Sudan University of Science and Technology

College of Engineering

School of Electrical and Nuclear Engineering

Design and Implementation of Remotely Operated Underwater Vehicle

تصميم وتنفيذ مركبة تعمل تحت الماء يتم التحكم فيها عن بعد

A Project Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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الآية

قال تعالى :

بسم الله الرحمن الرحيم

" إِنَّ فِي خَلْقِ السَّمَاوَاتِ وَالْأَرْضِ وَاخْتِلَافِ اللَّيْلِ وَالنَّهَارِ وَالْفُلْكِ الَّتِي تَجْرِي فِي الْبَحْرِ بِمَا يَنفَعُ النَّاسَ وَمَا أَنزَلَ اللَّهُ مِنَ السَّمَاءِ مِن مَّاءٍ فَأَحْيَا بِهِ الْأَرْضَ بَعْدَ مَوْتِهَا وَبَثَّ فِيهَا مِن كُلِّ دَابَّةٍ وَتَصْرِيفِ الرِّيَاحِ وَالسَّحَابِ الْمُسَخَّرِ بَيْنَ السَّمَاءِ وَالْأَرْضِ لَآيَاتٍ لِّقَوْمٍ يَعْقِلُونَ "

صدق الله العظيم

[سورة البقرة 164]

DEDICATION

As well as everything that we do, we would be honored to dedicate this work to our parents for their emotional and financial support, our brothers, our sisters and our friends, especially our friend **Seddig Sami,** whose has been a constant source of inspiration for us. They have given us the drive and discipline to tackle any task with enthusiasm and determination. Without their love and support this project would not have been made possible.

ACKNOWLEDGEMENT

First and above all, we praise God, the almighty for providing us this opportunity, and granting us the capability to proceed successfully. Grateful for this opportunity, we would like to give our sincere thanks to our supervisor**,** **Dr. Awadalla Taifour Ali** for his valuable guidance continues encouragement, suggestions, constructive ideas and advice in assisting us to complete this work.

ABSTRACT

ROV refers to Remotely Operated underwater Vehicle, it is a tethered vehicle which can be controlled by an operator on the surface without the need for the diver. The ROV can perform many tasks in different underwater fields. The main goal of this project is to develop and improve a small scale of underwater vehicle that can be used for pipelines Inspection and Environmental Investigation and make it more suitable for industrial use, also to document in detail how a small scale ROV is constructed from the start.

The challenge is to build a small scale ROV to perform the same tasks. The result of this thesis is the creation of a small scale ROV moved with three direct current motors and controlled through a joystick, with a camera which monitors the movement of the ROV and the underwater life. The design has been developed successfully. The developed ROV is smaller and lighter with a suitable design to move smoothly.

Control and monitoring had been implemented, in addition to minimizing the cost, which make it suitable for widespread deep water industrial applications. There were not many unexpected problems during the construction of smaller scale ROV and the diver tests showed that the underwater vehicle works as planned. However, there is still possibility for further improvements, such as adding manipulators and increasing the working depth of the underwater vehicle.

مستخلص

يُعنى المشروع بدراسة مركبة تعمل تحت الماء يتم التحكم بها عن بعد بواسطة مشغل موجود على السطح دون الحاجة الى الغطس للتحكم بها، ويمكن لهذه المركبة أداء العديد من المهام في مختلف المجالات تحت الماء. الهدف الاساسي من هذا المشروع هو بناء وتطوير مركبة صغيرة تعمل تحت الماء بحيث يمكن إستخدامها في عمليات فحص خطوط انابيب البترول كما يمكن استخدامها في الدراسات البيئية تحت الماء وتطويرها بحيث تصبح ملائمة للتطبيقات الصناعية ، ايضا يهدف المشروع الى توثيق كيفية بناء وتصميم المركبة بالتفصيل من الخطوات الأولى وحتى الانتهاء من التصميم .

يتمثل التحدي في كيفية بناء مركبة صغيرة لها نفس الاداء ، نتيجة لذلك تم بناء مركبة بثلاث محركات تيار مباشر يتم التحكم فيها عن بعد بواسطة عصا تحكم ، وبإستخدام كاميرا على سطحها يمكن مراقبة حركتها بالاضافة الى تصوير الحياة تحت الماء. تم تصميم المركبة والسيطرة عليها لجعل حركتها اكثر سلاسة وتم تنفيذ النظام بحيث يشمل عملية المراقبة والتحكم معا لتقليل التكلفة مما قد يساعد في عملية انتشارها في التطبيقات الصناعية .

لم تكن هنالك مشاكل غير متوقعة اثناء تصميم المركبة واظهرت نتائج اختبارات الغوص ان المركبة تعمل بشكل جيد كما هو مخطط مسبقا، ولكن هنالك اماكنية لتحسين وتطوير المركبة باضافة ذراع آلي أو زيادة عمق عمل المركبة تحت الماء.

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LIST OF ABBREVIATIONS

ROV	Remotely Operated Vehicles
DC	Direct Current
SISO	Single-Input Single-Output
PID	Proportional-Integral-Derivative
MIMO	Multiple-Input Multiple-Output
CPU	Central Processing Unit
RAM	Random Access Memory
ROM	Read Only Memory
I/O	Input/Output
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
PC	Personal Computer
MUV	Manned Underwater Vehicle
UUV	Unmanned Underwater Vehicle
ADS	Atmospheric Diving Suit
AUV	Autonomous Underwater Vehicle
GPS	Global Positioning System
GC	Gravity Center
DOF	Degrees Of Freedom
NED	North-East-Down
USB	Universal Serial Bus
IDE	Integrated Development Environment
IMU	Inertial Measurement Unit
ATX	Advanced Technology eXtended
GUI	Graphical User Interface
PVC	PolyVinyl Chloride
LABVIEW	LABoratory Virtual Instrument Engineering Workbench

LIST OF SYMBOLS

W	Weight, N
m	Mass, kg
g	Local gravitational, m/s^2
F_b	Buoyant force, N
ρ_l	Fluid density, kg/m^3
v_{olume}	Fluid volume, m^3
F_D	Drag force, N
v	Speed of the object relative to the fluid, m/s
A	Cross-sectional area, m^2
C_D	Drag coefficient, a dimensionless number
P	Rotate around X axis
q	Rotate around Y axis
r	Rotate around Z axis
ϕ	Rotation angle of X axis
θ	Rotation angle of Y axis
ψ	Rotation angle of Z axis
u	Translation velocity around X axis
v	Translation velocity around Y axis
w	Translation velocity around Z axis

CHAPTER ONE

INTRODUCTION

1.1 General Concepts

During the last 30 years the need for oceanic cartography, sea exploration and underwater oil extraction has led to the creation of an underwater vehicle that can be controlled from a distance. Remotely Operated Vehicles (ROVs) are unoccupied robots operated underwater and controlled by a person on a ship or boat. ROVs were created to help people to fulfill their needs fast and with minimum risk for their lives. ROVs are easy to maneuver through the water and are linked to the ship with a group of cables that carry electrical signals back and forth between the operator and the ROV.

ROV has a camera and lights. Additional equipment is often added to the ROV to increase its capabilities. For example still camera, arm robot, water samplers, light, also instruments that measure water clarity, and temperature. ROVs were first developed for industrial purposes, such as inspections of pipelines and testing the structure of offshore platforms. However, ROVs are used for many applications, many of them are scientific [7].

1.2 Problem Statement

To design, test, and build an ROV capable of performing different tasks underwater to solve the problem that human cannot work effectively underwater. These problems happened when investigation underwater runs by the police, inspection or research in some unknown river or sea activities, it happened when people have lots of difficulties to do their jobs especially in the deep sea, dangerous underwater area and toxic water.

Furthermore, the period is also limited to human to work underwater unless for professional divers. Nonetheless, in any works, due to many issues of human, it was always a troublesome matter. Hence, in doing any jobs underwater will give a huge trouble.

1.3 Objectives

The main objectives of this study are:

- Simulate the controlling of vehicles.
- Design of ROV.
- Implementation of ROV.
- Testing of ROV.
- To develop communication between Direct Current (DC) motor of the ROV and computer.
- To control the speed, position and direction of the ROV.

1.4 Methodology

- Study all of previous studies.
- Research about controlling vehicles.
- Drawing the block diagram.
- Drawing the wire diagram.
- Starting with the programming logic.
- Testing the operating system.
- Design an ROV underwater.

1.5 Thesis Layout

This project consists of five chapters: Chapter one gives an introduction about the principles of the project, in addition its reasons, motivation and objectives. Chapter two discusses the literature review of control systems, remotely control system, microcontroller System, remotely operated vehicle. Chapter three describes the mechanical part, the electrical part, software and hardware.

Chapter four shows the system implementation also shows the experimental results. Finally, chapter five provides the conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Control System

There are two major divisions in control theory, namely, classical and modern, which have direct implications over the control engineering applications. The scope of classical control theory is limited to Single-Input and Single-Output (SISO) system design, except when analyzing for disturbance rejection using a second input. The system analysis is carried out in the time domain using differential equations, in the complex-s domain with the Laplace transform, or in the frequency domain by transforming from the complex-s domain. Many systems may be assumed to have a second order and single variable system response in the time domain. A controller designed using classical theory often requires on-site tuning due to incorrect design approximations. Yet, due to the easier physical implementation of classical controller designs as compared to systems designed using modern control theory, these controllers are preferred in most industrial applications. The most common controllers designed using classical control theory is Proportional-Integral-Derivative (PID) controllers. A less common implementation may include either or both a lead and lag filter [1].

Ultimate the end goal is to meet requirements set typically provided in the time-domain called the Step response, or at times in the frequency domain called the Open-Loop response. The Step response characteristics applied in a specification are typically percent overshoot, settling time, etc. The open-loop response characteristics applied in a specification are typically Gain and Phase margin and bandwidth. These characteristics may be evaluated through simulation including a dynamic model of the system under control coupled with the compensation model. In contrast, modern control theory is carried out in the state space, and can deal with Multiple-Input and Multiple-Output (MIMO) systems. This overcomes the limitations of classical control theory in more sophisticated design problems, such as fighter aircraft control, with the limitation that no frequency domain analysis is possible. In modern design, a system is represented to the greatest advantage as a set of decoupled first order differential equations defined using state variables. Nonlinear, multivariable, adaptive and robust control theories come under this division. Matrix methods are significantly limited for MIMO systems where linear independence cannot be assured in the relationship between inputs and outputs [2].

A control system is a device, or set of devices, that manages, commands, directs or regulates the behavior of other devices or systems. Industrial control systems are used in industrial production for controlling equipment or machines [2]. There are two common classes of control systems, open loop control systems and closed loop control systems. In open loop control systems output is generated based on inputs. In closed loop control systems current output is taken into consideration and corrections are made based on feedback. A closed loop system is also called a feedback control system.

2.1.1 Open-loop control systems

In an open-loop control system, the controller independently calculates exact voltage or current needed by the actuator to do the job and sends it. With this approach, however, the controller never actually knows if the actuator did what it was supposed to because there is no feedback. This system absolutely depends on the controller knowing the operating characteristics of actuator [3].

The actuator on the process are very repeatable and reliable. Relays and stepper motors are devices with reliable characteristics and are usually open-loop operations. Actuators such as motors or flow valves are sometimes used in open-loop operation, but they must be calibrated and adjusted at regular intervals to ensure proper system operation [3].

2.1.2 Closed-loop control systems

In a closed-loop control system, the output of the process (controlled variable) is constantly monitored by a sensor; the sensor samples the system output and converts this measurement into an electric signal that it passes back to the controller. Because the controller knows what the system is actually doing, it can make any adjustment necessary to keep the output where it belongs. The signals from the controller to the actuator are the forward path, and the signal from the sensor to the controller is the feedback. The feedback signal is subtracted from the set point at the comparator [3].

The self-correcting feature of closed-loop control makes it preferable over open-loop control in many applications, despite the additional hardware required. This is because closed-loop system provides reliable, repeatable performance even when the system components themselves are not absolutely repeatable or precisely known [3].

2.2 Remotely Control System

Remote control is a means to operate a robot using human intelligence, which requires the availability of adequate human-machine interface. The main function of the Remote control system is to assist the operator to perform and accomplish complex, uncertain tasks in hazardous and less structured environments, such as space, nuclear plants, battlefield, surveillance, and underwater operations [4].

Robots have demonstrated a unique capacity to take on roles too difficult, too dangerous, or too undesirable for human workers. Industries have employed robots in hazardous work environments for decades. Urban search and rescue teams have also deployed robots in hope of locating survivors. In each of these situations, robots have served their purpose in places where humans cannot follow [4].

There is still a limit, however, on the complexity of the tasks that robots can perform autonomously. Therefore, it is sometimes vital that a human be able to control the robot from a distance. This has led to the development of remotely operated robots, which can be controlled remotely by human operators. A remotely operated robot is able to benefit from a human's perception, judgment, and adaptability, while the operator has the safety and convenience of a remote location. Unfortunately, many of the weaknesses of the current robot control interfaces are amplified when the user is in a remote location.

Various user interfaces, including joysticks, teach pendants and virtual reality interfaces, have been used to control robotic systems. Many of these interfaces attempt to present all necessary information for control of the robot to the operator through some sort of visual feedback. Remote operator is a machine that enables a human operator to move about, sense and mechanically manipulate objects at a distance. A remotely operated robot is a subclass of a remote operator. It is a robot that accepts instructions from a distance, generally from a human operator and performs live actions at a distant environment through the use of sensors or other control mechanisms. Usually it has sensors and effectors for manipulation and/or mobility, plus a means for the human operator to communicate with both.

Within the last two decades, different remotely operation systems have been developed to allow human operators to execute tasks in remote or hazardous environments, in a variety of applications ranging from space to underwater, nuclear plants, battlefields, surveillance, and so on. Remotely operation system tasks are distinguished by the continuous interaction between the human operators, remote operator system and the environment. With the development of Internet and other related technologies, the application of remotely operated robot becomes much wider and more indispensable than before [4].

2.3 Microcontroller

A microcontroller is a single-chip computer .Micro suggests that the device is small, and controller suggests that it is used in control applications. Another term for microcontroller is embedded controller, since most of the microcontrollers are built into or embedded in the devices that controlling. Microcontrollers have traditionally been programmed using the assembly language of the target device. Although the assembly language is fast, it has several disadvantages. An assembly program consists of mnemonics, which makes learning and maintaining a program written using the assembly language difficult. Also, microcontrollers manufactured by different firms have different assembly languages, so the user must learn a new language with every new microcontroller he or she uses. Microcontrollers can also be programmed using a high-level language, such as BASIC, PASCAL, or C. High-level languages are much easier to learn than assembly languages and also facilitate the development of large and Complex programs.

Microcontroller is a highly integrated chip that contains Central Processing Unit (CPU), Random Access Memory (RAM), Read Only Memory (ROM) and Input/output (I/O) ports. Unlike general-purpose computer, which also includes all of these components, microcontroller is designed for a very specific task to control a particular system. As a result, the parts can be simplified and reduced, which cuts down on production cost.

2.3.1 Microcontroller components

A microcontroller basically contains one or more following components:

- Central processing unit

Central Processing Unit is the brain of a microcontroller. CPU is responsible for fetching the instruction, decodes it, and then finally executed. CPU connects every part of a microcontroller into a single system. The primary function of CPU is fetching and decoding instructions. Instruction fetched from program memory must be decoded by the CPU.

- Memory

Memory in a microcontroller is same as microprocessor. It is used to store data and program. A microcontroller usually has a certain amount of RAM and ROM (EEPROM, EPROM, etc.) or flash memories for storing program source codes.

- Parallel input/output ports

Parallel input/output ports are mainly used to drive/interface various devices such as LCD’S, LED’S, printers, memories, etc. to a microcontroller.

- Serial interfacing ports

Serial ports provide various serial interfaces between microcontroller and other peripherals like parallel ports.

- Timers and counters

This is the one of the useful function of a microcontroller. A microcontroller may have more than one timer and counters. The timers and counters provide all timing and counting functions inside the microcontroller. The major operations of this section are perform clock functions, modulations, pulse generations, frequency measuring, making oscillations, etc. This also can be used for counting external pulses.

- Analog to digital converter

Analog to Digital Converter (ADC) converters are used for converting the analog signal to digital form. The input signal in this converter should be in analog form (e.g. sensor output) and the output from this unit is in digital form. The digital output can be used for various digital applications (e.g. measurement devices).

- Digital to analog converter

Digital to Analog Converter (DAC) perform reversal operation of ADC conversion. DAC convert the digital signal into analog format. It usually used for controlling analog devices like DC motors, various drives, etc.

- Interrupt control

The interrupt control used for providing interrupt (delay) for a working program. The interrupt may be external (activated by using interrupt pin) or internal (by using interrupt instruction during programming).

- Special functioning block

Some microcontrollers used only for some special applications (e.g. space systems and robotics) these controllers containing additional ports to perform such special operations. This considered as special functioning block [5].

2.3.2 Microcontroller application

Microcontrollers are widely used in modern electronic equipment. Some basic applications of microcontroller are given below:

- Used in biomedical instruments.
- Widely used in communication systems.
- Used as peripheral controller in Personal Computer (PC).
- Used in robotics.
- Used in automobile fields.

Microcontroller applications found in many lives filed, for example in Cell phone, watch, recorder, calculators, mouse, keyboard, modem, fax card, sound card, battery charger, door lock, alarm clock, thermostat, air conditioner, TV Remotes, in Industrial equipment like Temperature and pressure controllers, counters and timers [5].

2.4 Underwater Vehicles

The programmed vehicles are small vehicles programmed to control their movement in order to accomplish certain operations, and can be divided into two main types, remotely and autonomous vehicles according to the method of control and each type of them can be apportioned according to the work environment to the aircraft vehicles, car vehicles and underwater vehicles.

Underwater vehicle is a vehicle which works underwater for certain objectives and it varies by the purpose of the designing and the method of control and size. Underwater vehicles fall into two basic categories as shown in Figure 2.1. First is Manned Underwater Vehicles (MUVs) and the second is Unmanned Underwater Vehicles (UUVs) [6].

2.4.1 Manned underwater vehicles

Manned Underwater Vehicles is any vehicles that are not able to operate underwater without a human occupant and it's divided to submarine and submersible [6].

- Submarine

A submarine is a watercraft capable of independent operation underwater. The term most commonly refers to a large, crewed, autonomous vessel. Submarines are not tied to a surface support ship. Submarines are used for undersea archaeology; Military usage includes attacking enemy surface ships, defense and patrolling, exploration, oil, gas platform inspections and rescue missions. The submarine is shown in Figure 2.2.

- Submersible

More limited underwater capability. Submersibles are either manned or remotely operated. Manned carry air and all the fuel and food supplies with them, Submersibles are connected by cables that supply power and air to the crew. Submersible used for research and exploration. The submersible is shown in Figure 2.3.

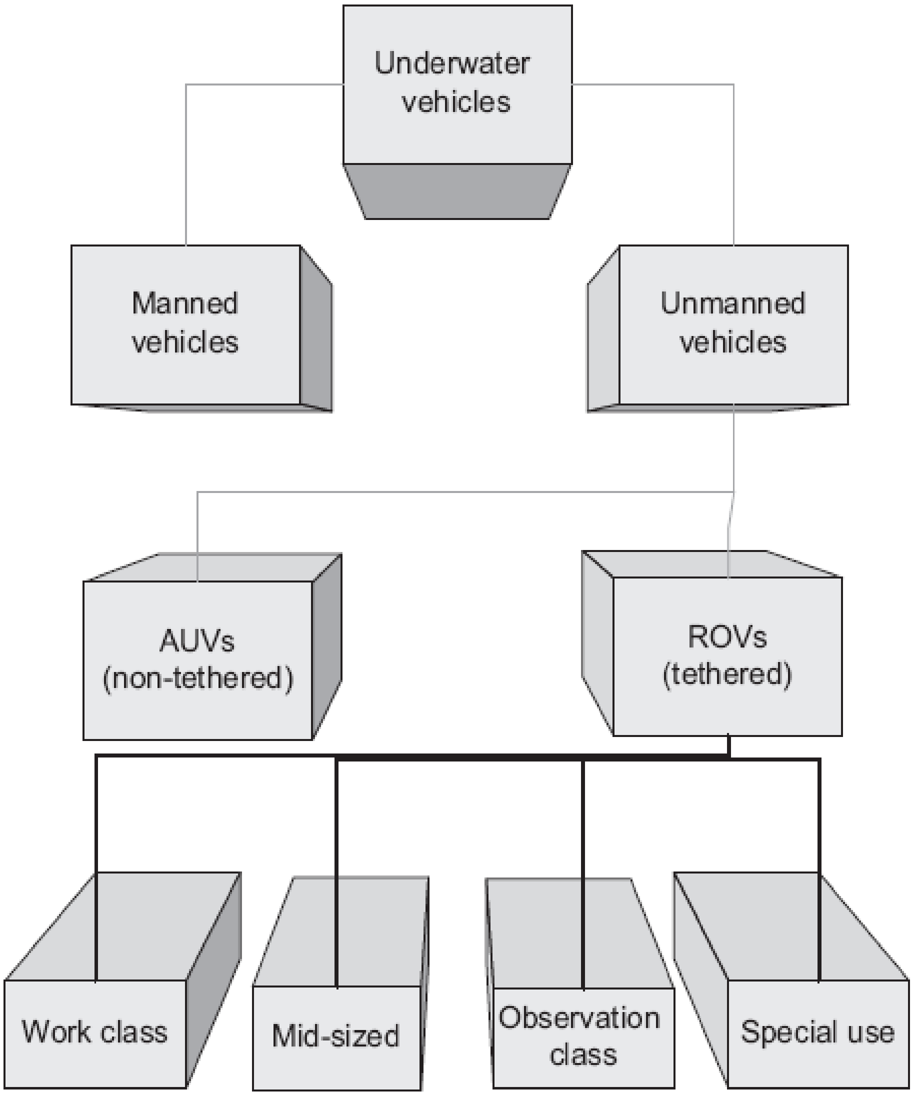


Figure 2.1: Underwater vehicles classification

Figure 2.2: Submarine

Figure 2.3: Submersible

- Atmospheric diving suit

Atmospheric Diving Suit (ADS) is a small one-man articulated submersible of anthropomorphic form which resembles a suit of armor, with elaborate pressure joints to allow articulation while maintaining an internal pressure of one atmosphere. The ADS is shown in Figure 2.4 can be used for very deep dives of up to 701 meters for many hours.

Figure 2.4: ADS

2.4.2 Unmanned underwater vehicle

Autonomous Underwater Vehicle (AUV) and is commonly known as unmanned underwater vehicle. AUVs can be used for underwater survey missions such as detecting and mapping submerged wrecks, rocks, and obstructions that can be a hazard to navigation for commercial and recreational vessels. AUV is shown in Figure 2.5.

An AUV conducts its survey mission without operator intervention. When a mission is complete, the AUV will return to a pre-programmed location where the data can be downloaded and processed [6].

Figure 2.5: AUV

2.5 Remotely Operated Vehicle

Remotely Operated Vehicle is an unmanned underwater vehicle also is a tethered vehicle which can be controlled by an operator on the surface, which controls its movement and actions without the need for a diver. The first ROV known, called (Poodle), was created by a French scientist, engineer and explorer Dimitri Rubik off in 1953. The first funding attempt of the early ROV technology was made by the US Navy in the 1960’s. They invented the so called "Cable-Controlled Underwater Recovery Vehicle" or also known as CURV. The CURV was able to per-form series of deep sea rescue operations, as well as recovering objects from the Ocean floor [6].

Another technology development of the ROVs was made by commercial firms that saw the future in ROV support of the offshore oil fields. These ROVs were first used as inspection vehicles and a decade later as vehicles for maintenance of the offshore oil fields. Nowadays ROVs are responsible for numerous tasks in many fields. ROVs can do something as simple as an inspection of an underwater structure, but more demanding work as well, such as inspection and maintenance of pipelines all the way to connecting pipelines together and placing underwater manifolds. All in all, ROVs can work on all stages, from construction to maintenance. ROVs are better than divers by the following advantages:

- ROVs perform tasks faster than divers and much more consistently and accurately.
- ROVs do not get cold, tired, or hungry.
- ROVs do not have a waiting period after a dive before they can fly.
- ROVs can spend unlimited time at depth and do not have to deal with decompression.
- ROVs can safely perform penetrations and can safely work around (oil, sewage, etc.).
- Micros ROV can be set up quickly, make a brief dive, and move to numerous sites in a day.
- A ROV can be operated from a variety of platforms, so a ladder or swim platform is not necessary.
- While an ROV can be lost or destroyed in extreme situations, loss of life is not a factor; Global Positioning System (GPS) can be added to find ROV.

2.5.1 Classification of remotely operated vehicles

Submersible ROVs can be classified into categories based on their size, weight, ability and their power.

- Micro-class ROVs are very small in size and weight. They usually weight up to 3 Kgs and are commonly used in places where a human diver cannot reach such as sewer, pipelines and places with small cavity.

- Mini-class ROVs can weigh up to 15 Kgs. They can also be used as a diver alternative and they can complete a job without the need of outside help.
- Light work-class ROVs are used for heavier works and most of them are carrying manipulators (small three finger grippers). Their frame is made from polymers or aluminum alloys. The maximum working depth for the category of ROVs is up to 1000 meters.
- Heavy work-class ROVs are mainly used by offshore oil companies and they carry at least 2 manipulators and a sonar unit.
- Trenching & Burial ROVs are able to carry a cable laying sled and work in depths up to 6000 m.
- AUV. These ROVs are autonomous and they work without an operator [6].

2.5.2 Remotely operated vehicle application

- Diver observation and support
- Dams and pipeline inspection
- Oil & gas industry (ROVs repair offshore oil platforms)
- Investigating sunken objects (ships, treasures, aero planes etc.)
- Environmental investigations
- Nuclear decommissioning projects
- Rescue missions
- Marine biology survey
- Valve or gauge monitoring
- Scientific Researchers

CHAPTER THREE

SYSTEM HAEDWARE AND SOFTWARE CONSIDERATION

3.1 System Mechanical Part

The Mechanical part discusses the fluid mechanics which are the branch of physics that studies fluids (liquids, gases, and plasmas) and the forces on them. Fluid mechanics can be divided into: fluid statics which study the fluids at rest, fluid kinematics which study the fluids in motion and fluid dynamics which study the effect of forces on fluid motion

3.1.1 Fluid statics

The five forces that control the movability of an underwater vehicle are buoyancy, weight, thrust, drag and lift force as shown in Figure 3.1.

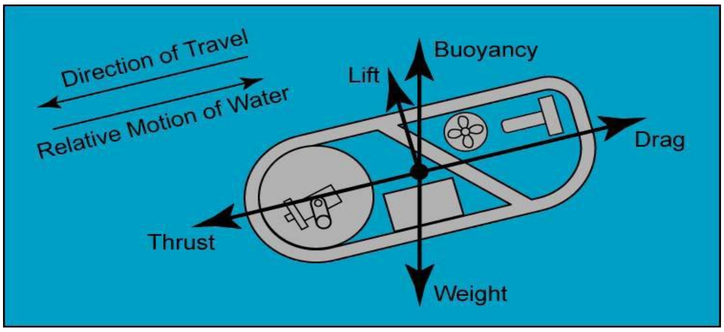


Figure 3.1: The five forces that control motion of an underwater vehicle

- Thrust force

Thrust is a mechanical force which is generated through the reaction of accelerating a mass of, as explained by Newton's third law. When a system expels or accelerates mass in one direction the accelerated mass will cause a proportional but opposite force on that system. ROV generates thrust (or reverse thrust) when the propellers are turned to accelerate water backwards (or forwards) [7]. The resulting thrust pushes the ROV in the opposite direction to the sum of the momentum change in the water flowing through the propeller as shown in Figure 3.2.

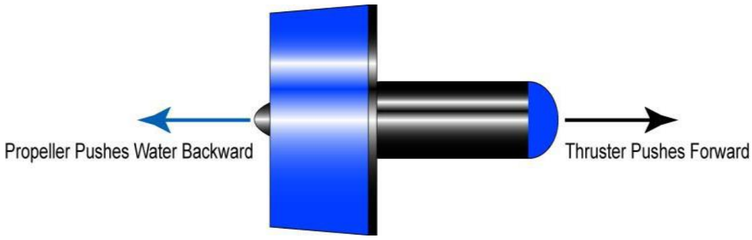


Figure 3.2: Motor’s propeller

The number and placement of the motors determines the possible movements of the ROV. For this process ROV performs three motors Arrangement, two motors are positioned parallel for horizontal movement and one motor is mounted vertically for vertical movement as shown in Figure 3.3:

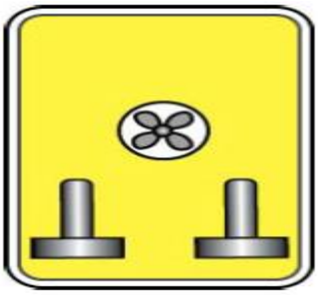


Figure 3.3: Motors placement

The two horizontal motors give a wide range of movement:

- Forward and reverse movement for the vehicle to move straight Forward and reverse, the both motors must generate equal thrust force as shown in Figure 3.4.

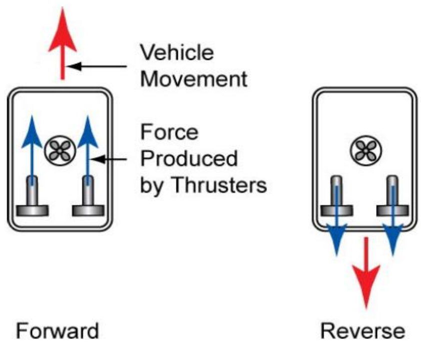


Figure 3.4: Forward and reverse movement

- Spin left and right when the horizontal motors act equally but in opposite directions, the forward and reverse thrusts cancel but the two motors produce a force couple which spins the vehicle in place as shown in Figure 3.5.

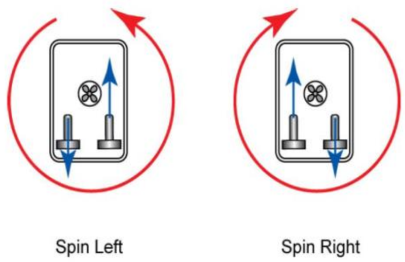


Figure 3.5: Spin left and right

- Turn right and left if only one motor is acting, the vehicle moves forward, but not in a straight line. The motor force and the force Created by drag produce a force couple that turns the vehicle as shown in Figure 3.6.

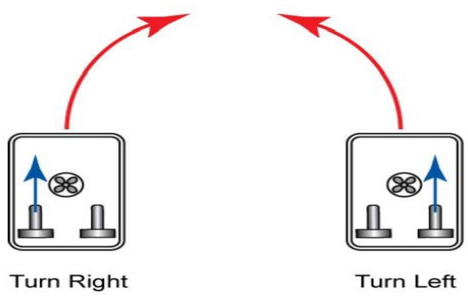


Figure 3.6: Turn right and left if only one motor is acting

- Weight force

The weight of an object is the force on the object due to gravity. Its magnitude is the product of the mass (m) of the object and the magnitude of the local gravitational (g) as shown in Equation (3.1).

$$W = mg \tag{3.1}$$

Where:

W: weight

m: object mass

g: local gravitational

- Buoyancy

Buoyant force is an upward force exerted by a fluid that opposes the weight of an immersed object as shown in Figure 3.7, Buoyancy is equal to the weight of the displaced fluid as shown in Equation (3.2) [8].

$$F_b = \rho_l \times v_{olume} \times g \tag{3.2}$$

Where:

F_b: Buoyant force

ρ_l: Fluid density

v_{olume}: Fluid volume

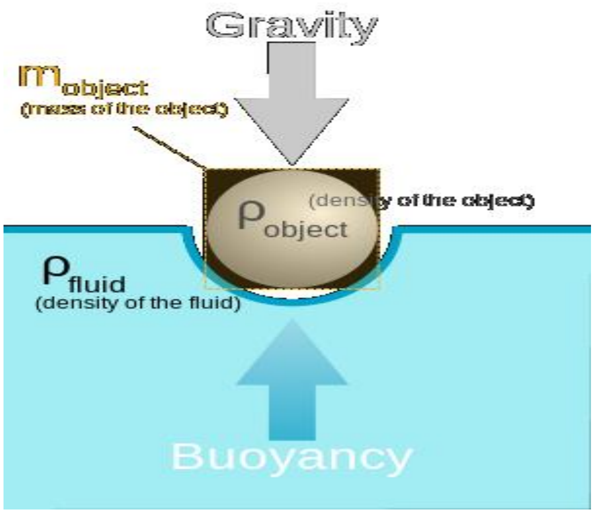


Figure 3.7: Buoyancy and gravity forces

- Drag force

Drag refers to forces acting opposite to the relative motion of any object moving with respect to a surrounding fluid. This can exist between two fluid surfaces or a fluid and a solid surface [7]. Drag force depends on the density of the fluid, and depends on size, shape, and velocity of the ROV. One way to express this is by means of the drag equation as shown in Equation (3.3).

$$F_D = \frac{1}{2}\rho v^2 C_D A \tag{3.3}$$

Where:

F_D: The drag force.

ρ: The density of the fluid.

v: The speed of the object relative to the fluid.

A: The cross-sectional area.

C_D : The drag coefficient – a dimensionless number.

- Lift force

The lift force acts in a direction that is perpendicular to the relative flow. Lift force only exists when there is relative motion between the vehicle and water. Created by different pressures on opposite sides of an object due to fluid flow past the object [7]. The net force referred to Newton's laws is the summation of all of the forces acting on an object. Some of the force groups can be thoughtfully ignored when considering the forces that affect the motion of a small ROV:

- Since a ROV is typically designed to be neutrally buoyant, the weight and buoyancy cancel each other.
- ROVs are typically slow movers so lift can be safely overlooked.
- This leaves only two force groups to be concerned about that impact on the motion of the ROV: drag and thrust.
- According to Newton's first law, speed must be constant if thrust and drag are balanced [7].

3.1.2 Mathematical model

Models of underwater vehicles works with two reference systems: one, located in the Gravity Center (GC) of the vehicle (body reference or {B}), and another, located in a point of the land (inertial reference, or {U}). The dynamics is shaped in the body reference. During the simulations, the measures obtained in the vehicle are transformed to the inertial reference. In this work, it is adopted transformation for angles of Euler. A generic model of a ROV with four degrees of freedom (4-DOF) was developed. The study of dynamics can be divided into two parts: kinematics, which treats only geometrical aspects of motion, and dynamics, which is the analysis of the forces causing the motion [9].

- Fluid kinematics

Two reference frames are used to express the motion of the ROV, an inertial reference frame that is coincident with the North-East-Down (NED) frame and a body-fixed frame affixed to the vehicle center of mass as shown in Figure 3.8. The ROV's state vector with respect to its body-fixed frame is defined in Equation (3.4).

$$q = [u\ v\ w\ p\ q\ r]^T \tag{3.4}$$

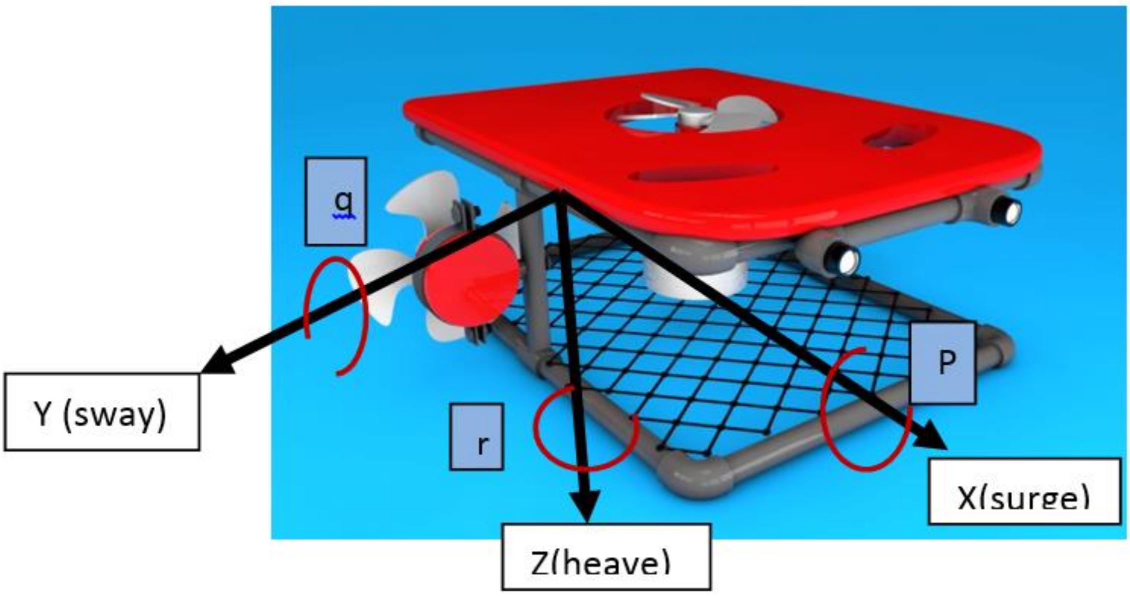


Figure 3.8: Body fixed frame

Where the first three elements are the translational velocities and the second three elements are the rotational rates of the vehicle about the X, Y and Z axis, respectively. The vehicle states the inertial frame is given by the Equation (3.5).

$$\eta = [X\ \ Y\ \ Z\ \ \phi\ \ \theta\ \ \psi\ ]^T \tag{3.5}$$

The spatial transformation matrix between the inertial frame and ROV's body-fixed frame is given by J as shown in Equation (3.6), which includes the angular velocity transformation matrix J1 as shown in Equation (3.7). And the linear velocity transformation matrix J2 is shown in Equation (3.8), it consists of three vectors as shown in Equation (3.9), Equation (3.10) and Equation (3.11). The transform J2 is a rotation matrix obtained using the typical Z–Y–X (ψ-θ-ϕ) yaw, pitch and roll Euler rotation sequence and J1 is the associated angular velocity transformation matrix [9].

$$J=\begin{bmatrix} J1 & O_{3\times 3} \\ O_{3\times 3} & J2 \end{bmatrix} \tag{3.6}$$

$$J1 = \begin{bmatrix} 1 & \sin(\varphi)\tan(\theta) & \cos(\varphi)\tan(\theta) \\ 0 & -\cos(\varphi) & \sin(\varphi) \\ 0 & \sin(\varphi)\cos(\theta) & \cos(\varphi)\cos(\theta) \end{bmatrix} \tag{3.7}$$

$$J2 = [j_{21} \quad j_{22} \quad j_{23}] \tag{3.8}$$

$$J_{21} = \begin{bmatrix} \cos\psi\cos\Theta \\ \sin\psi\cos\Theta \\ -\sin\Theta \end{bmatrix} \tag{3.9}$$

$$J_{22} = \begin{bmatrix} \cos\psi\sin\Theta\sin\varphi - \cos\psi\sin\varphi \\ \sin\psi\sin\Theta\sin\varphi + \cos\psi\cos\varphi \\ \cos\Theta\sin\varphi \end{bmatrix} \tag{3.10}$$

$$J_{23} = \begin{bmatrix} \cos\psi\sin\Theta\sin\varphi - \sin\psi\sin\varphi \\ \sin\psi\sin\Theta\cos\varphi + \cos\psi\sin\varphi \\ \cos\Theta\cos\varphi \end{bmatrix} \tag{3.11}$$

The motor layout on the ROV cannot actively control the roll and pitch motion of the vehicle. However, the motion around these axis is self-regulated due to large buoyant restoring moments. Assuming that the pitch and roll motions are small, the local and inertial state vectors can be simplified as shown in Equation (3.12) and Equation (3.13).

$$q = [u\ v\ w\ \ r]^T \tag{3.12}$$

$$\eta = [X\ \ Y\ \ Z\ \ \ \psi\ ]^T \tag{3.13}$$

Applying $\phi = 0\ ,\theta = 0$ in J of Equation (3.6) and eliminating the rows and columns associated with the roll and pitch motion leaves the following simplified transformation between the inertial and body-fixed representations of the vehicle state as shown in Equation (3.15).

$$\dot{\eta} = Jq \tag{3.14}$$

$$J = \begin{bmatrix} \cos\psi & \cos\psi - \sin\psi & 0 & 0 \\ \sin\psi & \cos\psi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{3.15}$$

Any further mention to η, q and J is specific to the reduced entities of Equation (3.14).

- Fluid dynamics

The dynamics model, describing the ROV's performance, is described in Equation (3.16)

$$(M + M_A)q^{\bullet} + Cq + Dq + g = \tau \tag{3.16}$$

The term $M \in R^{4\times4}$ and $M_A \in R^{4\times4}$ are the inertial and add mass matrix respectively, $C \in R^{4\times4}$ is the matrix of Coriolis terms, $D \in R^{4\times4}$ is the drag matrix, $g \in R^4$ is the vector of gravity and buoyancy forces and moments, finally $\tau \in R^4$ is the control forces and moments acting on the ROV center of mass [9].

I. Mass and added mass

For the reduced dynamic model considered, the mass and added mass matrices are defined as shown in Equation (3.17) and Equation (3.18) receptively.

$$M = \begin{bmatrix} m & 0 & 0 & 0 \\ 0 & m & 0 & 0 \\ 0 & 0 & m & 0 \\ 0 & 0 & 0 & I_r \end{bmatrix} \tag{3.17}$$

$$M_A = \begin{bmatrix} x_{u^\bullet} & 0 & 0 & 0 \\ 0 & y_{v^\bullet} & 0 & 0 \\ 0 & 0 & z_{w^\bullet} & 0 \\ 0 & 0 & 0 & I_{r^\bullet} \end{bmatrix} \tag{3.18}$$

In the matrix M, m is the true vehicle mass and I_r is the inertial around the Z axis (yaw) of the vehicle. In the add mass matrix M_A, $x_{u^\bullet}$, $y_{v^\bullet}$ and $z_{w^\bullet}$ define the add mass x, y and z axis, that are induced by acceleration along each axis. I_r defines an added inertia in the yaw degree of freedom caused by a changing rotational rate of the vehicle around the yaw axis [9].

II. Coriolis

For the reduced 4-DOF dynamics equations, the Coriolis matrix is defined as shown in Equation (3.19).

$$C = \begin{bmatrix} 0 & 0 & 0 & -mv \\ 0 & 0 & 0 & mu \\ 0 & 0 & 0 & 0 \\ mv & -mu & 0 & 0 \end{bmatrix} \tag{3.19}$$

The Coriolis matrix satisfies $C = -C^{T}$, a property that is commonly applied to simplify control law derivations.

III. Drag Forces

The drag matrix D contains a blend of linear and quadratic drag terms is defined as shown in Equation (3.20).

$$D = \begin{bmatrix} k_u + k_{u|u|}\,|u| \\ k_v + k_{v|v|}|v| \\ k_w + k_{w|w|}|w| \\ k_r + k_{r|r|}\,|r| \end{bmatrix} \tag{3.20}$$

Where diagonal is an operator that takes a vector and creates a square matrix with the elements of the vector on the diagonal. In **D**, $\mathbf{k_i}$ and $\mathbf{k_{i|i|}}$ (I = u, v, w, r) are the linear and the quadratic drag coefficients associated with the surge, sway, heave, and yaw motion of the vehicle, respectively. Note that the off-diagonal terms of the drag matrices are neglected as the hydrodynamic coupling is assumed to be insignificant at low speeds [9].

3.2 System Electrical Part

System electrical part can be described by using block and wire diagram which declare the hardware consideration.

3.2.1 Block diagram

describes how to control in three DC motors to do the six required movements (forward, reverse, left, right, up and down) of ROV by using an input controller which sends signal from computer Laboratory Virtual Instrument Engineering Workbench (LABVIEW) to the microcontroller which sends commands to motor drivers, servo motor and lights. Camera receives signal directly from a PC. Block diagram is shown in Figure 3.9.

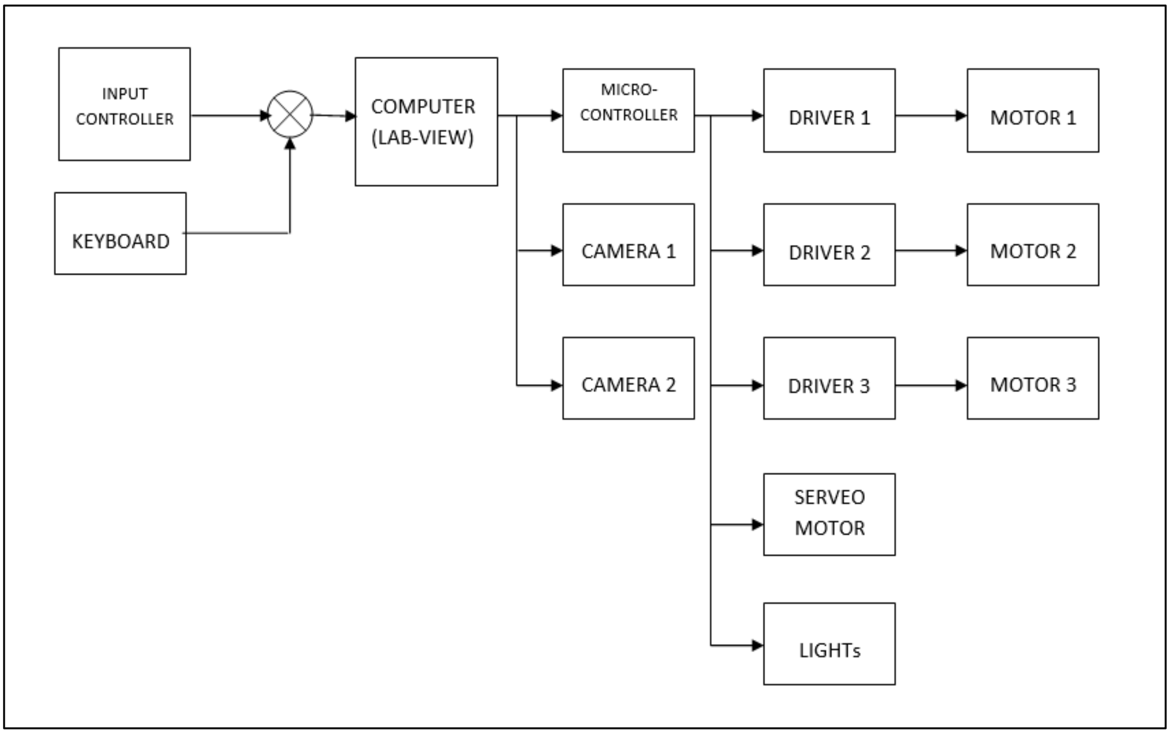


Figure 3.9: System block diagram

3.2.2 Wire diagram

Wire diagram is network of wires showing how to connect the circuit components, it explains the signal requirement for the movability and the ON-OFF control, also it declares the power feeding lines for the circuit. Wire diagram describes how all wires connected between the system circuit components. Microcontroller pins used for sending the signal to the lights, servo motor and the drivers, each driver receive two signals with two wires from microcontroller pins to perform the control of speed and direction of the motor, also, drivers receive power from power supply with two wires, one is the (+12V) DC and the other is grounded. Microcontroller receives the control and power signals from the PC with one wire. Also Camera receives signal and power directly from the PC with one wire as shown in Figure 3.10.

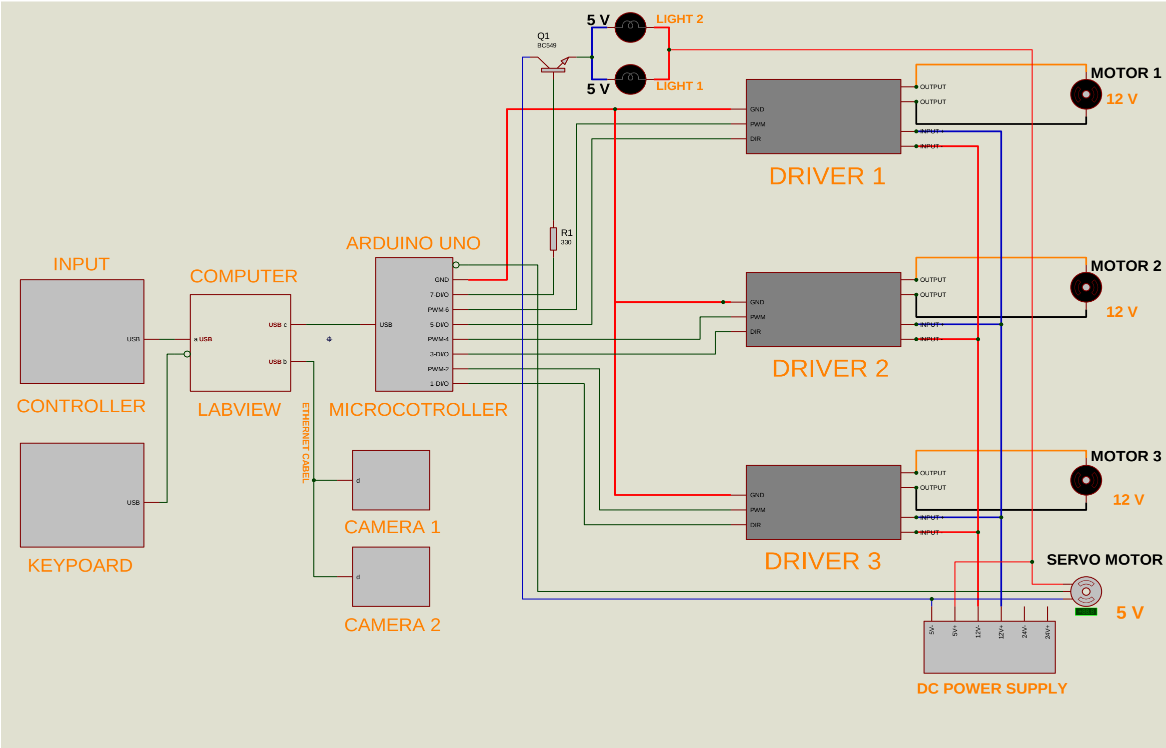


Figure 3.10: System wire diagram

3.3 Hardware Considerations

Remotely operated vehicle consists of many electrical components such as (system input, microcontroller (Arduino), motors, drivers, DC servo motor, camera, power supply and Ethernet cable).

3.3.1 System input

Remotely Operated Vehicle is controlled by a controller based on a microcontroller and joystick or Keyboard used for ROVs movement. The microcontroller used for this purpose is a microcontroller. Figure 3.13 below shows the controller of the ROV. The joystick has twelve buttons, four buttons for the direction and two buttons for diver and surface also has four buttons for speed control also has two buttons for light control. A microcontroller is able to read the values of joystick through the digital input of the microcontroller. The controller is powered by a normal 5V Universal Serial Bus (USB) cable.

Figure 3.11: System input (joystick)

3.3.2 Microcontroller-Arduino

Arduino is a small microcontroller board with a USB plug to connect to your computer and a number of connection sockets that can be wired up to external electronics, such as motors, relays, light sensors, laser diodes, loudspeakers, microphones, etc. Arduino can either be powered through the USB connection from the computer or from a 9V battery, Figure 3.12 describe all Arduino pins. Arduino can be controlled from the computer or programmed by the computer and then disconnected and allowed to work independently.

The hardware consists of an open source hardware board that is designed around the Atmel AVR Microcontroller. The intention of Arduino was to make the application of interactive components or environments more accessible. Arduino is programmed via an Integrated Development Environment (IDE) and run on any platform that supports Java like LABVIEW. An Arduino program is written in either C or C++ and is programmed using its own IDE.

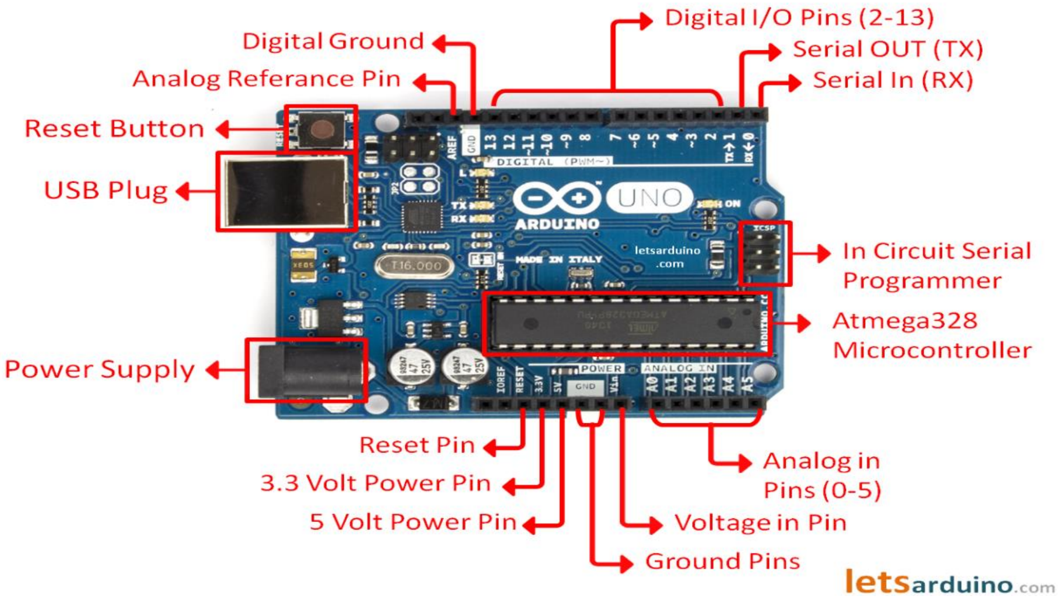


Figure 3.12: Arduino microcontroller

3.3.3 Motors

The selection of the motors is based on two main factors, pumping capacity and the power required to drive it. The pump needs to be able to operate while submerged in salt water and it must be able to run dry while pumping. For the last factors the bilge pump is selected as shown in Figure 3.13 for its specifications and its advantages.

- Specifications

Table 3.1: the specification of 1100 gph bilge pump.

Model	GPH	AMPS@12V	AMPS@ 13.6V	Fuse size
27D	1100	3.3	5	6
Height	Weight (lbs.)	Width	Hose DIA	Float switches
4-1/4"	.75	2-3/8"	1-1/8"	35-40

- Advantages

Bilge pump have many advantages such as its submersible, ignition protected**,** high efficiency, low amp motor**,** no burn-out when dry and stainless steel shaft.

Figure 3.13: Bilge pump (motor)

3.3.4 Direct current servo motor

Direct current servo motor (DSS-M15) as shown in Figure (3.14), is a heavy-duty metal gear, digital servo with 360°wide angle, high torque power, improved stability and durability. The servo is able to work with 6V and deliver a strong torque power of over 15Kg. This DSS-M15 servo demonstrates a maximum torque of 18Kg without much vibration or heat.

Figure 3.14: DSS-M15 servo motor

3.3.5 Camera system

For underwater camera system two cameras have been added to the system: one for monitoring the direction of the ROV a color CCD camera was used. The maximum resolution of the camera can reach up to 700TV lines. The lens of the camera is 2.1mm and the viewing angle is 140 degrees. Figure 3.15 below shows the camera used in order to monitor the movement of the ROV. The camera has 2 cables the red cable is for powering up the camera and the second wire is used as signal wire. The power supply needed to power up the camera is 9-12V and will use the same power supply. The signal wire of the camera will be connected on the laptop by using a special converter called (Easy cap).

Figure 3.15: CCD camera

The other one is USB Camera and it is used for discovering the underwater life and it is shown in Figure 3.16.

Figure 3.16: USB camera

3.3.6 Motor driver

Motor driver (MD10C) is an enhanced version of the MD10B which is designed to drive high current brushed DC motor up to 10A continuously. It offers several enhancements over the MD10B such as support for both phase and sign-magnitude Pulse Width Modulation (PWM) signal as well as using full solid state components which result in faster response time and eliminate the wear and tear of the mechanical relay. Motor driver is shown in Figure 3.17 have many features such as:

- Bi-directional control for 1 brushed DC motor.
- Support motor voltage ranges from 3V-5V to 25V.
- Maximum current up to 10A-13A continuous and 15A-30A peak (10 seconds). 3.3V and 5V logic level input.
- Solid state components provide faster response time and eliminate the wear and tear of mechanical relay.
- Fully NMOS H-Bridge for better efficiency and no heat sink is required.
- Speed control PWM frequency up to 10 KHz-20 KHz.
- Support both locked anti phase and sign-magnitude PWM operation.
- The new MD10C can be powered from a single power source and external V_{in} is not required.
- Dimension: 75mm x 43mm.

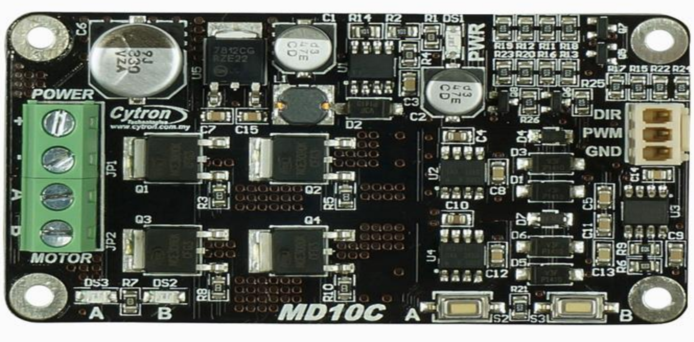


Figure 3.17: Single DC motor driver

3.3.7 Inertial measurement unit

An Inertial Measurement Unit (IMU) as shown in Figure 3.18 is a measurement device that combines three different sensors into one measuring board. The IMU consists of a gyroscope that measures angular velocities, three accelerometers that measures the acceleration in each direction and a magnetometer that measures the magnetic field. With this information, it is straight-forward to use the Kalman filter to estimate the orientation of the device. In this way we can attain knowledge of the orientation, rotation and linear motion of the ROV. Since the IMU came with a built in configured Kalman filter there was no need to estimate the orientation with the help of the accelerometer and the magnetometer, therefore it was decided to use the IMUs orientation estimate. The IMU had to be placed inside the waterproof hull. It is usually a good decision to place the IMU closer to the mass center, but in this case it is not the best place since the IMU could be disturbed by the electronics. Strong currents in the electronics that control the motors generate a magnetic field, which could potentially cause a problem with the magnetometer-measurement. Since the magnetometer data is only used by the Kalman filter to estimate the angles, it is only the angle-estimates that could be corrupted by this effect.

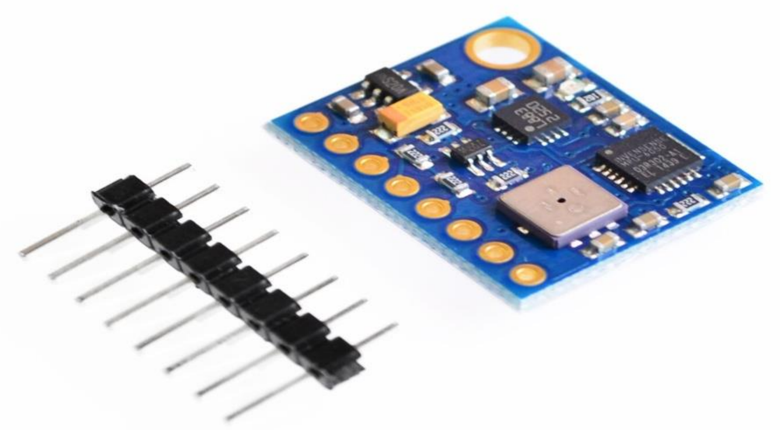


Figure 3.18: IMU

3.3.8 Power supply

A power supply is an electronic device that supplies electric energy to an electrical load. The primary function of a power supply is to convert one form of electrical energy to another and, as a result, power supplies are sometimes referred to as electric power converters. Some power supplies are discrete, stand-alone devices, whereas others are built into larger devices along with their loads.

All power supplies have a power input, which receives energy from the energy source, and a power output that delivers energy to the load. Figure 3.19 shows some information about Advanced Technology eXtended (ATX) computer power supply which used as power supply for feeding the circuit. The ATX is the most common supply out there and is in use in most desktop computers today.

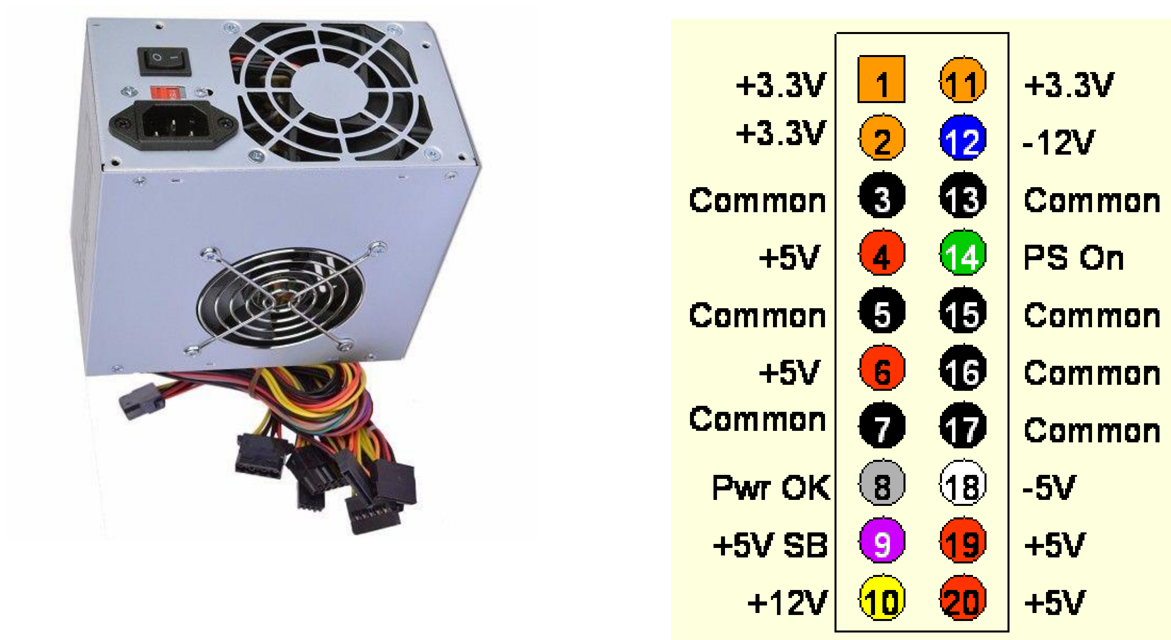


Figure 3.19: Power supply and wire color code

3.3.9 Ethernet cable

One of the most important parts of the ROV is the cables used for the communication of the ROV with the outside world. An Ethernet cable is a type of network cable that interconnects two wired network devices, it can be used for control operated vehicle by extracting the internal wire and use it to transfer power and signal, as shown in Figure 3.20. In addition, sometimes cables that are carrying signals are separated from the cables that are carrying power. The cable must be able to withstand the power that is about to be transferred. The power is translated into amperes. It is necessary that the cable must have enough material to conduct this power to the far end.

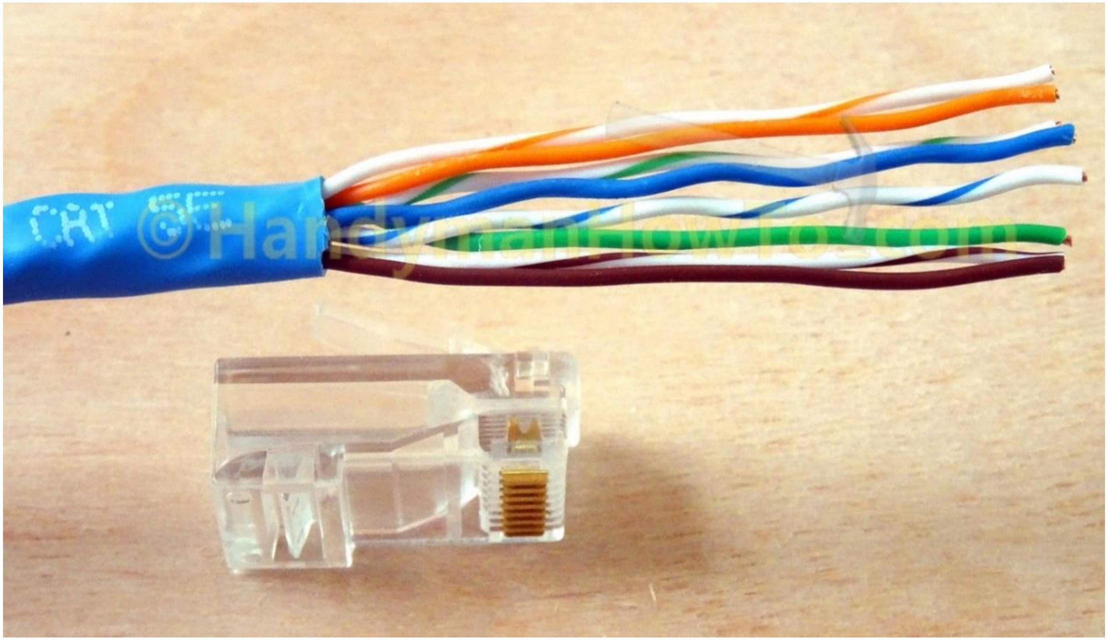


Figure 3.20: Ethernet cable

3.4 System Software

LABVIEW is the software used for programming the Atmel microcontroller of the Arduino. Dc motors and servos are both controlled with the same principle PWM. Therefore, Servo library was used. Servo function creates the objects to be controlled. Four objects were created since three dc motors and one servo motor were used in this project. Attach function was used for attaching the four objects on the PWM outputs of the microcontroller.

3.4.1 LABVIEW

LABVIEW is a graphical programming language that uses icons instead of lines of text to create applications. In contrast to text-based programming languages, where instructions determine program execution, LABVIEW uses data flow programming, where the flow of data determines execution. In LABVIEW a user interface with a set of tools and objects can be build, the user interface is known as the front panel. The block diagram contains the graphical representations of functions that control the front panel objects. In some ways, the block diagram resembles a flow chart [10].

The programming language used in LABVIEW, also referred to as G, is a data flow programming language. Execution is determined by the structure of a graphical block diagram (the LABVIEW-source code) on which the programmer connects different function-nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution [10].

LABVIEW ties the creation of user interfaces (called front panels) into the development cycle. LABVIEW programs subroutines are called virtual instruments (VIs). Each VI has three components: a block diagram, a front panel, and a connector panel as shown in Figure 3.21 and Figure 3.22 respectively.

The last is used to represent the VI in the block diagrams of other, calling VIs. Controls and indicators on the front panel allow an operator to input data into or extract data from a running virtual instrument.

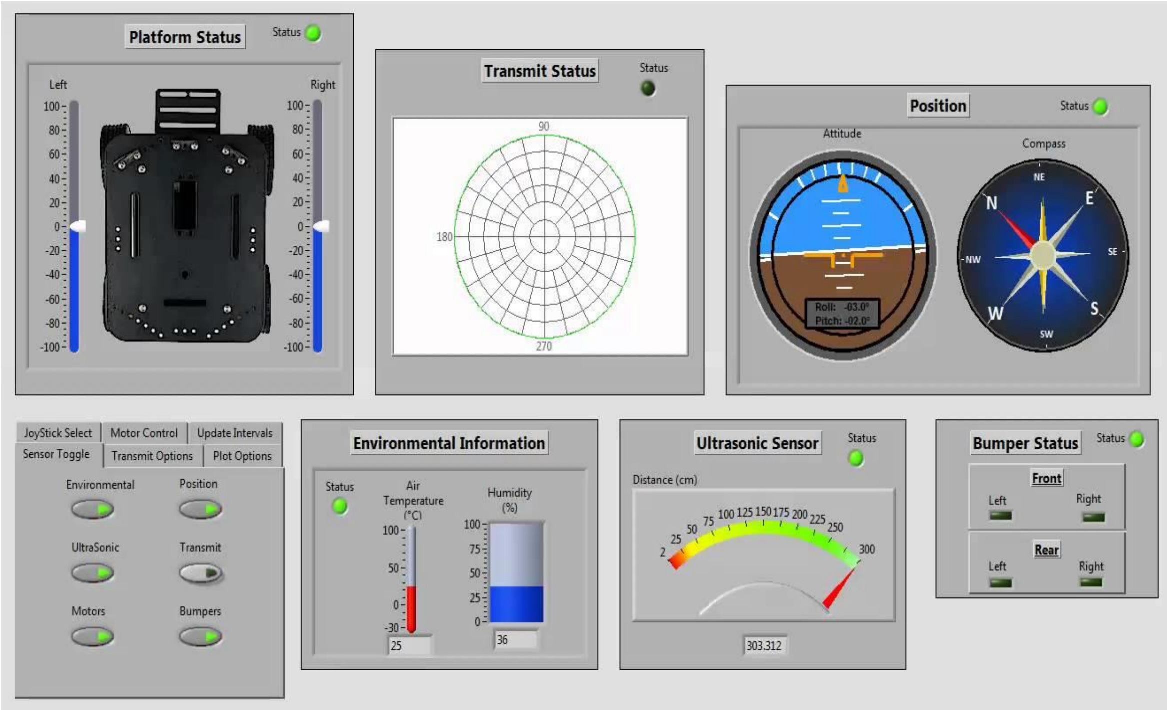


Figure 3.21: LABVIEW front panel

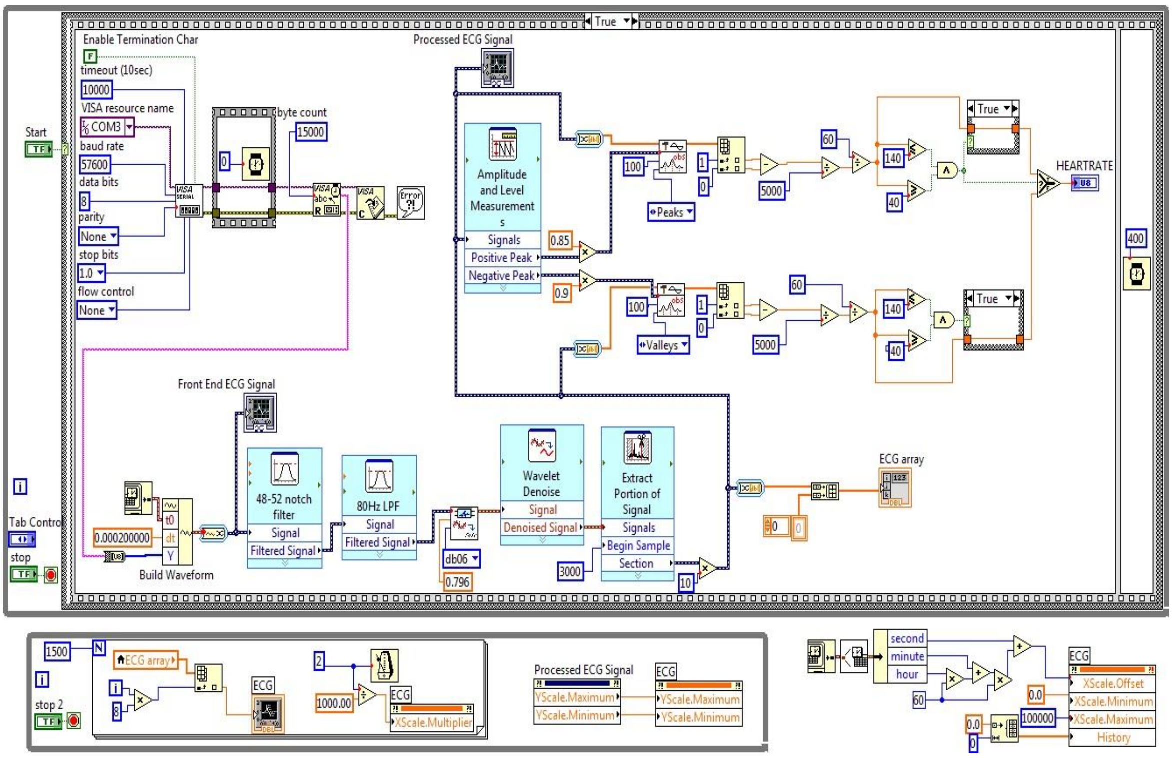
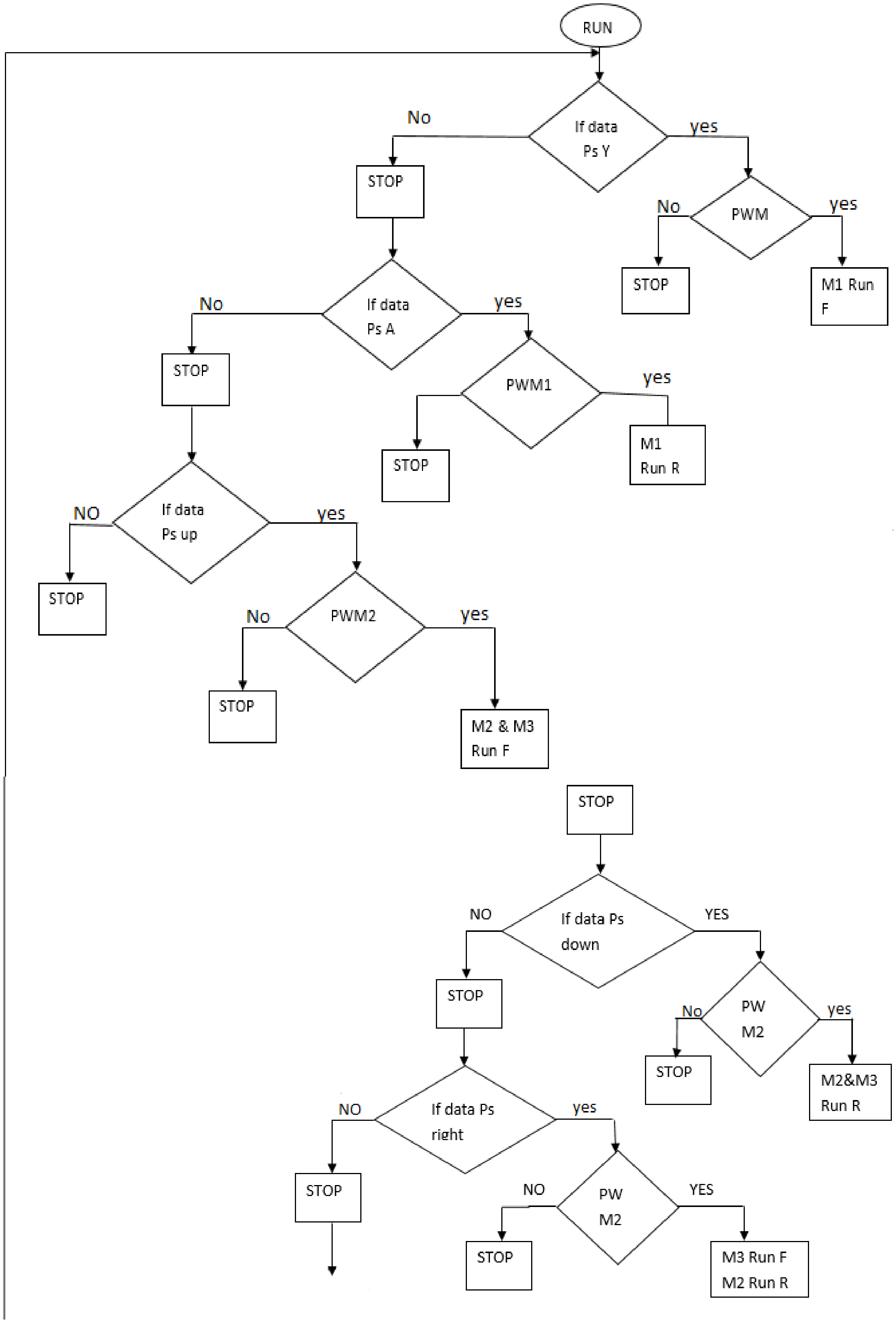


Figure 3.22: LABVIEW block diagram

3.4.2 System flow chart

The system code flow chart is shown in Figure 3.23.



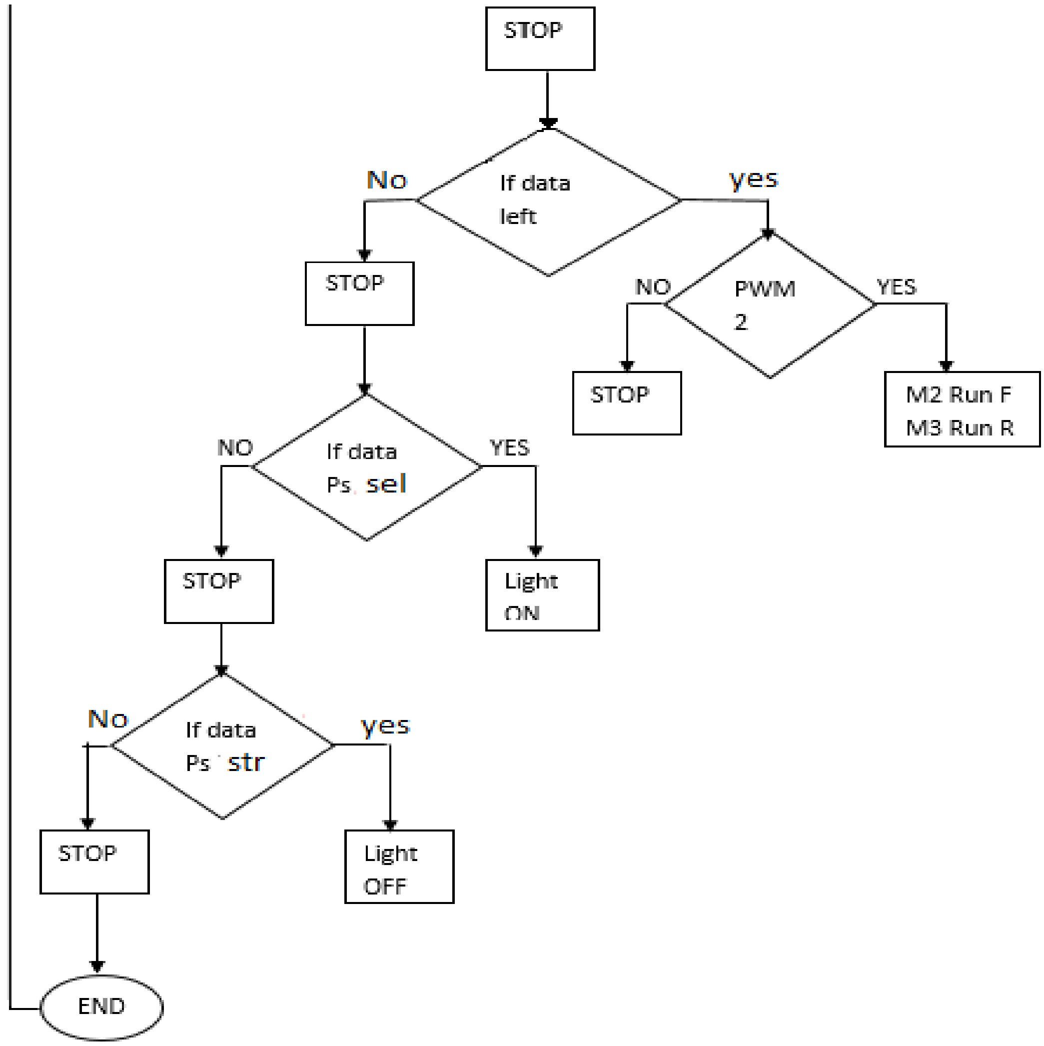


Figure 3.23: System code flow chart

Where:

Ps Y: joystick Y button

Ps A: joystick A button

Ps UP arrow: joystick UP arrow button

Ps Down arrow: joystick Down arrow button

Ps Str: joystick start button

Ps Sel: joystick select button

Ps Right arrow: joystick Right arrow button

Ps left arrow: joystick left arrow button

3.4.3 System code

The code (block diagram) of the ROV control system is consist of five parts:

- Arduino block diagram

The Arduino block diagram is shown in Figure 3.24.

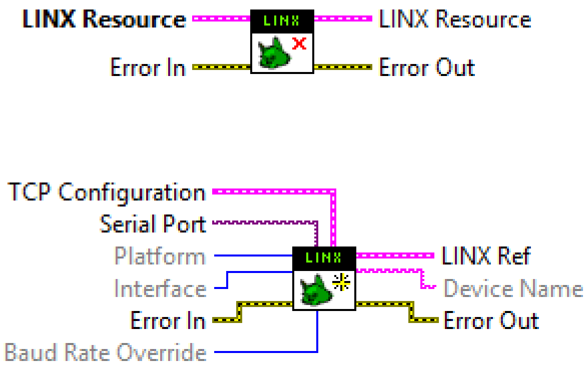


Figure 3.24: Arduino block diagram

- Joystick block diagram

The joystick block diagram is shown in Figure 3.25

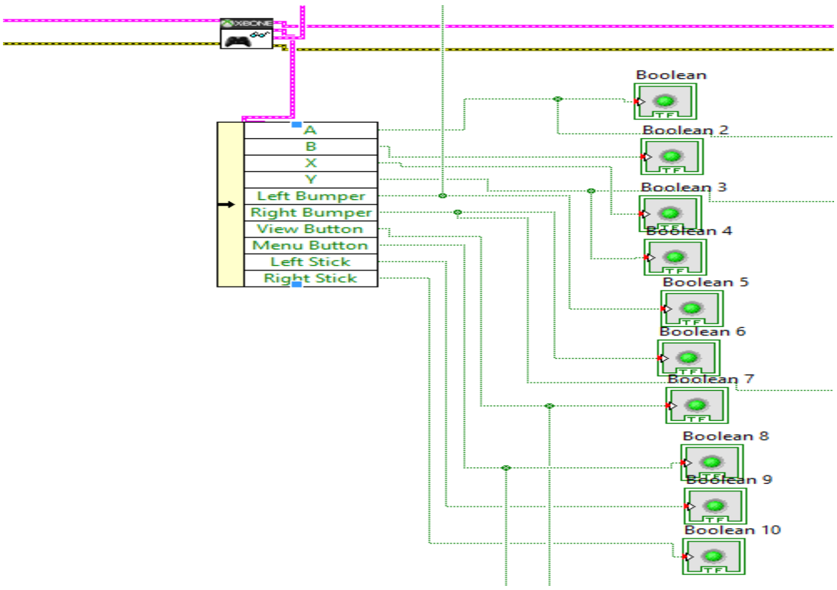


Figure 3.25: Joystick block diagram

- Servo motor block diagram

Servo motor block diagram is shown in Figure 3.26.

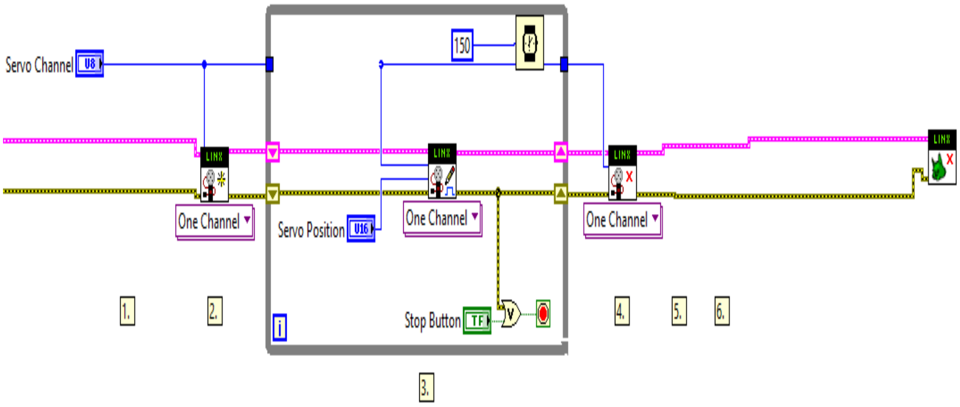


Figure 3.26: Servo motor block diagram

- Bilge pump (motor) movements block diagram

The bilge pump (motor) movements block diagram is shown in Figure 3.27.

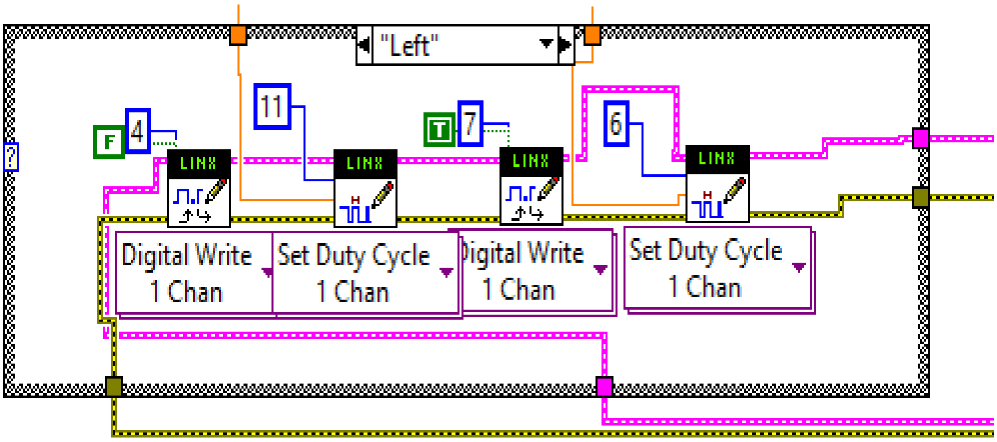


Figure 3.27: Bilge pump (motor) movement block diagram

- Camera block diagram

The camera block diagram is shown in Figure 3.29.

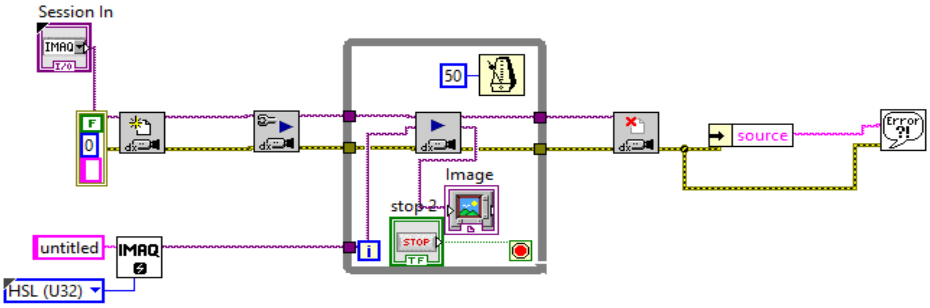


Figure 3.29: Camera block diagram

CHAPTER FOUR

SYSTEM IMPLEMENTATION AND TESTING

4.1 System Implementation

Remotely operated vehicle contains a PVC hull, three motors and a camera which was collected together and installed as described steps below:

4.1.1 Mechanical design

The mechanical design of the ROV system is designed using 4D design program which called CINEMA as shown in Figure 4.1.

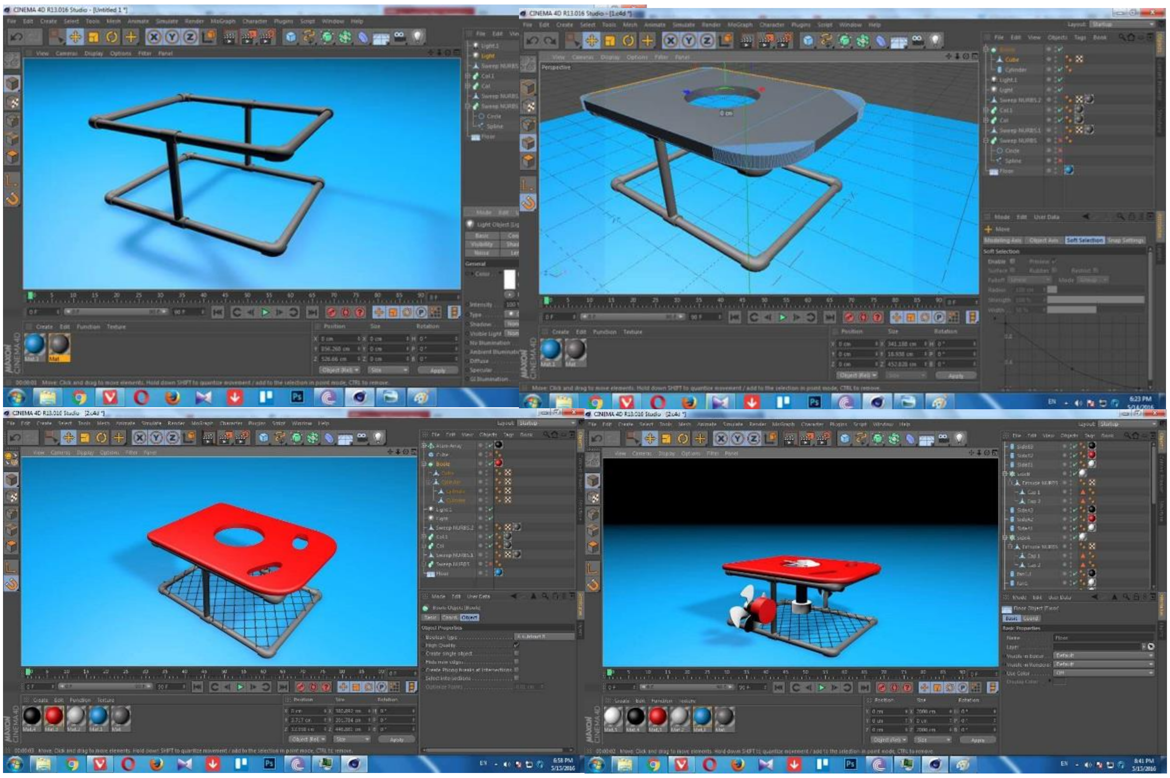


Figure 4.1: ROV design in CINEMA 4D program

According to the design which made as shown in Figure 4.2, the following steps had been done to get the best design of the ROV.

Figure 4.2: Final design of the ROV in CINEMA 4D

- First, the hull is made of a (3/4 inch) PolyVinyl Chloride. PVC pipes are cut into 4 pieces (20 cm) as a width of the ROV and 8 pieces (15 cm) as a length of the ROV as shown in Figure 4.3.

Figure 4.3: Cutting and linking PVC pipes

The PVC pipes are linked by (T) PVC connection and 2 pieces (15 cm) as a height of the ROV as shown in Figure 4.4.

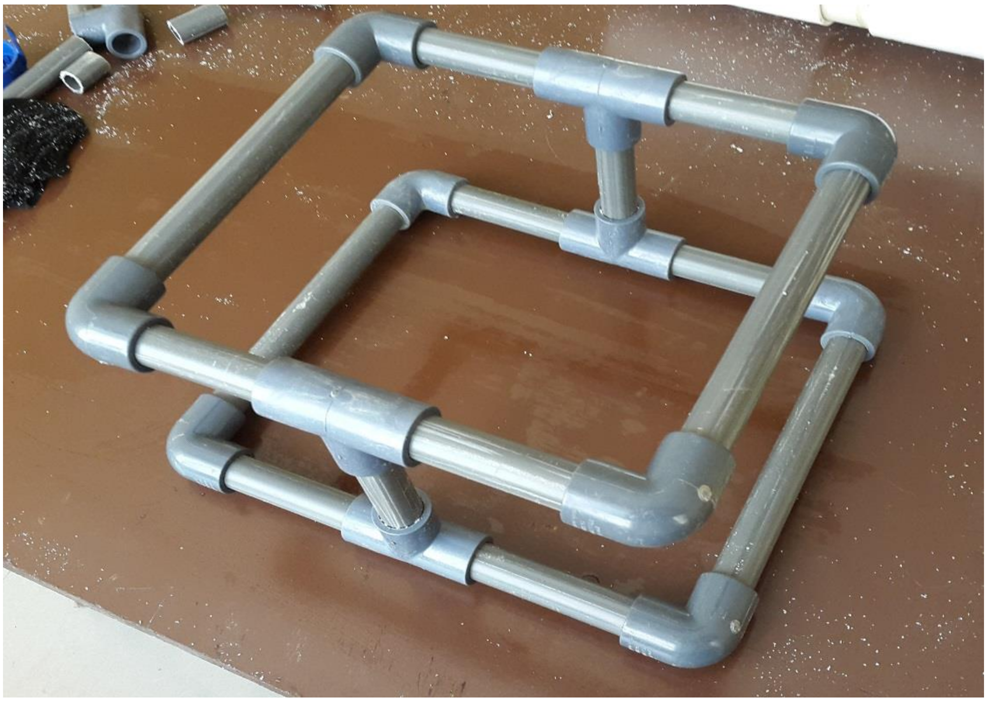


Figure 4.4: Final PVC hull of the ROV

- In the second step, a buoy piece is used to help ROV to float at the static mode and the buoy piece set on the hull as shown in Figure 4.5.

Figure 4.5: ROV hull with buoy piece floats at static mode

- In the third step, the motors were added to the hull, two motors are linked to the two side stands as shown in Figure 4.6.

Figure 4.6: Two motors linked on the two sides

A small circle hole is made on the buoy piece for the third motor as shown in Figure 4.7.

Figure 4.7: The buoy piece with hole on it

Bilge pumps are cut, then the propellers are installed on the bilge pumps and connected to each motor as shown in Figure 4.8

Figure 4.8: Motor and propeller

After three propellers were connected to the motors, the third motor is set vertically in the middle of the X-Panda which set on the base of the ROV. Two LED lights linked in front of the ROV as shown in Figure 4.9.

Figure 4.9: X-Panda and lights in the ROV

- In the last step the camera is added to the ROV and all components (servo, camera, motors and LED lights) are connected by a 5 meter Ethernet cable which sends control and power signals to the control box. The final design of the ROV as shown in Figure 4.10.

Figure 4.10: Final design of the ROV

4.1.2 Control box

Control box created by using a power supply, Arduino and motor drivers. Drivers receive 12v power from the power supply and receive the signals from Arduino as show in Figure 4.11

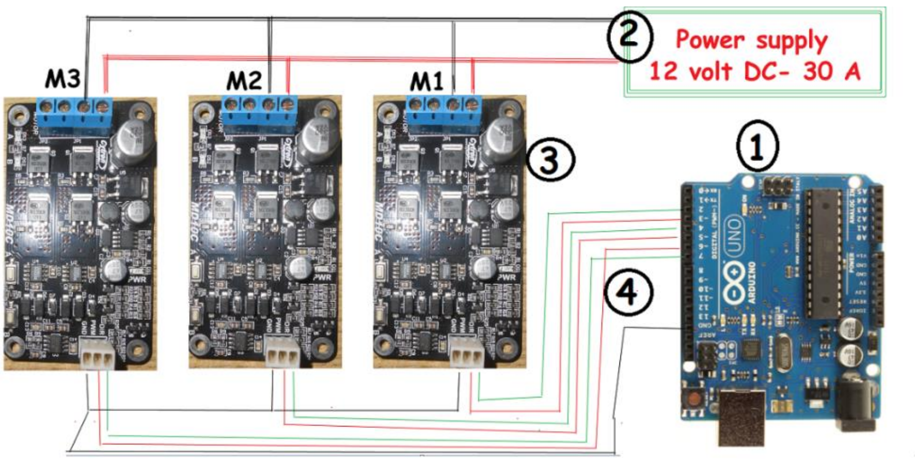


Figure 4.11: Drivers circuit

Where:

1: Arduino Uno

2: Power supply 12 volt - 30A

3: drivers

4: wires

M1: motor no. 1

M2: motor no. 2

M3: motor no. 3

Drivers connected to Ethernet cable to control the ROV movement. The control box shown in Figure 4.12

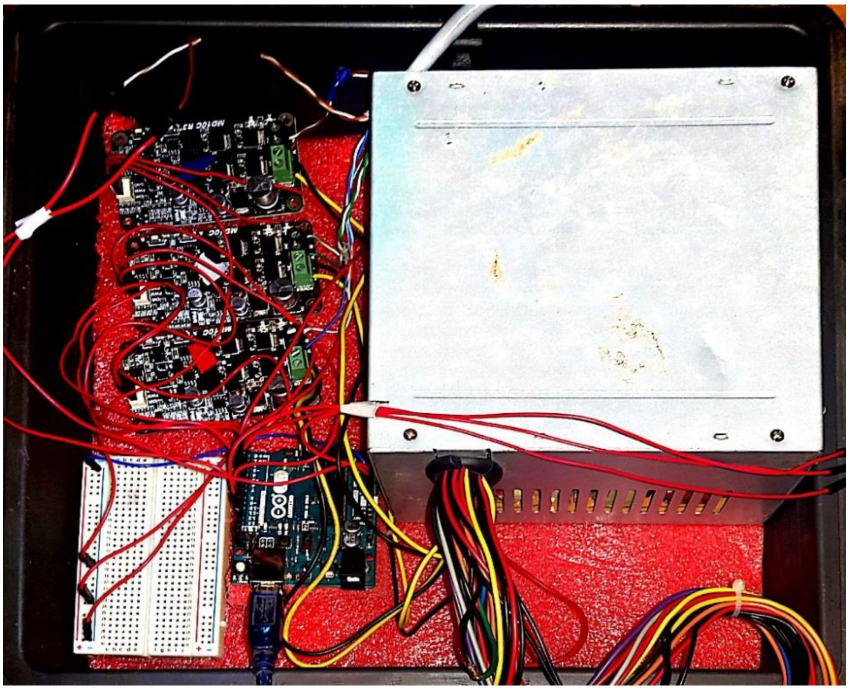


Figure 4.12: control box

4.2 Remotely Operated Vehicle Testing

An important and significant step in the construction of the vehicle is testing. Each time a component or program phase was done there would be a test to check for proper functionality. There were two types of tests dry test and wet test. Tests done in the Moluk pool.

4.2.1 Dry test

Dry tests played a vital role in this study. They are the most common form of testing and allowed to determine if the components are running correctly. The dry tests came in many different forms, but they can be categorized into three main types of tests. The first is the test of the internal plumbing system, the second is the test of the stabilizing motors, and the third and most common is system component tests [11].

- First dry test is reviewed the hull and the holes had been plugged to prevent from leaking and all electronic components had been isolated (camera, servo, LED lights)
- In the second test, the ROV had been connected by Ethernet cable to the control box which is connected to the computer. All components had been tested starting with a servo motor motion test which was moved rotational and reach near to 360 degrees. Then the camera turned on and the live photo on the computer had been checked also two LED lights were turned on and off.
- In the third test, the motors are tested by turning on motors clockwise and anticlockwise direction by changing the speed and changing the direction from the input controller from 10% to the full speed. Voltage is measured by voltmeter versus speed rate with every changing of the speed, then two curves between voltage (volt) and speed rate (%) are plotted. One of them the voltage measured from the drivers and the other

is measured from the ROV and taking into account the voltage drop due to the length of cable as shown in Figure 4.13

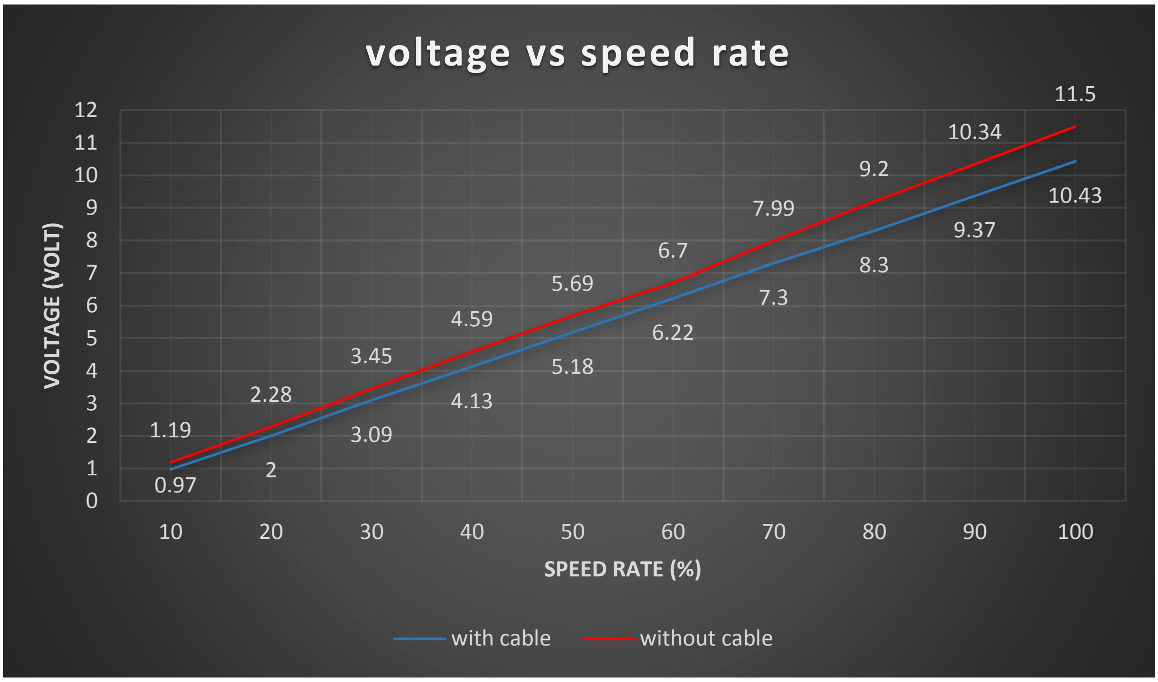


Figure 4.13: Curve between voltage and speed rate and voltage drop

From the Figure 4.13 the voltage drop at full speed is calculated and it is equal 1.07 V per 5 meters, so the voltage drop in 1 meter is 0.214 volts.

The last dry test is to determine the expected speed of the ROV according to all the forces affecting the ROV which studied before.

After the dry test is finished, expected speed is determined by calculating the area of the ROV and the drag force by using the Eq. (3.3). The speed is calculated for:

- Forward and reverse movement

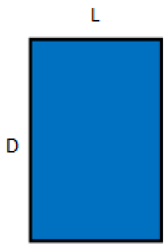
$$F_d = 0.5\, \rho_w \times A_{eff} \times C_d \times V^2$$

Drag force for one pump at 12v and 6 A is 9.8N and at 10.43v (voltage drop) is 8.5N, so:

$F_d = 2 \times 8.5 = 17N$

The drag coefficient C_d is determined from Figure 4.14 as:

$$\frac{L}{D} = \frac{150}{260} = 0.58, C_d = 2.5$$



L/D	C_D
0.0	1.9
0.1	1.9
0.5	2.5
1.0	2.2
2.0	1.7
3.0	1.3

Figure 4.14: Drag coefficient for forward and reverse movement

ρ_w : water density = 1000 kg/m^3

A_{eff}: Projected area

$$A_{eff} = 2 \times 260 \times 30 + 2 \times 100 \times 30 + 2 \times \pi \times 30^2 + 100 \times 30 + 70 \times 50 + 40 \times 40 + 260 \times 20 + \pi \times 15^2 + 25 \times 20 + 20 \times 30 = 42361.73 \text{ mm}^2$$

$$V = \left[\frac{17}{0.5 \times 1000 \times 42361.73 \times 10^{-6} \times 2.5}\right]^{0.5} = 0.567 \text{ m/s}$$

So the expected speed for forward and reverse movement is 56.7 cm/s

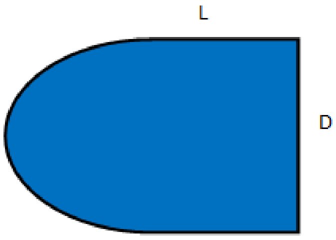
- Up and down movement

$$F_d = 0.5\, \rho_w \times A_{eff} \times C_d \times V^2$$

$F_d = 1 \times 8.5 = 8.5N$

The drag coefficient C_d is determined from Figure 4.15 as:

$$\frac{L}{D} = \frac{360}{260} = 1.38, C_d = 0.9$$



L/D	C_D
0.5	1.2
1.0	0.9
2.0	0.7
4.0	0.7

Figure 4.15: Drag coefficient for up and down movement

ρ_w : water density $= 1000 \ \mathrm{kg/m^3}$

A_{eff}: Projected area

$$A_{eff} = 360 \times 260 - \pi \times 75^2 - 2 \times 30 \times 80 + 2 \times 40 \times 60 + 2 \times 45 \times 40 + 2 \times 40 \times 20 + \pi \times 50^2 = 88982.52 \ \mathrm{mm^2}$$

$$V = \left[\frac{8.5}{0.5 \times 1000 \times 88982.52 \times 10^{-6} \times 0.9}\right]^{0.5} = 0.461 \ \mathrm{m/s}$$

So the expected speed for up and down movement is 46.1 cm/s

4.2.2 Wet test

There are two wet tests done in the Moluk pool to perform major system checks in the vehicle designed environment. The first test is the vehicle leak test to test the sealing of the hull and external components. The second test is the horizontal and vertical motion test to check the main motor movement in the horizontal and vertical motion. Similar to the dry tests the wet tests are crucial to achieving our final mission test.

The goal of the horizontal and vertical motion test is to observe the vehicle performance in horizontal and vertical motion to a prescribed distance [11].

- Vehicle leak test

In this test the ROV is put on the surface of the water to test the buoyancy and the leaking. The ROV stood balanced on the static mode as shown in Figure 4.16

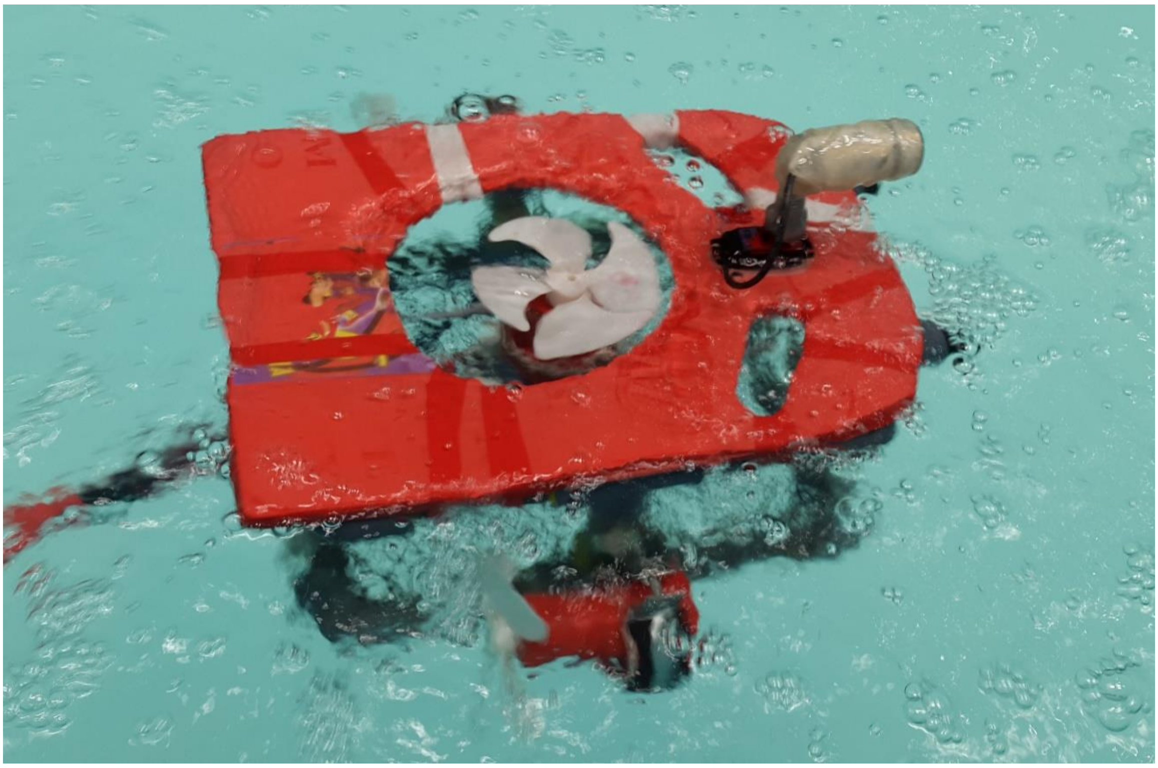


Figure 4.16: ROV floats at static mode

- Horizontal and vertical motion test

First, the ROV motion is tested by moving ROV forward and reverse after two side motors are turned on clockwise and anticlockwise direction.

In the second test the ROV vertical motion tested by moving ROV up and down after vertical motor turned on clockwise and anticlockwise.

The speed of the ROV is calculated at all movement directions (forward, reverse, up and down) and every time the speed rate is changed by the controller from (10-100) % of the full speed, and the curve between real speed and speed rate plotted as shown in Figure 4.17.

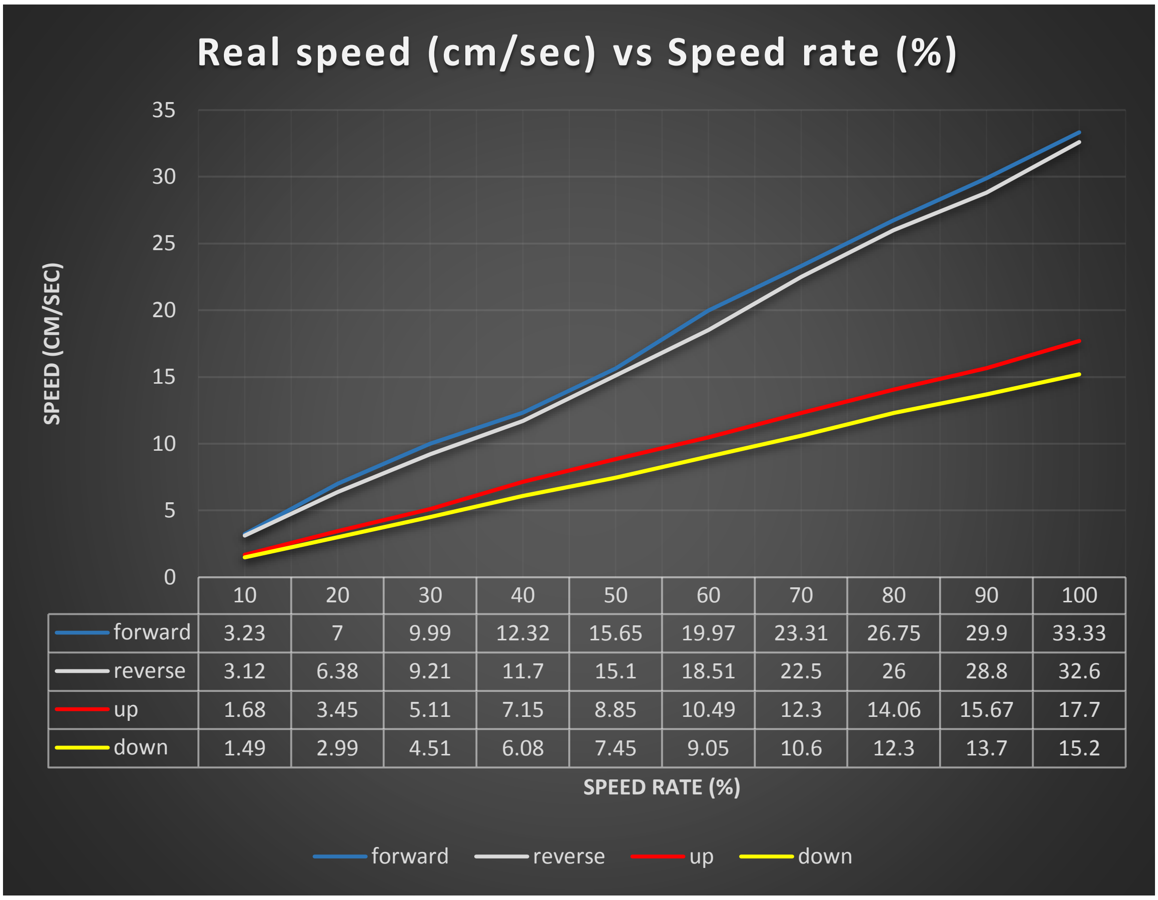


Figure 4.17: Curves of the ROV speed for all direction movement

From Figure 4.17 the actual full speed for forward and reverse movement is (33.3, 32.6) cm/s respectively. And for up and down movement the actual full speed is (17.7, 15.2) cm/s respectively.

4.3 Simulation

In this section Kinematic equations have been applied in the ROV model by using the rotational matrix to simulate the rotational of the model in MATLAB by using the data which produced by IMU sensor (see Appendix).

- First the ROV has been rotated right and the simulation show the response according to the rotational matrix and the rotation degree as shown in Figure 4.18.

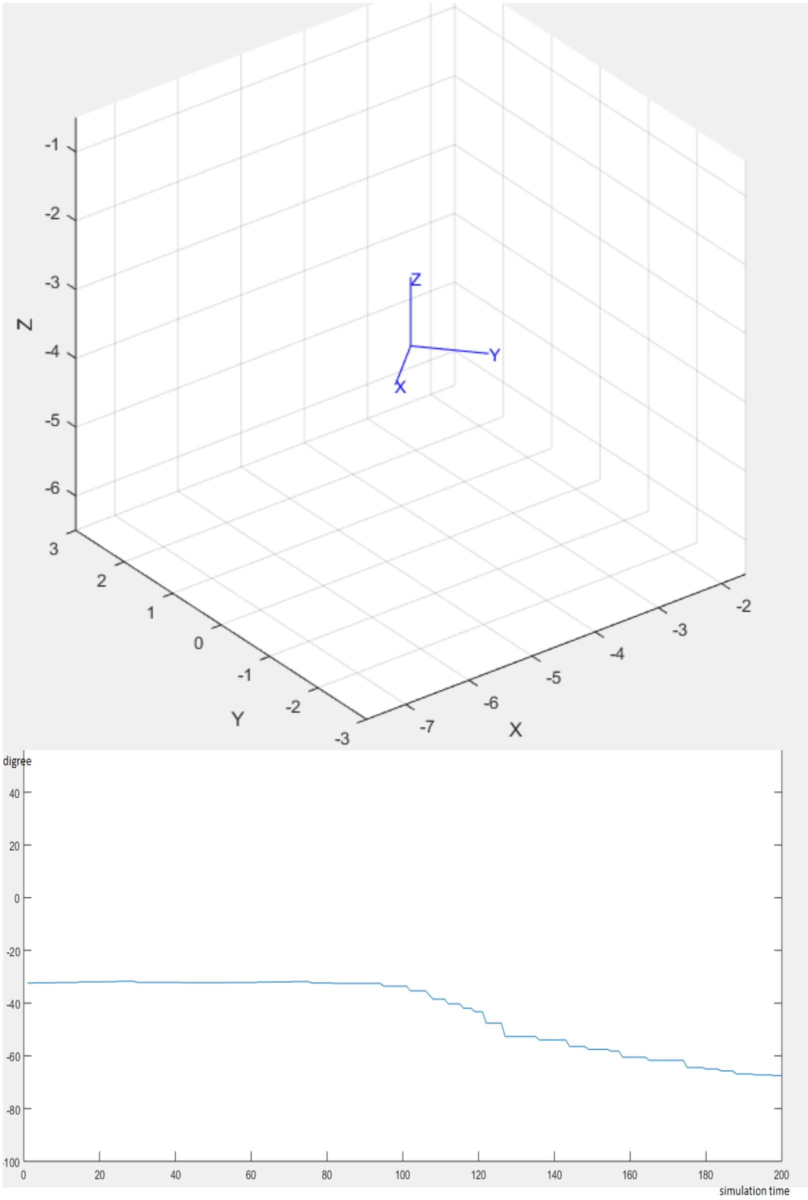


Figure 4.18: simulation for rotate ROV right

- Second the ROV has been rotated left and the simulation show the response according to the rotational matrix and the rotation degree as shown in Figure 4.19

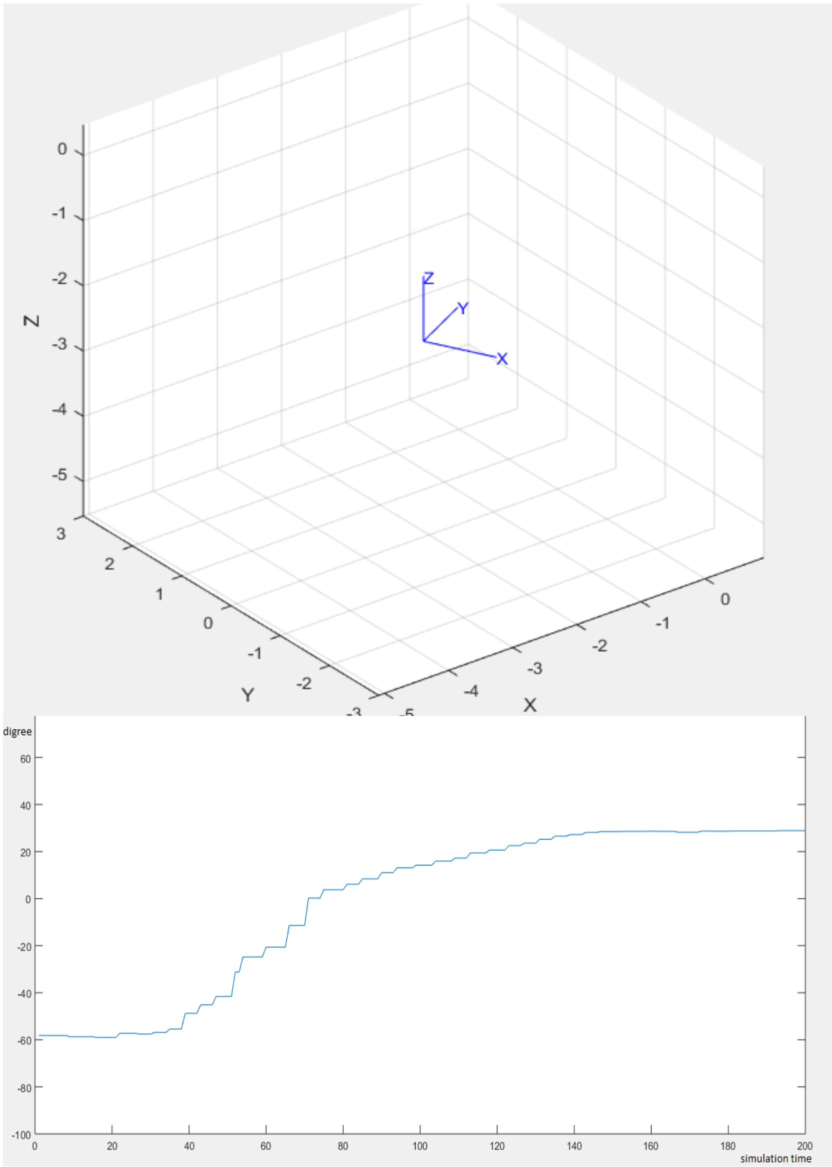


Figure 4.19: simulation for rotate ROV left

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main goal of this project is to design a ROV manipulator and control system of the ROV by using LABVIEW. The project is chosen due to issue difficulties and inconvenient for human in facing conditions such as in deep sea, dangerous underwater area and toxic water especially for those who face the underwater jobs. Furthermore, the limited time for human to work underwater and the small number of costly professional diver also seem to be one of the biggest issues in solving underwater tasks.

To solve this problem, by using LABVIEW, a Graphical User Interface (GUI) is designed to control the ROV. Besides that, the communication between the DC motor of ROV and the computer were developed through this project to provide enormous power and flexibility. Other than that, the speed, position and direction of ROV were controlled by using joystick. As for the results of this project, the control diagram of ROV has been developed. Account of the loss in voltage has been reached that the loss in voltage directly proportional to the length of the wire, so it is advisable when using long wire increasing the voltage source.

5.2 Recommendations

The project has a lot of space for further improvements.

- The ROV could have a temperature sensor it provides us with the temperature inside the water.
- Compass sensor that shows the direction of the ROV.
- ROV can be upgraded to be Autonomous Underwater Vehicle.

- Finally, another feature that may be added on the ROV is a small manipulator arm that is controlled through two or more waterproof servos.

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APPENDIX

MATLAB m.file for simulate the model rotation

```
clear
clc
a=arduino('com10','uno');
dev=i2cdev(a,'0x68');
writeRegister(dev,107,0);
writeRegister(dev,27,0);
tic;

ROLL=0;
i=0;
%pause(1);
for toc=1:2000
write(dev, 59, 'int8');  %Reading Register 59 AccX_out
data = read(dev, 14, 'int8');%Request 14 Register Data starting with REG59
%Registers 59 - 64 Accelorometer 16bit data in the 3 Axis
AcX(toc) = (double(bitshift(int16(data(1)), 8)) +
double(bitshift(int16(data(2)), -8)));
AcY(toc) = (double(bitshift(int16(data(3)), 8)) +
double(bitshift(int16(data(3)), -8)));
AcZ(toc) = (double(bitshift(int16(data(5)), 8)) +
double(bitshift(int16(data(6)), -8)));
%Calculating the angles using acceleration data
angle_X=180*atan2(-AcX,AcZ)/pi;
angle_y=180*atan2(-AcY,AcZ)/pi
%Registers 67 - 72 Gyroscope 16bit data in the 3 Axis
   GyX(toc) = (double(bitshift(int16(data(9)), 8)) +
double(bitshift(int16(data(10)), -8)));
```

```
   GyY(toc) = (double(bitshift(int16(data(11)), 8)) +
double(bitshift(int16(data(12)), -8)));
   GyZ(toc) = (double(bitshift(int16(data(13)), 8)) +
double(bitshift(int16(data(14)), -8)));

  ROLL=(ROLL+(GyY(toc)*0.01));
  R(toc)=9*ROLL/131
   drawnow;
   if i==0
      angle_y(toc)=0;
   end

   t1=transl(angle_y(toc)/30,0,angle_X(toc)/30)*trotz(angle_y(toc),'deg');
  % t1=trotz(angle_y(toc),'deg');
   t2=transl(angle_y(toc)/30,0,angle_X(toc)/30)*trotz(angle_y(toc),'deg');
   %t2=trotz(angle_y(toc),'deg');
   wktranimate(t1,t2)
   i=1;
end
```