


**Figure 2.1:** The existing underwater vehicle

### 2.2.1 Buoyancy

Buoyancy is calculated in order to find which buoyancy condition the ROV is. Using the formula below, $B$ the buoyancy force in Newton, $\rho$ is the density of water which equivalent to 1000 kg/m$^{3,}$ g is gravity acceleration which is 9.8 m/s$^2$ and $v$ is the total volume of ROV (Hepperle, 1996). Taking the total volume of ROV is 0.034m$^3$, the buoyancy of ROV is,

$$B_{calculated} = \rho g v \tag{1}$$

$$B_{calculated} = 333.04N \tag{2}$$

By using experimental way, it is noticed that the buoyancy of ROV is a bit different from calculated, which is equivalent to 280N. To estimate the condition of ROV, either neutral, positive or negative buoyancy, this can be calculate by using the density formula, which $\rho_{\mathrm{rov}}$ is the density, $m$ is the mass of ROV which equivalent to 22.5kg and $v_{calculated}$ is the volume of ROV calculated.

$$\rho_{\mathrm{rov}} = m/v \tag{3}$$

$$\rho_{\mathrm{rov}} = 661.76\ kg/m^3 \tag{4}$$

Using volume obtained from experiment, $v_{experimental}$ is 0.0336 $m^3$, so the density of ROV is,

$$\rho_{\mathrm{rov}} = 669.64\ kg/m^3 \tag{5}$$

In order to find the percentage of buoyancy (Novell, 2008), below is the calculation involved,

$$percentage\ of\ buoyancy = \frac{\rho_{\mathrm{rov}}}{\rho_{\mathrm{water}}} \mathrm{X}\ 100\% \tag{6}$$

$$percentage\ of\ buoyancy_{calculated} = 66.18\% \tag{7}$$

$$percentage\ of\ buoyancy_{experimental} = 66.96\% \tag{8}$$

Using the calculation above, it is known that the density calculated is about 66.18% or 66.96% the density of water. The ROV is therefore floating at about 66.18% or 66.9% below surface of water, and 33.82% or 33.1% above surface water. This concludes that the ROV is in positive buoyancy, which is very useful in a situation where any malfunction occur; it will float automatically without the need of thrusters.

### 2.2.2 Thrust force

The thrust of propeller depends on the volume of water accelerated per time unit with the amount of acceleration and density water. In momentum considerations, thrust can be express by (Hepperle, 1996),

$$T = \frac{\pi}{4}\ X\ D^2\ X\ \left(v + \frac{\Delta v}{2}\right) X\ \rho\ X\ \Delta v \qquad (9)$$

Where D is the diameter of propeller which is 0.16m, $v$ is input velocity which is assume to be 1 m/s and $\Delta v$ which the added velocity is assume to be 1 m/s. This shows that the thrust must be produce by the propeller to produced desired velocity with reference to input velocity. Thrust for this calculation is equal to 30.16N.

### 2.2.3 Power consumption

Power consumption can be calculated as follow, where $T$ is thrust force. This simply means that in order to move 1 m/s of velocity with stated buoyant force, the value of power needed can be calculate as follow,

$$power = Watts\ or\ newton\ meter\ per\ second \tag{10}$$

$$power = T\ X\ v \tag{11}$$

This shows that 30.16 Watts of power needed in order to produce the needed thrust force with speed of 1 m/s.

## 2.3 KINEMATICS

### 2.3.1 Two reference frame

Two coordinate systems are use in this mathematical model to analyze the position of underwater vehicle. The first one is earth reference frame, XYZ and the other is ROV-fixed coordinate frame, xyz. Earth reference frame is a global-fixed reference frame attach to real frame that is use to track where the position of ROV (Anan, 2001). The second reference frame is the ROV reference frame, which is place fix to the body of the ROV. Function of the ROV frame is to enable velocity and acceleration, and describe the movement of ROV. As an example, the vehicle is moving forward (surge) or rolling about its axis which is the x-axis (Anan, 2001).

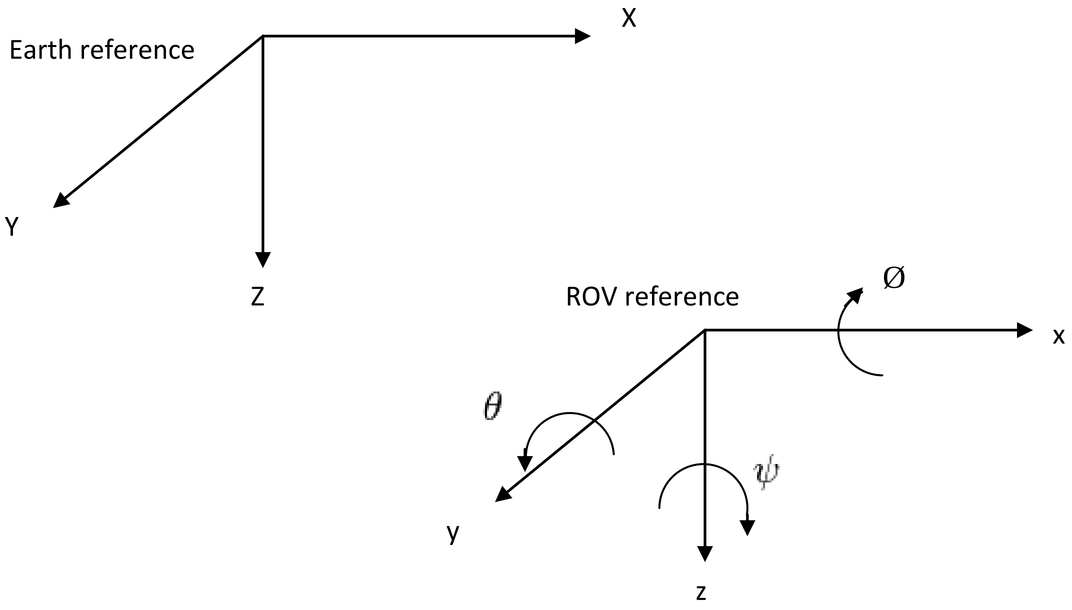


**Figure 2.2:** Coordinate reference system for underwater vehicle.

Three translation displacements are used, X (surge), Y (sway) and Z (heave), and three Euler angles Ø (roll), $\theta$ (pitch), and $\psi$ (yaw) to represent position of ROV. X-axis is points for forward movement and z-axis is pointing downward in order to be consistent with the earth reference frame. Throughout the mathematical model, Euler angles will be use to represent rotation around the three axes (Anan, 2001).

### 2.3.2 Mathematical model of ROV position

In order to present an attitude, Euler angles is use to calculate the position of ROV, with respect to both Earth and ROV reference frame. According to (Anan, 2001), a set of Euler angles is defined as a set of angles from three successive rotations around three axes. Three rotation matrices is use to represent the ROV to earth rotation, denoted by ${}^{Earth}_{ROV}R$ . Each rotation matrices is denoted as $R_Z$, $R_Y$ and $R_X$ which means rotational at axis Z, rotational at axis Y and rotational at axis X. $\psi$, $\theta$, and Ø is define as the rotation angles around z, y and x-axis respectively. Thus, a rotation matrix between reference frame of ROV and Earth is given as,

$$ {}^{Earth}_{ROV}R = R_Z(\psi) R_Y(\theta)\, R_X(\emptyset) \tag{12}$$

where$R_Z(\psi)$,$R_Y(\theta)$ and $R_X(\emptyset)$ are,

$$R_Z\left(\psi\right) = \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{13}$$

$$R_Y\left(\theta\right) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \tag{14}$$

$$R_X(\varphi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & -\sin\varphi \\ 0 & \sin\varphi & \cos\varphi \end{bmatrix}. \tag{15}$$

Substitute $R_Z(\psi)$,$R_Y(\theta)$ and $R_X(\emptyset)$ into ${}^{Earth}_{ROV}R$ results in,

$$ {}^{Earth}_{ROV}R = \begin{bmatrix} c\psi \mathrm{c}\theta & c\psi \mathrm{s}\theta \mathrm{s}\varphi - \mathrm{s}\Psi\mathrm{c}\varphi & c\psi \mathrm{s}\theta \mathrm{c}\varphi + \mathrm{s}\psi\mathrm{s}\varphi \\ \mathrm{s}\psi\mathrm{c}\theta & c\psi\mathrm{c}\varphi + s\psi\mathrm{s}\theta\mathrm{s}\varphi & s\psi\mathrm{s}\theta\mathrm{c}\varphi - \mathrm{c}\psi\mathrm{s}\varphi \\ -\mathrm{s}\theta & \mathrm{c}\theta\mathrm{s}\varphi & \mathrm{c}\theta\mathrm{c}\varphi \end{bmatrix} \tag{16}$$

wherec$\theta$ and s$\varphi$ simply means cos $\theta$sin $\varphi$.

In order to identify the linear position of ROV with respect to Earth, ${}^{Earth}_{ROV}X$ matrix is used that consist of X, Y and Z which means the position ROV with respect to Earth at x-axis, y-axis and z-axis respectively. ${}^{ROV}_{ROV}X$consist of the position of ROV with respect to its own reference frame, denoted by ${}^{R}_{R}X$, ${}^{R}_{R}Y\ and\ {}^{R}_{R}Z$ which is use to simplify the equation instead of ${}^{ROV}_{ROV}Y$ or ${}^{ROV}_{ROV}Z$. However since the ROV is situated at origin of the ROV reference, then ${}^{ROV}_{ROV}X$ becomes [ 0 0 0].

$$ {}^{Earth}_{ROV}X = {}^{Earth}_{ROV}R\ {}^{ROV}_{ROV}X + {}_{ROV}\,{}^{Earth}_{Origin}X \tag{17} $$

$$ {}^{Earth}_{ROV}X = {}^{Earth}_{ROV}R\ \ + {}_{ROV}\,{}^{Earth}_{Origin}X \tag{18} $$

$$ {}^{Earth}_{ROV}X = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{19} $$

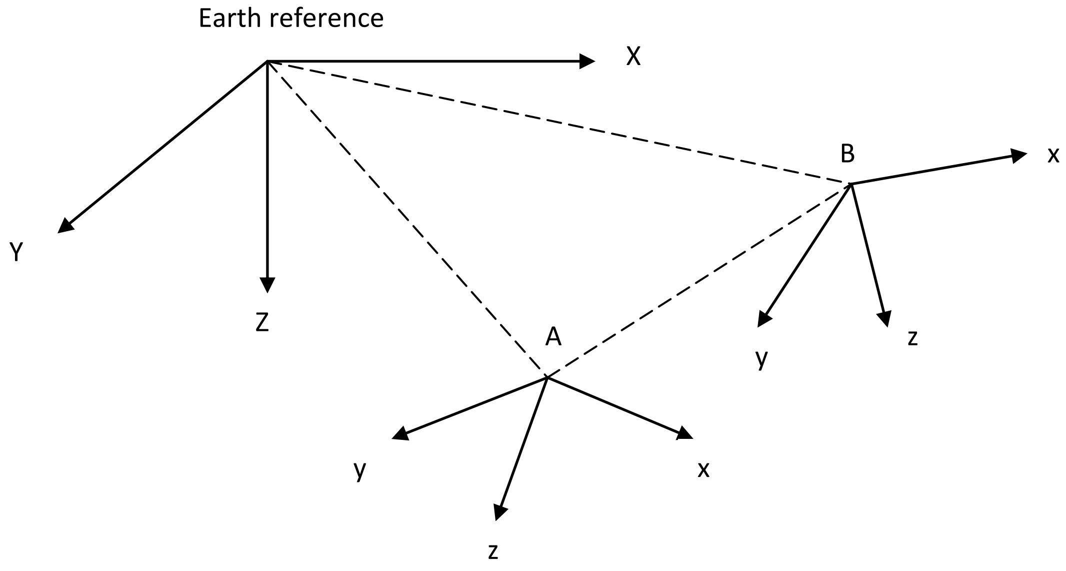


**Figure 2.3:** Transformation from point A to point B of a translated and rotated reference frame

${}_{ROV\ Origin}^{Earth}X$is consist of the origin position of ROV with respect to Earth reference, in which a, b and c is the origin position of ROV.

$$ {}_{ROV\ Origin}^{Earth}X = \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{20}$$

Solving for ${}_{ROV}^{Earth}X,$ the X, Y and Z position of ROV therefore is,

$$\mathrm{X} = (c\psi \mathrm{c}\theta) + (c\psi \mathrm{s}\theta \mathrm{s}\varphi - \mathrm{s}\psi \mathrm{c}\varphi) + \left(c\psi \mathrm{s}\theta \mathrm{c}\varphi + \mathrm{s}\psi \mathrm{s}\varphi\right) + a \tag{21}$$

$$\mathrm{Y} = (\mathrm{s}\psi \mathrm{c}\theta) + (c\psi \mathrm{c}\varphi + s\psi \mathrm{s}\theta \mathrm{s}\varphi) + (s\psi \mathrm{s}\theta \mathrm{c}\varphi - \mathrm{c}\psi \mathrm{s}\varphi) + b \tag{22}$$

$$\mathrm{Z} = (-\mathrm{s}\theta) + (\mathrm{c}\theta \mathrm{s}\varphi) + (\mathrm{c}\theta \mathrm{c}\varphi) + c \tag{23}$$

## 2.4 DYNAMICS MODEL OF ROV

The dynamics model of the ROV uses the Newton-Euler motion equation of a rigid body in fluid. The motion equation can be written in matrix form as,

$$M\dot{V} + C(V)V + D(V)V + G = T \tag{24}$$

where*M* is a mass and inertia matrix, *C(V)* is a Coriolis and centripetal matrix, *D(V)* is hydrodynamic damping matrix, *G* is the gravitational and buoyancy vector, *T* is external force and torque input vector and *V* is the velocity state vector (Gonzalez, L.A. 2004). The mass and inertia matrix consist of two components, rigid body mass and inertia, $M_{RB}$ and hydrodynamic added mass,$M_A$, thus,

$$M = M_{RB} + M_A \tag{25}$$

Throughout the derivation of dynamics, there are several assumptionsmade in order to simplify the ROV modeling:

a) The ROV travel speed is low which is less than 1 m/s
b) Sway, roll and pitch movement is negligible, as due to limitation of thrusters available
c) Vehicle is symmetrical at its three planes
d) Vehicle orientation remain at horizontal posture during all maneuvers, thus roll movement is negligible
e) The vehicle's degree of freedom are decoupled

The decoupling for the vehicle's degree of freedom is valid due to low traveling speed, the Coriolis and centripetal matrices are negligible (Gonzalez, L.A. 2004). The simplified dynamic model for the AUV becomes,

$$M\dot{V} + D(V)V + G = T \tag{26}$$

### 2.4.1 Mass and inertia matrix

Since the ROV is assume to be symmetric in all planes, $M_{RB}$ is simplified to be as(Gonzalez, L.A. 2004),

$$M_{RB} = \begin{bmatrix} m & 0 & 0 & 0 & 0 & 0 \\ 0 & m & 0 & 0 & 0 & 0 \\ 0 & 0 & m & 0 & 0 & 0 \\ 0 & 0 & 0 & I_x & 0 & 0 \\ 0 & 0 & 0 & 0 & I_y & 0 \\ 0 & 0 & 0 & 0 & 0 & I_z \end{bmatrix} \tag{27}$$

Assuming that the sway, roll and pitch movement is negligible, the equation above can be simplify to become,

$$M_{RB} = \begin{bmatrix} 22.5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 22.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 3.6219 \end{bmatrix} \qquad (28)$$

where the mass of the ROV is 22.5 kg. Thus it can be notice that only moment at z axis was determined to be 3.6219 kg/m$^2$, which correspond to yaw movement. Simplifying the added mass matrix, $M_A$ becomes,

$$M_A = \begin{bmatrix} X_{\dot{u}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_{\dot{\omega}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & N_{\dot{r}} \end{bmatrix} \qquad (29)$$

$$M_A = \begin{bmatrix} -11.51 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -746.69 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -18.21 \end{bmatrix} \qquad (30)$$

### 2.4.2 Hydrodynamics damping matrix

The hydrodynamics damping matrix represents the drag and lift forces acting on the ROV while it move. Due to low velocity, lift forces are assumed to be negligible compared to drag forces. The damping matrix *D(V)* is (Gonzalez, L.A. 2004),

$$D(V) \; = \begin{bmatrix} X_u + X_{u|u|}|u| & 0 & 0 \\ 0 & Y_v + Y_{v|v|}|v| & 0 \\ 0 & 0 & Z_w + \; Z_{w|w|}|w| \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\begin{matrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ K_p + K_{p|p|}|p| & 0 & 0 \\ 0 & M_q + \; M_{q|q|}|q| & 0 \\ 0 & 0 & N_r + \; N_{r|r|}|r| \end{matrix} \Bigg] \tag{31}$$

This can be simplifies to,

$$D(V) \; = \begin{bmatrix} X_u + X_{u|u|}|u| & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_w + \; Z_{w|w|}|w| & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & N_r + \; N_{r|r|}|r| \end{bmatrix} \tag{32}$$

$$D(V) \; = \begin{bmatrix} 24 + 7.5570|u| & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1.3845 + \; Z_{w|w|}|w| \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\begin{matrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 6.6675 + \; N_{r|r|}|r| \end{matrix} \Bigg] \tag{33}$$

### 2.4.3 Gravitational and buoyancy vector

Gravitational vector and buoyancy vector is defined as $G$ where it consist of $f_B$ , the buoyant force vector and $f_G$ which is the gravitational force vector. Overall $G$ can be defined as,

$$G = \begin{bmatrix} f_B + f_G \\ r_B X f_B + r_G X f_G \end{bmatrix} \tag{34}$$

where$f_B$ and $f_G$ is,

$$f_B = R^{-1} \begin{bmatrix} 0 \\ 0 \\ -B \end{bmatrix} \tag{35}$$

$$f_G = R^{-1} \begin{bmatrix} W \\ 0 \\ 0 \end{bmatrix} \tag{36}$$

and$r_B$ is the center of buoyancy while $r_G$ is the center of gravity in the ROV frame reference. As the reference frame for the ROV is placed at the centre of gravity, $r_G$ can be simplified to be $r_G = [\ 0\ \ 0\ \ 0\ ]$ and thus $G$ is simplified to,

$$G = \begin{bmatrix} f_B + f_G \\ r_B X f_B \end{bmatrix} \tag{37}$$

Since $r_B$ is defined as $r_G = [\ x_B y_B z_B\ ]$ that is the distance in x, y and z of coordinates from the origin of ROV reference frame, G can be simplifies as,

$$G = \begin{bmatrix} (B-W)\sin\theta \\ -(B-W)\sin\varphi\cos\theta \\ -(B-W)\cos\varphi\cos\theta \\ B\cos\theta\,(z_B\sin\varphi - y_B\cos\varphi) \\ B\,(x_B\cos\varphi\cos\theta + z_B\sin\theta) \\ -B\,(x_B\sin\varphi\cos\theta + y_B\sin\theta) \end{bmatrix} \tag{38}$$

Throughout this research, it is assumed that $r_B$ = [ 0 0 0 ] in which the center of buoyancy is aligned with the center of gravity along all the axes. The weight of the ROV is found to be 225N, while the buoyant force is 280N, in which the difference is use to simplify equation above, as

$$G = \begin{bmatrix} 0 \\ 0 \\ -55 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{39}$$

This simply means that the buoyancy force only affect the vertical movement, which -55N is the residual buoyancy or about 24% of the vehicle total weight. This assumption also shows that only heave movement is affected by the gravitational and buoyant force of the ROV.

### 2.4.4 Thrust mapping matrix

The ROV consist of five thrusters which are required to move in three DOFs, surge, heave and yaw. Thruster forces and moments are denoted as $T$(Gonzalez, L.A. 2004), and it can be expressed as,

$$T = LU \tag{40}$$

where$U$ is thrust vector generated by five thrusters,

$$U = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \end{bmatrix} \tag{41}$$

and$L$ is the thrust mapping matrix which is given by,

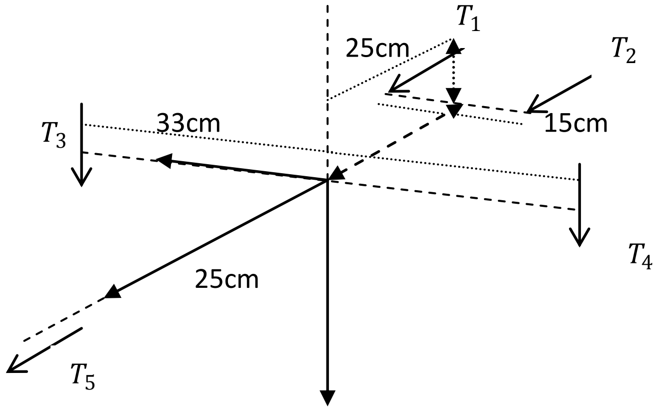


**Figure 2.4:** Thrust mapping matrix for $L$

$$L = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -0.15 & 0.15 & 0 & 0 & 0 \end{bmatrix}. \tag{42}$$

L is a thrust mapping matrix which maps the five thrusters space to forces and moments of the ROV. In figure 2.4, $T_1$ and $T_2$ represent the rear horizontal thrusters, $T_3$ and $T_4$ is the vertical thrusters and $T_5$ is front thruster. The first row indicates the horizontal motors responsible for surge which are the $T_1$, $T_2$ and $T_5$. The last row indicates the distance for motor $T_1$and $T_2$ from the center of gravity of the ROV.

## 2.5 CONTROL TECHNIQUES OFUNDERWATER VEHICLE

Controlling underwater vehicle require certain field of knowledge such as kinematics and dynamics, navigation system, control theory and hydrodynamics. This is crucial as keeping underwater vehicle stable is not an easy task to be achieve, as it usually involve the effect of parametric uncertainties such as added mass and hydrodynamics coefficient that greatly contribute to the cause of instability of the vehicle (Yildiz, Gokalp andYilmaz, 2009). The term control itself can be divided into three main categories which are motion control, mission control and formation control. Over the years, evolution of vehicle control contribute to the vehicle ability to perform complicated task, keeping their goal as the main objective while able to maneuver smoothly during changing position from one point to another. Common technique of analyzing the motion of underwater vehicle is to define two coordinate frames which are body-fixed and earth fixed reference frame. Algorithms are used to control the basic tasks in AUV such as the depth and steering control, and the methods can be divided into two main groups which are linear methods and non linear methods (Yildiz, Gokalp and Yilmaz, 2009).

During early 1990s, a decoupled control design was proposed and developed, that is by dividing the six degree of freedom (DOF) into three non-interacting subsystems focused on steering, diving and speed control that applied closed-loop PID-controllers. A few examples of UV control can be seen such as the Sliding Mode Fuzzy Controller (SFMC)(Song and Smith, 2000), Fuzzy logic control (Smith, et. al., 1994), Neuro-fuzzy control systems (Wang and Lee, 2001) and Non-regressor based algorithm control (Yuh, West and Lee, 2001). Other factor that affects the vehicle itself is the umbilical cable, which is usually neglected due to its complex solution (Fang, Hou andLuo, 2007). In order to test the umbilical cord hydrodynamics effect on the body, some researches came up with the idea of submerged inverted double pendulum that was design to simulate the effect of dynamics behavior (Kreuzer and Pinto, 1996).

## 2.6 RELATED WORK

Several researches were done on the use of image processing technique to control UV, which can be done by implementing the sensing system using camera. Onboard camera enables the system to “see” on its surrounding environment and at the same time capturing images to require its physical data (Lin and Tseng, 2006). Certain technique being develop since the early 90s is by using vision-based system to control AUV. Human eye capture the image based on the light reflection and process by the brain. Captured images consist of various characteristics such as colors, shape, size, distance and depth of numerous objects on the surrounding environment. Ability of brain to process all of the information and send the signal to our body parts to perform specific task making brain as one of the most complicated part in human body.

Implementing the concept on how our eyes and brain work, researchers are developing vision-based system to allow UV to be control with the use of onboard camera and software to read and at the same time analyze images to perform specific task. This application has been used widely in pipeline inspection, in which AUV will follow the pipeline and search for any damage or leakage on it. This can be done by the vision-based system, in which the AUV will be preprogram to detect the pipeline boundaries, geometry and orientation (Foresti, Gentili andZampato, 1998). Another application of vision-based system is in underwater cable tracking where single camera and an acoustic sensor use to determine relative position in a three dimensional space. Visual data from the camera provide information regarding two dimensions, while the acoustic data provides the AUV with the third dimension (Balasuriya, et al, 1997).

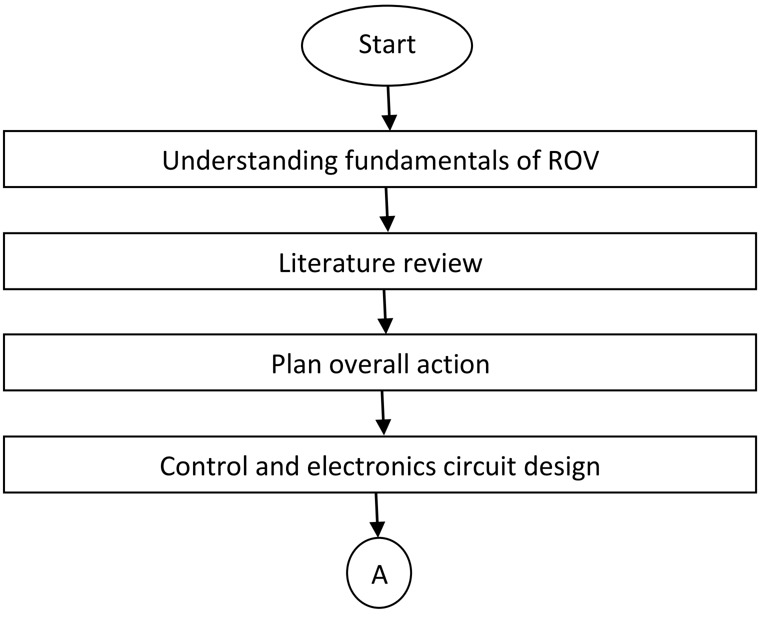
# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

This chapter mainly discuss on methods involve in the development of ROV. This covered the remotely controlled method, autonomous controlled method using image processing, and the implementation of software as well as hardware in completing this project. Within this chapter also shows the overall flow diagram from start until completing this project.

## 3.2 FLOW DIAGRAM


Start
Understanding fundamentals of ROV
Literature review
Plan overall action
Control and electronics circuit design
A

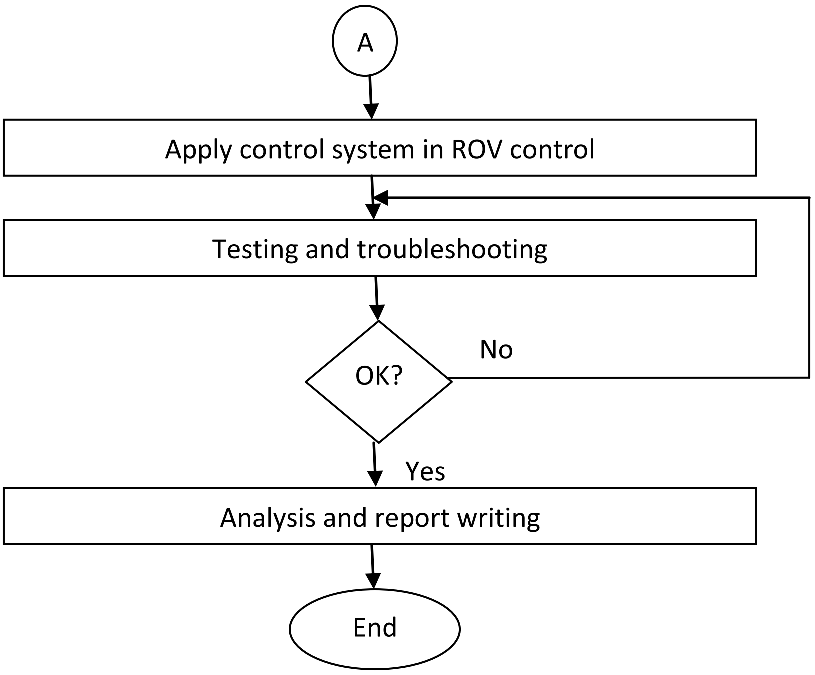

A
Apply control system in ROV control
Testing and troubleshooting
OK?
No
Yes
Analysis and report writing
End

**Figure 3.1:** Methodology flow diagram

## 3.3 ROV CONTROL METHODS

Two methods of controlling approach will be use in this project. These are remotely controlled using PlayStation 2 controller, and by autonomous control using image processing via webcam. For control system test purpose, image processing technique will be applied in the test.

### 3.3.1 Remotely controlled ROV using PlayStation 2 controller

There are various ways to control an underwater vehicle. Depends on the application and purpose of the UV, some UV might require joystick to be control and some might not need it. In this project, DualshockPlayStation 2 (PS2) remote control will be use to act as the controller that provide signals to Arduinomicrocontroller board, before being process and later power up necessary thrusters.

**Figure 3.2:**Sony Playstation 2 controller

Source:webassetsh.scea.com

Some wiring striping is needed initially to figure out the function of each pin (Curiousinventor, 2008). Only six pins from total of nine pins are used to interface with Arduino microcontroller board. Refer to Table 3.1 list for the color and function of each pin.

**Table 3.1:** Sony Playstation 2 wiring connections

| Bil. | Wire color | Function | Description |
|---|---|---|---|
| 1. | Brown | Data | An open collector output |
| 2. | Orange | Command | (No description) |
| 3. | Grey | Vibration motor power | Supply power to drive internal motor |
| 4. | Black | Ground | Act as the ground for electronics circuit |
| 5. | Red | Power 3.3V/5V | Power up controller |
| 6. | Yellow | Attention | Chip select or slave select line |
| 7. | Blue | Clock | 500kHz clock, communication via SPI bus |
| 8. | White | Unknown | (No description) |
| 9. | Green | Acknowledge | Send signal to playstation for it to notice the controller |

Source: Curiousinventor (2008)

In order for the PS2 controller to produce a readable output, bit layout is assigned to both left and right stick. LY, LX, RY and RX simply means left stick y-axis, left stick x-axis, right stick y-axis and right stick x-axis. Figure 3.3 shows the analog stick bit signal layout, which can be view by Serial Monitor.

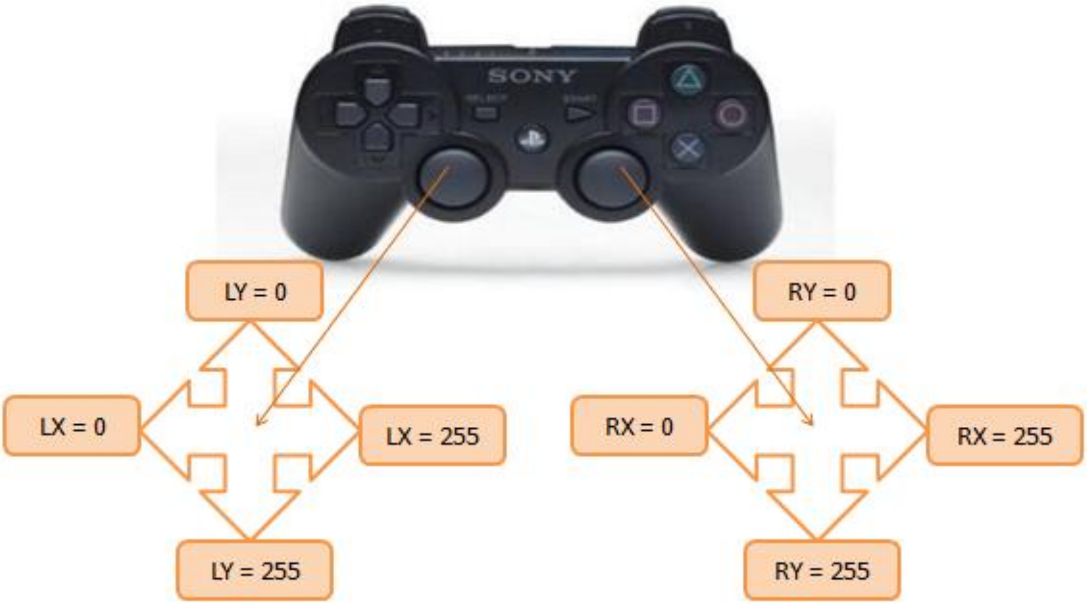
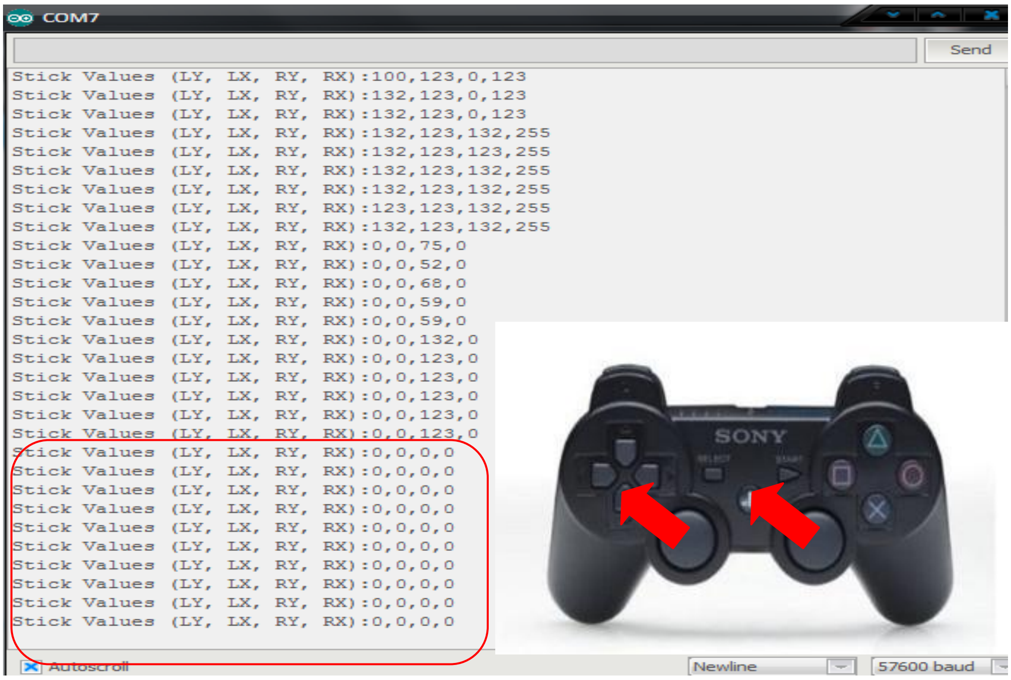


**Figure 3.3:** Analog stick bit signal layout

Connecting necessary pin to Arduino board, some simple programming is written to enable the bit reading from PS2 controller. Below is a sample of print screen on the output produced which can be view by Serial Monitor tab inside Arduino environment in which the red box shows the bit reading when analog stick is pressed according to the red arrow,



```
Stick Values (LY, LX, RY, RX):100,123,0,123
Stick Values (LY, LX, RY, RX):132,123,0,123
Stick Values (LY, LX, RY, RX):132,123,0,123
Stick Values (LY, LX, RY, RX):132,123,132,255
Stick Values (LY, LX, RY, RX):132,123,123,255
Stick Values (LY, LX, RY, RX):132,123,132,255
Stick Values (LY, LX, RY, RX):132,123,132,255
Stick Values (LY, LX, RY, RX):123,123,132,255
Stick Values (LY, LX, RY, RX):132,123,132,255
Stick Values (LY, LX, RY, RX):0,0,75,0
Stick Values (LY, LX, RY, RX):0,0,52,0
Stick Values (LY, LX, RY, RX):0,0,68,0
Stick Values (LY, LX, RY, RX):0,0,59,0
Stick Values (LY, LX, RY, RX):0,0,59,0
Stick Values (LY, LX, RY, RX):0,0,132,0
Stick Values (LY, LX, RY, RX):0,0,123,0
Stick Values (LY, LX, RY, RX):0,0,123,0
Stick Values (LY, LX, RY, RX):0,0,123,0
Stick Values (LY, LX, RY, RX):0,0,123,0
Stick Values (LY, LX, RY, RX):0,0,123,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
Stick Values (LY, LX, RY, RX):0,0,0,0
```

**Figure 3.4:** Sample of bit signal

### 3.3.2 Autonomously controlled ROV using image processing

Autonomous control UVs have been practically used in underwater task that requires long operating period and at the same time covering a wide area of operation. AUV capable of doing task without the need of pilot, preprogrammed to its specific task and tethered free, thus enabling it to dive up to its maximum depth.

This project will implement the use of Web camera to capture images and later process by Roborealm software. Navigation of the ROV is by line tracking, in which several image processing techniques will be use to filter any unwanted image distortion and noises, focusing on specific line to follow. A USB webcam is used to capture image, which capable of delivering video acquisition rate of 30 frame per second (fps) and capable of capturing images with 1280x720 widescreen resolution.

## 3.4 HARDWARE IMPLEMENTATION

One of the important software used throughout this project is Roborealm. Purpose of using Roborealm is to process images before sending signals to microcontroller. Visual Basic script and Serial module available in Roborealm software act as the programming platform, establishing connection between the software and the microcontroller via serial connection. Other than that, Arduino Software is used to program the Arduino boards, that act as the microcontroller and plays important role in transmitting processed signal from Roborealm toward respective motor driver that later power up the thrusters.

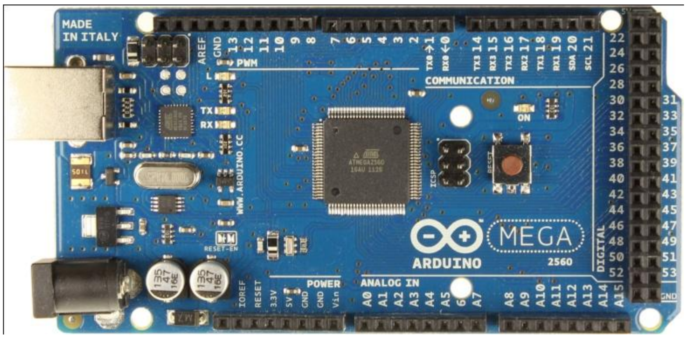


**Figure 3.5:** Arduino Mega 2560 microcontroller board

Source :Arduino (2011)

This project will implement the Arduino Mega 2560board that uses ATmega2560 microcontroller. Referring to (ArduinoBoardMega2560, 2012), Arduino Mega consist of 54 digital I/O pins, enabling this board to be the main board connecting the input from PlayStation 2 controller pins to driver ICs. The driver circuit schematic diagram is shown in Appendix A. Table below shown the pin configuration of Arduino and the motor driver.

| Abbreviation | Description |
|---|---|
| A1 and A2 | Pin 38 and 39 Arduino to pin 5 and 7 of IC1 |
| A3 and A4 | Output source from IC1 to DC motor 5 |
| B1 and B2 | Pin 34 and 35 Arduino to pin 10 and 12 of IC1 |
| B3 and B4 | Output source from IC1 to DC motor 4 |
| C1 and C2 | Pin 30 and 31 Arduino to pin 5 and 7 of IC2 |
| C3 and C4 | Output source from IC2 to DC motor 3 |
| D1 and D2 | Pin 26 and 27 Arduino to pin 10 and 12 of IC2 |
| D3 and D4 | Output source from IC2 to DC motor 2 |
| E1 and E2 | Pin 22 and 23Arduino to pin 5 and 7of IC3 |
| E3 and E4 | Output source from IC3 to DC motor 1 |
| X1 | From Pin 10 Arduino to Pin 6 of IC1 |
| X2 | From Pin 8 Arduino to Pin 11 of IC1 |
| X3 | From Pin 6 Arduino to Pin 6 of IC2 |
| X4 | From Pin 4 Arduino to Pin 11 of IC2 |
| X5 | From Pin 2 Arduino to Pin 6 of IC3 |
| IC1, IC2 and IC3 | L298 Motor driver |

**Table 3.2 :**Arduino and motor driver pin configuration

## 3.5 CONTROL SIMULATION USING SIMULINK

In this thesis, Matlab serve as the environment for numerical computation and visualization, enabling control system of the ROV to be simulated and thus allow users to tune their own controller by using PID tune function available in the software. All of the functions required were taken from Chapter 2 of this thesis, and only surge, yaw and heave movement and equation is used in this simulation. The simplified equation of those three movements is listed as below,

$$10.99\dot{u} \ + 24u = F \tag{43}$$

$$-744.19\dot{w} - 1.38w - 55 = F \tag{44}$$

$$-14.59\dot{r} \ + \ 6.67r = T \tag{45}$$

By using those three equations, Simulink is used to simulate and obtain the desired control system, at the same time tuning the system to produce a stable system. Diagrams below showed the block diagram of each movement, noting that the value of PID was tune by using the function block parameters of the PID controller and manual tuning from Simulink. Block diagram of simulation and PID value is stated below, while the result from simulation can be view in Chapter 4.

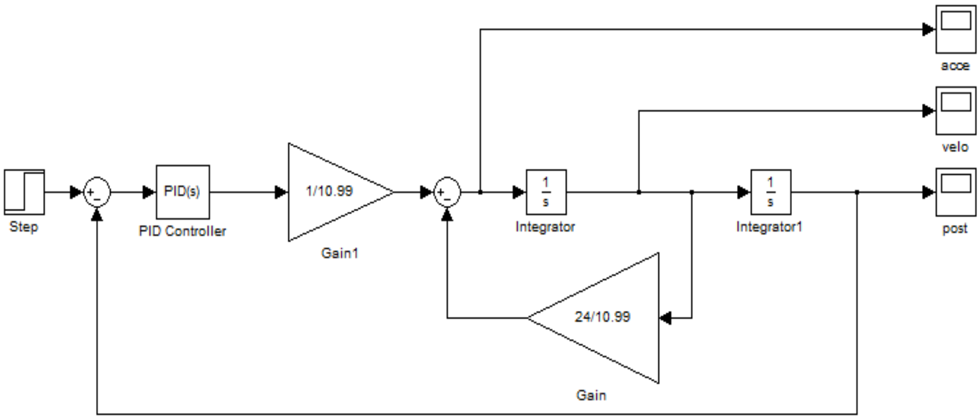


**Figure 3.6:** Surge block diagram

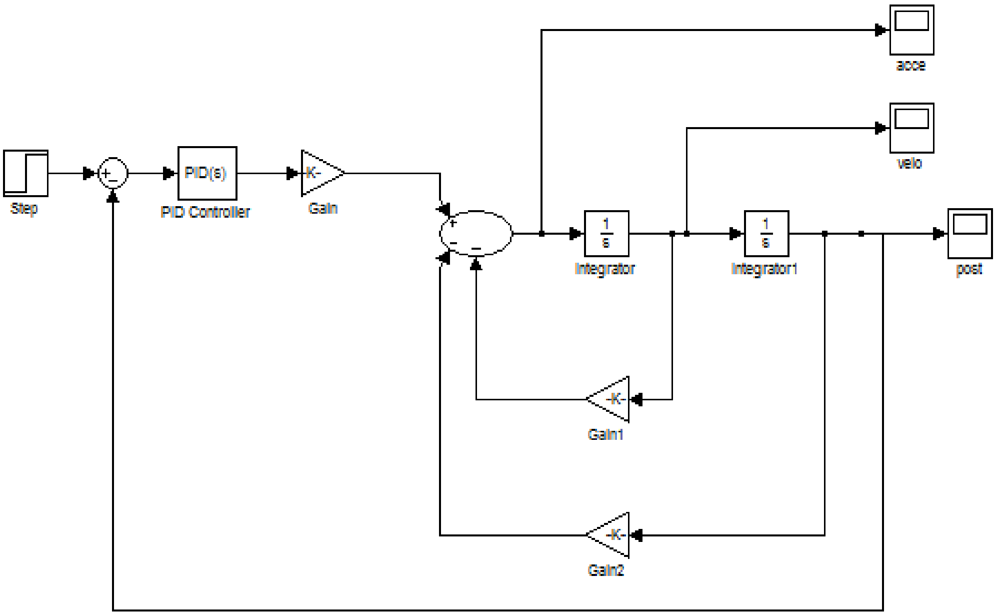


**Figure 3.7:** Heave block diagram

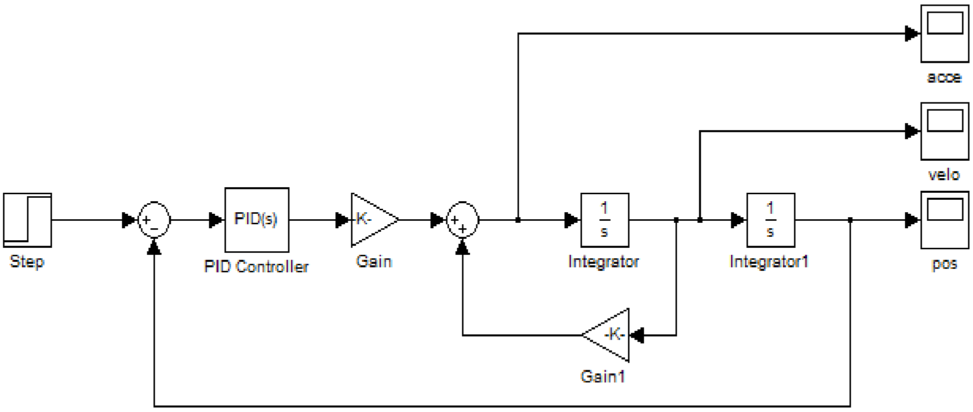


**Figure 3.8:** Yaw block diagram

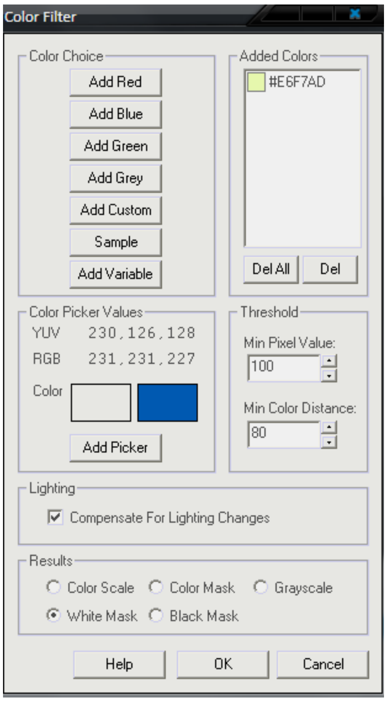
## 3.6 IMAGE PROCESSING TECHNIQUE

### 3.6.1 Image Acquisition

A USB webcam is used for video acquisition. Presetting of the webcam allow users to use any image resolutions, for this purpose, a resolution of 320x160 is use at a rate of 15fps. The webcam is mounted at different position inside the ROV compartment depends on which movement to test.

### 3.6.2 Color Filter

Figure 3.9 shows color filter module that is use to filter out any unwanted colors of the lines. Desired color can be vary due to lighting changes, with this module several ranges of color can be place together as desired and at the same time compensate with the changes due to lighting issues. Results allow output images to be change into any color for further use.



#E6F7AD

YUV 230,126,128

RGB 231,231,227

Min Pixel Value: 100

Min Color Distance: 80

☑ Compensate For Lighting Changes

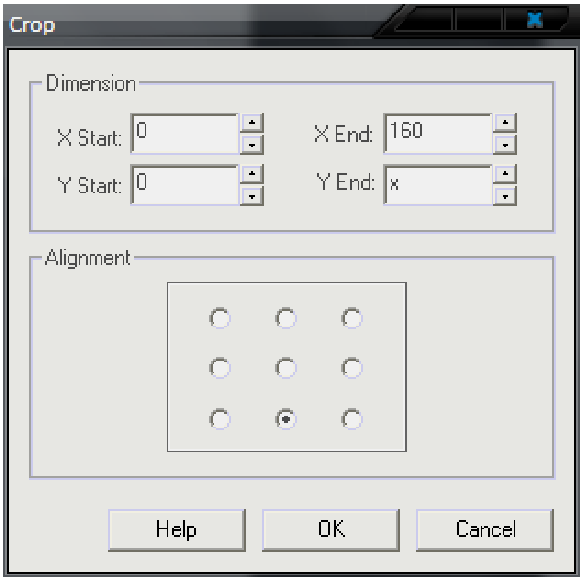
○ Color Scale ○ Color Mask ○ Grayscale

● White Mask ○ Black Mask

**Figure 3.9: Color filter module**

### 3.6.3 Crop Feature

This module allow user to remove unwanted part of the image in two different ways. One is by dimension setting, in which we can alter the image dimension by key in any value of start and stop of both X and Y axis as long as the size do not exceed or less than the actual image resolution.



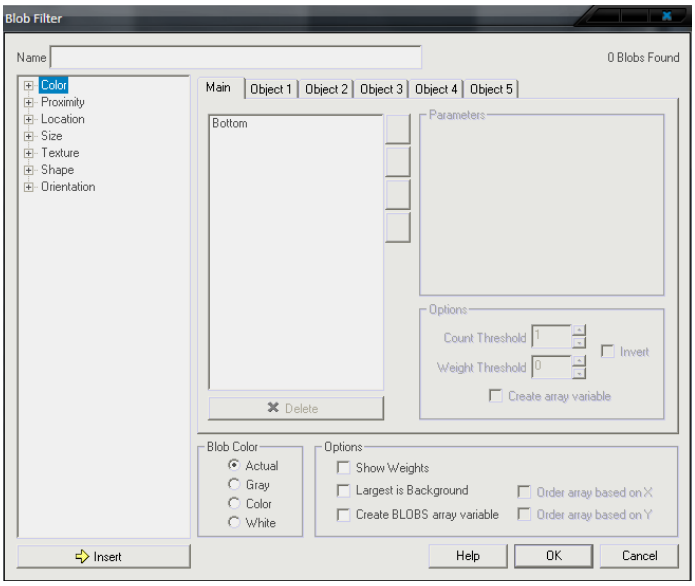
X Start: 0
X End: 160
Y Start: 0
Y End: x

○ ○ ○
○ ○ ○
○ ● ○

Figure 3.10: Crop image module

### 3.6.4 Blob Filter

Blob filter is use in order to remove any unwanted image that disturb the actual image to focus on. Any noise resemble desired image in term of color will cause later process to be inefficient and with this module, those noise can be remove so that only one blob is use as reference for next process.



Count Threshold 1
Weight Threshold 0
□ Invert
□ Create array variable

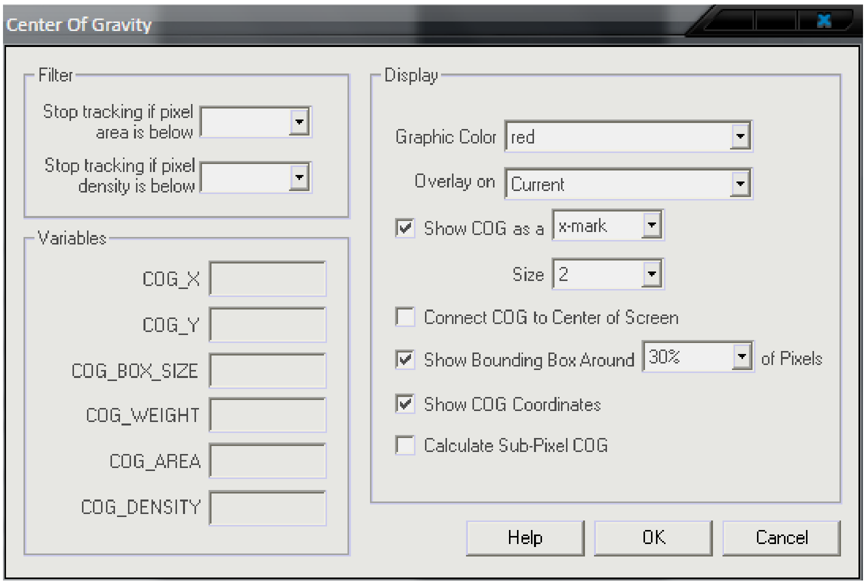
Blob Color
● Actual
○ Gray
○ Color
○ White

Options
□ Show Weights
□ Largest is Background
□ Create BLOBS array variable
□ Order array based on X
□ Order array based on Y

**Figure 3.11: Blob filter module**

### 3.6.5 Center of Gravity

Center of gravity is use to find the center of the lines from the image; enable a count value to increase each time when ROV passes one line. The variables COG_X and COG_Y are the final values of x and y center point of line. Either value will be use in the program as responded variables when testing control system.

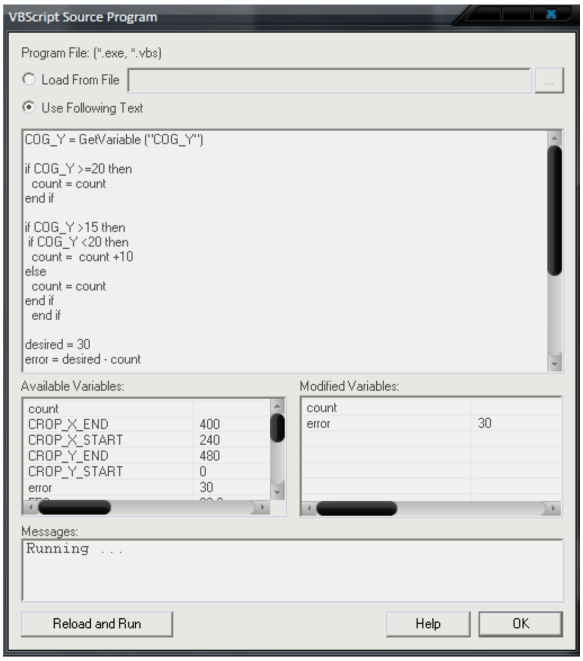


Graphic Color red
Overlay on Current
☑ Show COG as a x-mark
Size 2
□ Connect COG to Center of Screen
☑ Show Bounding Box Around 30% of Pixels
☑ Show COG Coordinates
□ Calculate Sub-Pixel COG

**Figure 3.12: Center of Gravity module**

### 3.6.6 VB Script Program

VB script plug in serve as a way to create custom scripts that is useful for statistics processing before sending the values anywhere required. With this a quick custom operations can be perform without the need of other plugin.



```
COG_Y = GetVariable ("COG_Y")

if COG_Y >=20 then
  count = count
end if

if COG_Y >15 then
 if COG_Y <20 then
  count =  count +10
else
  count = count
end if
  end if

desired = 30
error = desired - count
```

| Available Variables: | |
|---|---|
| count | |
| CROP_X_END | 400 |
| CROP_X_START | 240 |
| CROP_Y_END | 480 |
| CROP_Y_START | 0 |
| error | 30 |

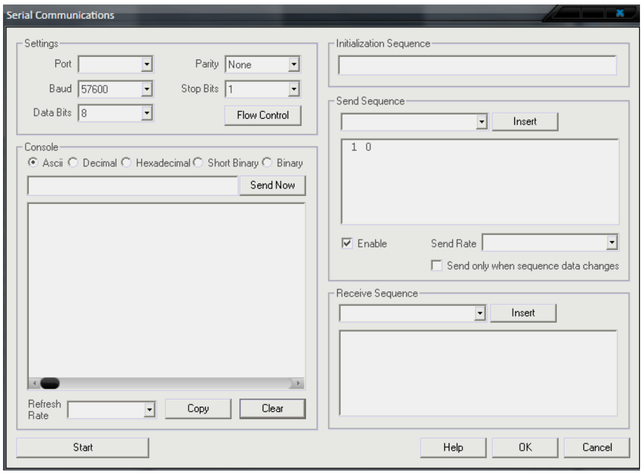
| Modified Variables: | |
|---|---|
| count | |
| error | 30 |

```
Running ...
```

Figure 3.13: VB script program module

### 3.6.7 Serial communication

The serial communication module allows Roborealm to communicate with serial based controllers and in this project, the Arduino Mega. This enables users to configure the communication port with various parameters and setting (port, baud, parity, etc).



Port
Parity None
Baud 57600
Stop Bits 1
Data Bits 8

● Ascii ○ Decimal ○ Hexadecimal ○ Short Binary ○ Binary

1 0

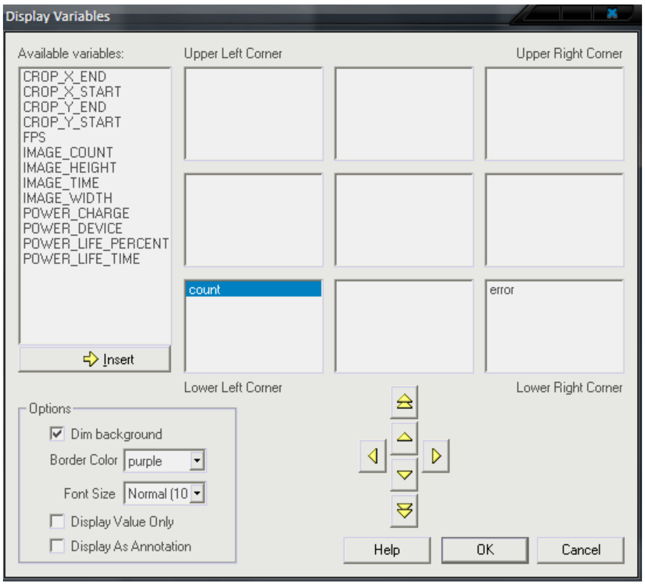
☑ Enable
Send Rate
□ Send only when sequence data changes

Refresh Rate

Figure 3.14: Serial communication module

### 3.6.8 Display Variables

Display any variables available that allow user to monitor the number of count when ROV passes marked lines.



CROP_X_END
CROP_X_START
CROP_Y_END
CROP_Y_START
FPS
IMAGE_COUNT
IMAGE_HEIGHT
IMAGE_TIME
IMAGE_WIDTH
POWER_CHARGE
POWER_DEVICE
POWER_LIFE_PERCENT
POWER_LIFE_TIME

count

error

☑ Dim background
Border Color purple
Font Size Normal (10
□ Display Value Only
□ Display As Annotation

Figure 3.15: Display variables module

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 INTRODUCTION

This chapter highlights results, findings and analysis of the project. The outcome of this research and discussion will be further explained on next chapter.

## 4.2 RESULTS AND FINDINGS

### 4.2.1 Image Processing

#### 4.2.1.1 Image Acquisition

Figure 4.1 shows the image of line marking on the bottom of water tank that will be the guide for ROV. Image was captured using webcam mounted on the bottom of ROV compartment, with resolution of 320 X 160.

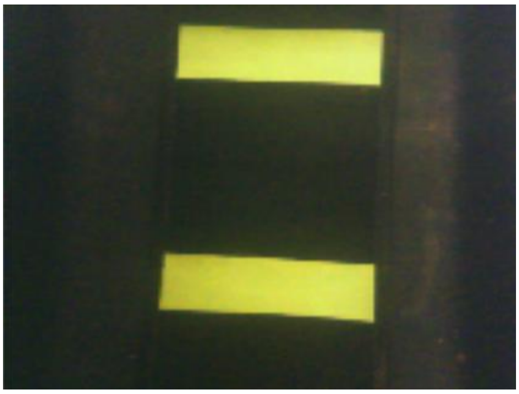


**Figure 4.1: Yellow lines marking**

### 4.2.1.2 Color Filter

Color filter module applied enable only specific color to be visible, and in this case the color yellow was filtered and turned into white mask. As can be seen up to this module, several noise and unwanted image can be seen on the figure.

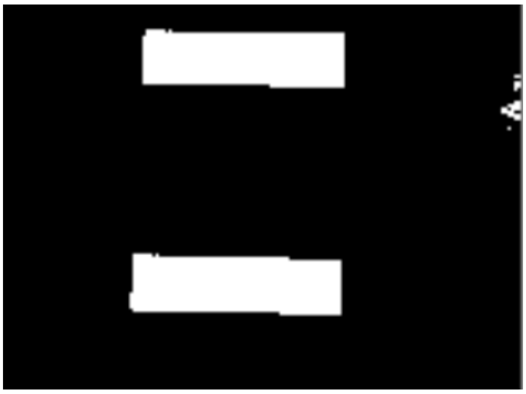


**Figure 4.2 : Yellow color filtered**

### 4.2.1.3 Blob Filter

This module eliminates the unwanted images and noises, only focus image is clearly visible for further purpose. As can be seen, only the yellow tape is visible where other noises were not visible in the image.

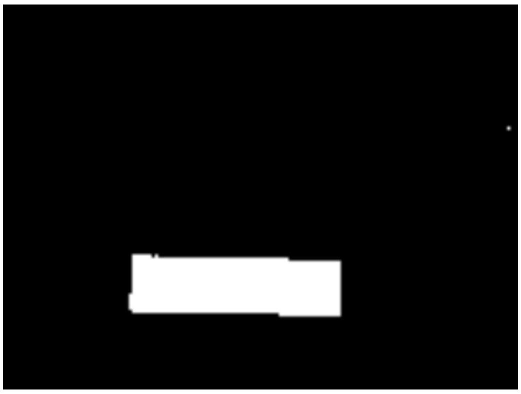


**Figure 4.3: Blob filter**

### 4.2.1.4 Center of Gravity

Red mark on Figure 4.4 shows the center of gravity or center of mass of the line. X and Y values on the box simply means the coordinates of the line center with respect to the resolution of the image, and in this case the coordinate of the center line is; X equal to 72 and Y equal to 33.

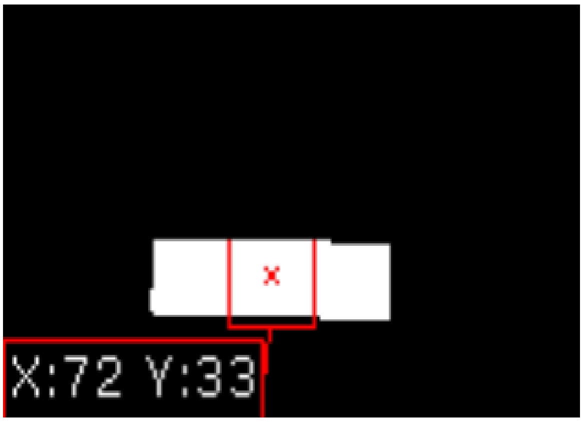


**Figure 4.4: Center of gravity**

### 4.2.1.5 VB Script Program

The program written in this module stated that when the COG_X or COG_Y passes certain point on the image, the count will add 10 to the value. When the ROV move as it passes the lines, the count value will increase by 10 until the desired value achieved causes the ROV to stop move and counting stops and reset to zero. As example, a range of gap was introduced on Y coordinates, where the count value is only allowed to increase when the COG of the marked line passes the predefined gap. The sample program can be view in Appendix B.

### 4.2.1.6 Serial Communication

In serial communication, port and baud rate settings is based on the connection of Arduino to the desktop, and the speed can be adjust to any value available, for this project baud rate of 57600 is chosen to accommodate the baud rate of Arduino program. Table below shows the value setting for serial communication:

| Settings | Value |
|---|---|
| Port | COM3 (port setting differs according to USB Ports) |
| Baud | 57600 |
| Data bits | 8 |
| Parity | NONE |
| Stop bits | 1 |

**Table 4.1 : Serial communication setting**

### 4.2.2 Control System Experiments

The control system is tested by using different experiment set up. More details explanations and figures can be view from next chapter. Below is the basic flowchart on how Arduino will perform its process, and sample program can be view in Appendix C.

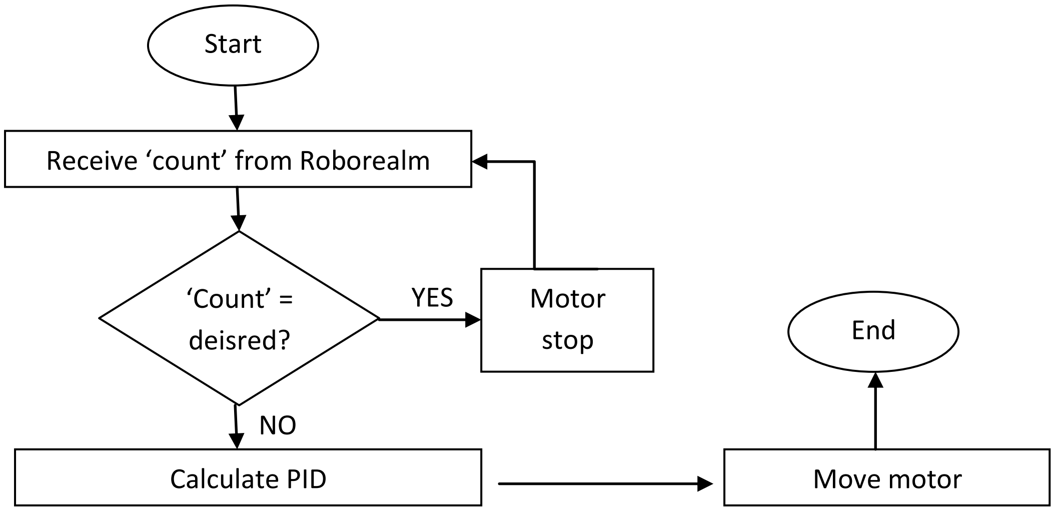


**Figure 4.5 :Arduino flowchart**

#### 4.2.2.1 Surge

Surge test of ROV was done by marking the flow on the water tank bottom. USB webcam is placed inside, at the bottom of ROV compartment to enable image capture of the line marking. The distance between each yellow marked line is 10 cm, where the set point value or desired was 40 cm. Due to limitation of water tank size, only small distance movement can be perform.

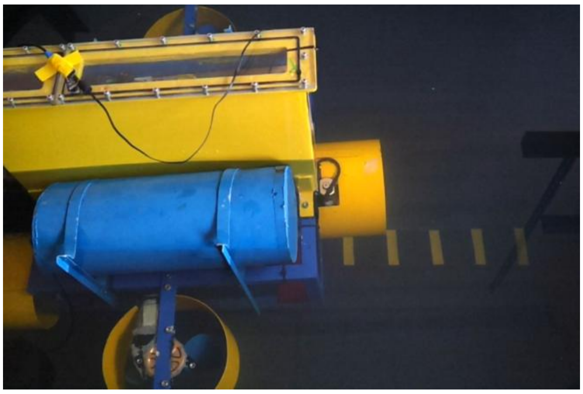


**Figure 4.6 : Surge test**

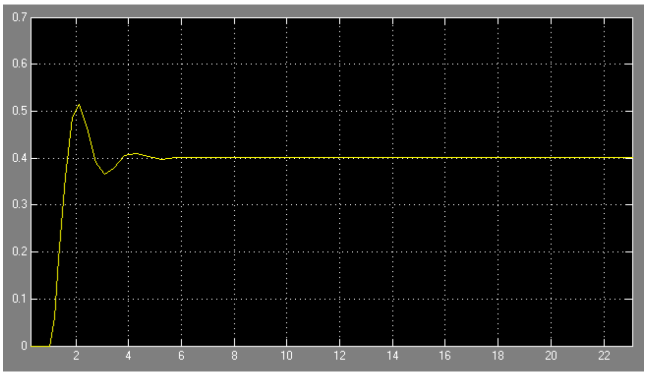


**Figure 4.7 : Simulink simulation for surge**

#### 4.2.2.2 Heave

For heave test, a mark was placed in front of the ROV to observe on how the ROV will maneuver itself to submerge. Each yellow marking resemble as 10cm submerge, where the ROV is tested to perform at maximum tank depth.

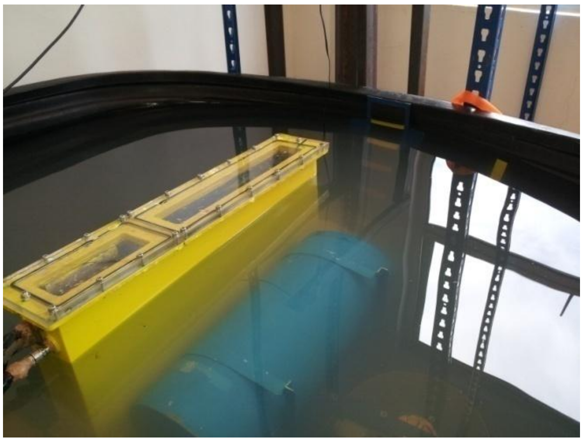


**Figure 4.8 : Heave test**

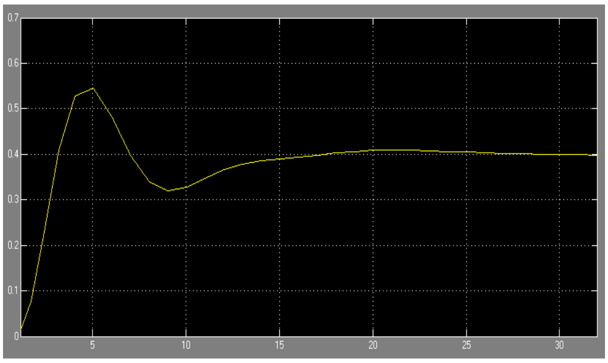


**Figure 4.9 : Simulink simulation for heave**

### 4.2.2.3 Yaw

Yaw was tested to see on how the ROV perform its turn movement. The ROV was observed to see on how it reacts to a 90° turn. The tank was mark according to the angles in which the ROV will follow to move from initial 0° to desired position of 90°.

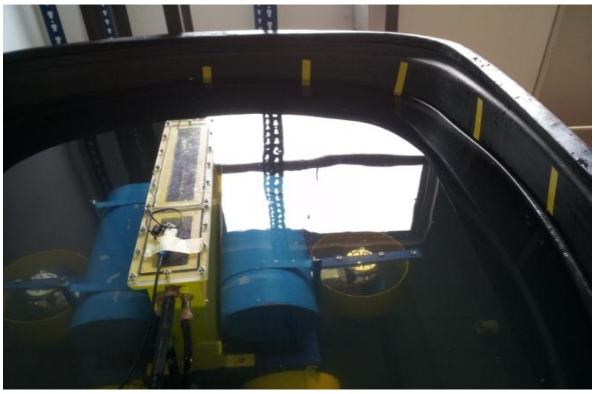


**Figure 4.10 : Yaw test**

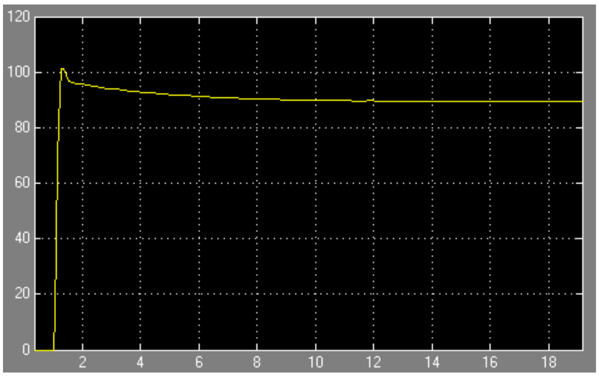


**Figure 4.11 : Simulink simulation for yaw**

## 4.3 DISCUSSIONS

During those two tests conducted several problem was encountered regarding on the stability of ROV. The ballast tank and weight position had to be changed to encounter this problem. Marking used was easily affected by the lightning condition where processed image from Roborealm can be easily distorted, where light caused glare on webcam. Due to the milky condition of water that disturbs the image processing, several test were done to achieve desirable observation. Other than that, the test can only be conducted for a short time due to heat problem of the motor driver, thus fans are placed next to motor driver to reduce the heat problem and longer period of test was achievable before replacing the circuit with relays.

On surge test, ROV managed to achieve the desired point and a little overshoot was observed after it stopped where it glides up to another marking line. Overall control system of this movement is acceptable where the ROV manage to get to the desired point with tolerable overshoot of about 25% or 0.1 meter.

Heave test was not successful due to several problems and limitation. Due to small water tank, only 10cm of submerge was able to be test where the initial desired depth targeted was to be 30cm depth. When the ROV submerge, it hit the bottom of tank, causing it to bounce back and blew the motor driver due to high current being pulled by the motor that exceeded the limit of the driver.

For yaw test, throughout several tests conducted to achieve its desired position, it was noticed that the water tank contribute to a large limitation where the ROV will easily hit its rear to the tank. After a few test, the ROV turned constantly overshoot the desired stop, proving the control system simulation result. Through observation of tests conducted the motor stop at 90° before glide to additional 10° to 20° or equivalent to 11% to 22%.

USB cable length plays important role in keeping the data safely transferred. For USB webcam, a powered USB hub was used to help in keeping the data transfer smoothly without any data loss and minimum cable length should be use to ensure data consistency.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 INTRODUCTION

This chapter elaborates finding and conclusion on this project. Other than that, development and brief recommendation is stated for future improvement on continuing this project in developing the remotely operated underwater vehicle.

## 5.2 CONCLUSION

As for conclusion, control system is crucial in any system application such as for this project. Purpose of this project is to develop and test the control system of ROV, in which the behavior of the vehicle can be observed while testing to ensure a smooth and stable movement. Main objective was to develop and maneuver ROV to perform its basic movements which are surge, heave and yaw. Autonomous controlling method was used to control the vehicle, and several changes with simple modification was done on the vehicle.

Another objective of this thesis was to develop control system of the vehicle, which was achieved by using Matlab to simulate the control behavior. The results of simulation for all three movements can be view in Figure 4.7, 4.9 and 4.11.This graph shows the control system graph for respective movement.

The third objective to test the control system and observe behavior was performed by applying autonomous control method, where webcam was used to capture images to be process by Roborealm. Two tests were managed to be performed and several predicted behavior was observed based on simulation.

In real world application, underwater vehicle contribute to numerous fields, from sea floor research to monitoring sea activity that requires a precise and stable vehicle to perform those task. From this project, a real world application of the vehicle can be experience with the basic control system and experimental activity conducted in completing this thesis.

## 5.3 FUTURE DEVELOPMENT

For future improvement, it is suggested that the ROV balance is recheck each time before testing purpose due to unstable condition that can be cause by the misalignment of the ballast tank. Another important consideration is to replace the cable piping that can easily tear from the result of constantly wet and dry condition of its surrounding. Cables connector from outside of the compartment to inside should be consider on replacing with a more proper and suitable type of connector. Other type of motor driver circuit should be considered in order to have longer period of testing.

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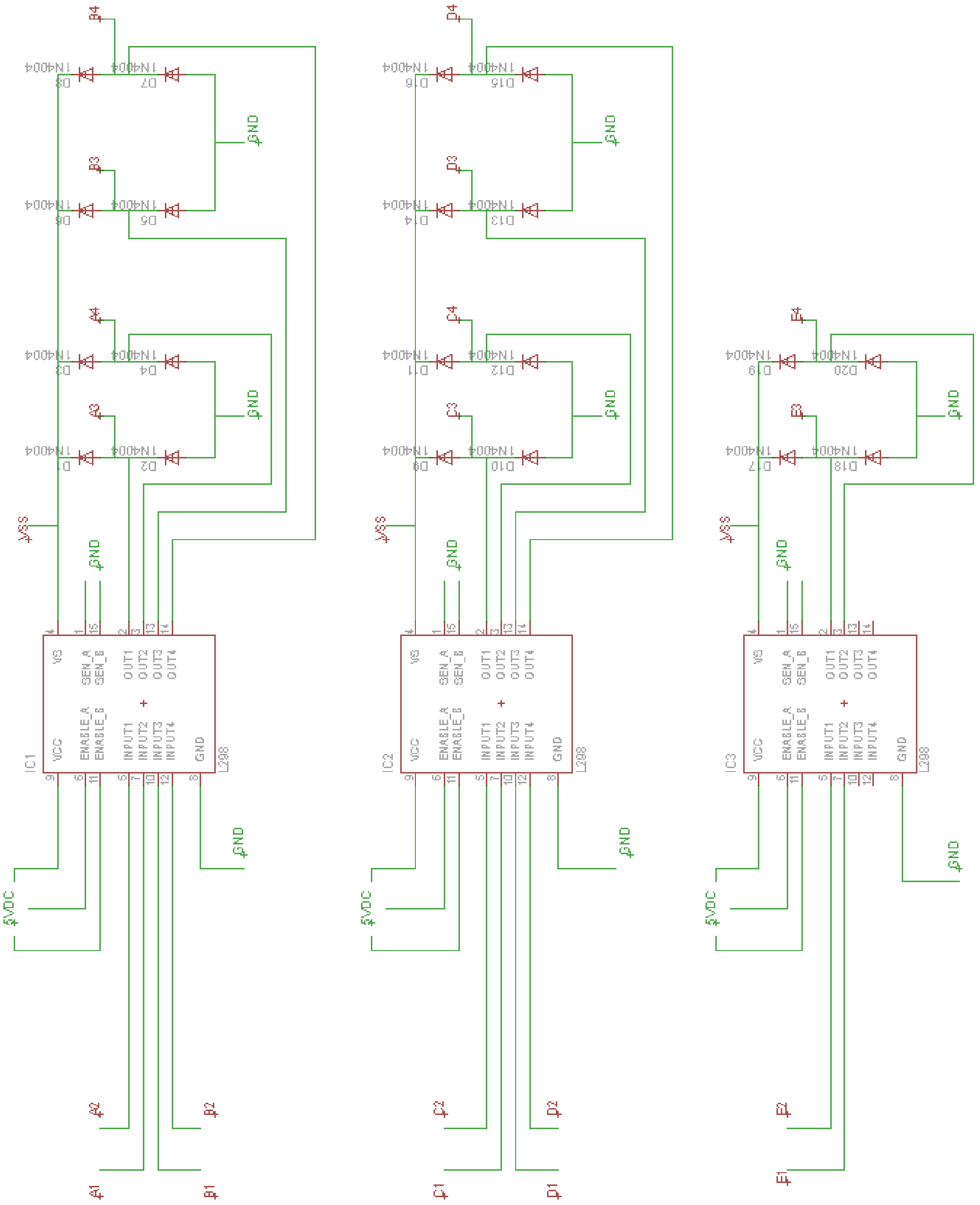
# APPENDIX A

## MOTOR DRIVER CIRCUIT



# APPENDIX B

## ROBOREALM VB SCRIPT SAMPLE PROGRAM

```
COG_X = GetVariable ("COG_X")

if COG_X <=200 then
 if COG_X >=205 then
  count = count
 end if
end if

if COG_X >200 then
 if COG_X <205 then
  count =  count +10
else
  count = count
end if
  end if

‘desired = 40
if count > 40 then
  count = 40
end if

SetVariable "count", count
```

# APPENDIX C

## ARDUINO SAMPLE PROGRAM

```
int pwr = 13;

int m1_pwm = 2;
int m1_inputA = 22;
int m1_inputB = 23;

int m3_pwm = 6;
int m3_inputA = 30;
int m3_inputB = 31;

int m4_pwm = 8;
int m4_inputA = 34;
int m4_inputB = 35;

int m5_pwm = 10;
int m5_inputA = 38;
int m5_inputB = 39;

int m2_pwm = 4;
int m2_inputA = 26;
int m2_inputB = 27;

int data_available;
int count;
double error, prev_error,integral,derivative,calc_PID;
int perc_PID;
int sampletime = 10;

unsigned long lastTime;
unsigned long now;

void setup()
{
  Serial.begin(57600);

  pinMode(m1_pwm, OUTPUT);
  pinMode(m1_inputA, OUTPUT);
  pinMode(m1_inputB, OUTPUT);

  pinMode(m3_pwm, OUTPUT);
  pinMode(m3_inputA, OUTPUT);
  pinMode(m3_inputB, OUTPUT);

  pinMode(m4_pwm, OUTPUT);
  pinMode(m4_inputA, OUTPUT);
  pinMode(m4_inputB, OUTPUT);

  pinMode(m2_pwm, OUTPUT);
  pinMode(m2_inputA, OUTPUT);
  pinMode(m2_inputB, OUTPUT);
  pinMode(m5_pwm, OUTPUT);
  pinMode(m5_inputA, OUTPUT);
  pinMode(m5_inputB, OUTPUT);
}
void loop()
{
    if(Serial.available()> 0)
   {

     data_available = Serial.parseInt();
     count = Serial.parseInt();

     int desired = 40;
     if (count == 40) /
       {
         motorstop(m1_inputA,m1_inputB);
         motorstop(m3_inputA,m3_inputB);
         motorstop(m4_inputA,m4_inputB);
       }
     else
       {
         unsigned long now = millis();
         int timechange =(now -lastTime);
         if(timechange>=sampletime)
         {
         double sampletimeinsec = ((double)sampletime)/1000;
```

```
        double error = desired - count;
        integral += error*sampletimeinsec;
        double derivative = (error - prev_error)/sampletimeinsec;

        double kp = ; //key in value PID here
        double ki = ;
        double kd = ;

        calc_PID = kp*error + ki*integral + kd*derivative;

        prev_error = error;
        lastTime = now;

        perc_PID = calc_PID;
        move_motor(m1_inputA, m1_inputB, m1_pwm,perc_PID);
        move_motor(m3_inputA, m3_inputB, m3_pwm,perc_PID);
        move_motor(m4_inputA, m4_inputB, m4_pwm,perc_PID);
        }
      }

    }
}

void motorstop (int motorinputA, int motorinputB)
{
    digitalWrite(motorinputA,LOW);
    digitalWrite(motorinputB, LOW);
}
```

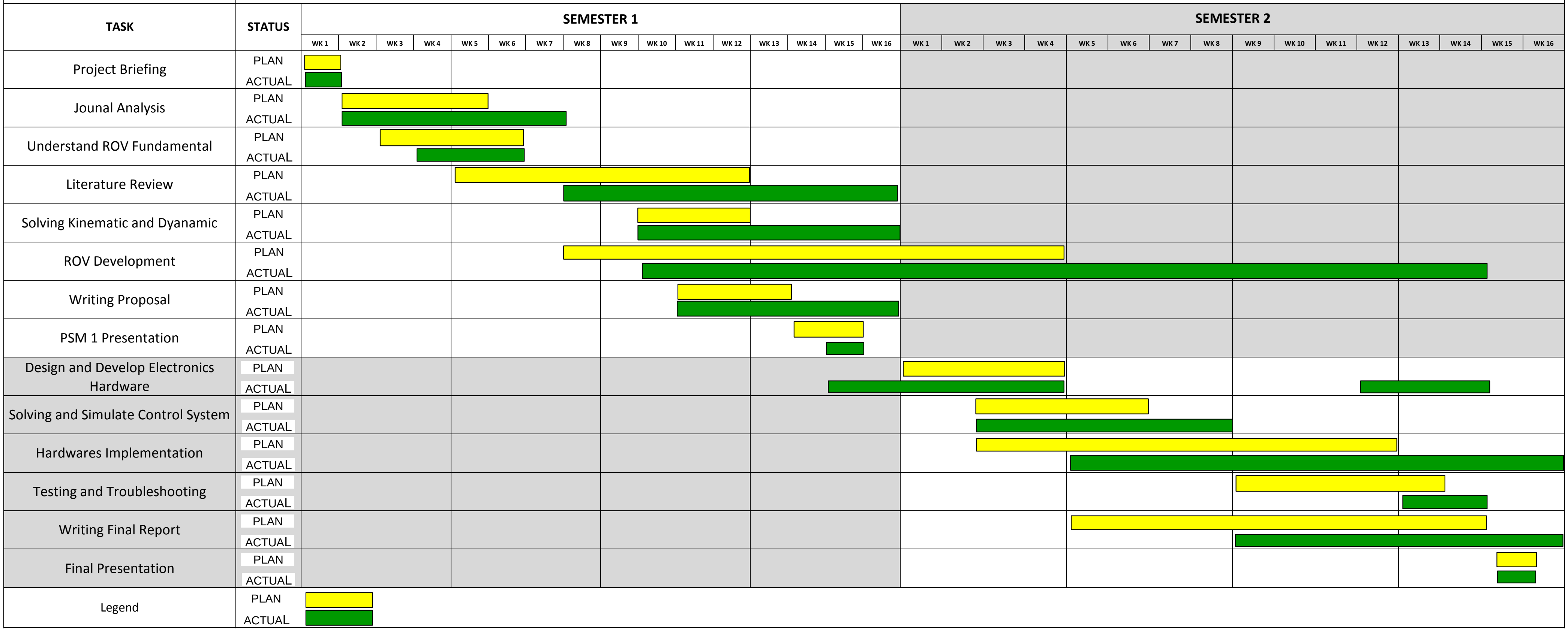
```
void move_motor ( int motorinputA, int motorinputB, int motorpwm, int PID)
{
  if (PID <= -1)
  {
     analogWrite(motorpwm, 150);
     digitalWrite(motorinputA,LOW);
     digitalWrite(motorinputB,HIGH);
  }

   if (PID == 0)
  {
     analogWrite(motorpwm, 0);
     digitalWrite(motorinputA,LOW);
     digitalWrite(motorinputB,LOW);
  }

   if (PID >= 1)
  {
     analogWrite(motorpwm, 200);
     digitalWrite(motorinputA,HIGH);
     digitalWrite(motorinputB,LOW);
  }
  else
  {}
}
```

APPENDIX D

# GANTT CHART OF FINAL YEAR PROJECT


TASK
STATUS
SEMESTER 1
WK 1
WK 2
WK 3
WK 4
WK 5
WK 6
WK 7
WK 8
WK 9
WK 10
WK 11
WK 12
WK 13
WK 14
WK 15
WK 16
SEMESTER 2
WK 1
WK 2
WK 3
WK 4
WK 5
WK 6
WK 7
WK 8
WK 9
WK 10
WK 11
WK 12
WK 13
WK 14
WK 15
WK 16
Project Briefing
PLAN
ACTUAL
Jounal Analysis
PLAN
ACTUAL
Understand ROV Fundamental
PLAN
ACTUAL
Literature Review
PLAN
ACTUAL
Solving Kinematic and Dyanamic
PLAN
ACTUAL
ROV Development
PLAN
ACTUAL
Writing Proposal
PLAN
ACTUAL
PSM 1 Presentation
PLAN
ACTUAL
Design and Develop Electronics Hardware
PLAN
ACTUAL
Solving and Simulate Control System
PLAN
ACTUAL
Hardwares Implementation
PLAN
ACTUAL
Testing and Troubleshooting
PLAN
ACTUAL
Writing Final Report
PLAN
ACTUAL
Final Presentation
PLAN
ACTUAL
Legend
PLAN
ACTUAL