Sudan University of Sciences and Technology
College of Engineering
School of Electrical and Nuclear Engineering

Submarine Multi-purposes Control System

نظام تحكم لغواصة متعددة الأغراض

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

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بسم الله الرحمن الرحيم

(فَتَعَالَى اللَّهُ الْمَلِكُ الْحَقُّ ۗ وَلَا تَعْجَلْ بِالْقُرْآنِ مِن قَبْلِ أَن يُقْضَىٰ إِلَيْكَ وَحْيُهُ ۖ وَقُل رَّبِّ زِدْنِي عِلْمًا)

صدق الله العظيم

سورة طه (114)

DEDICATION

As well as everything that we do, we would be honor to dedicate this work to our parents for their emotional and financial support, our sisters, our brothers, whose has been 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, **Ust. Gaffer Babiker** for his valuable guidance continuous encouragement, suggestions, constructive, ideas and advice in assisting us to complete this work

Abstract

A submarine is a watercraft for independent operation beneath water. In order to surpass under water it must obey some ground laws specially Archimedes principle with taking consideration of its flexible and economic structure and propulsion systems design. The main purpose of this research is to design and conrol a prototype submarine to make experimentally available. The need for economic innovative design to ensure smart structure, propulsion, diving system and efficient power system has focused in the implemented prototype. The propulsion and power systems are provided by motor and battery. Depth rating comparison with other resplendent submarine makes the prototype unique in some cases. To submerge hydrostatically this research on designing basically implies Archimedes principle and buoyancy force, where negative buoyancy exerted either by increasing its own weight or decreasing its displacement of water.

مستخلص

الغواصة هي قارب مائي لعملية مستقلة تحت الماء. ولكي تتجاوز تحت الماء، يجب عليها أن تمتثل لبعض القوانين الأرضية ولا سيما مبدأ أرخميدس مع مراعاة هيكلها المرن والاقتصادي وتصميم أنظمة الدفع. والغرض الرئيسي من هذا البحث هو تصميم غواصة نموذجية لجعل هذه الغواصة متاحة تجريبيا. وقد ركزت الحاجة إلى تصميم اقتصادي مبتكر لضمان البنية الذكية ونظام الدفع والغوص ونظام الطاقة الفعال في النموذج الأولي المنفذ. يتم توفير أنظمة الدفع والطاقة بواسطة الموتور والبطارية. إن مقارنة تصنيف العمق بغواصة أخرى تجعل النموذج الأولي فريدًا في بعض الحالات. إن دمج هذه الأبحاث في التصميم بطريقة هيدروستاتكية يعني ضمن مبدأ أرخميدس وقوة الطفو ،حيث يتم الطفو السلبي إما بزيادة وزنه أو تقليله من الماء .

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LIST OF ABREVATIONS

ROV	Remotely Operated Vehicle
DSV	Deep-Sea Submergence Vehicle
DSRV	Deep Submergence Rescue Vehicles
HMI	Human Machine Interface
VLF	Very Low Frequency
ELF	Extremely Low Frequency
DOF	Degrees of Freedom
ESC	Electronic Speed Control
SCCB	Serial Camera Control Bus
LED	Light Emitting Diode
IDE	Integrated Development Environment
PC	Personal Computer
USB	Universal Serial Bus
DC	Direct Current
GPS	Global Positioning System
PVC	Poly Vinyl Chloride
CPVC	Cylinder Poly Vinyl Chloride

LIST OF SYMBOLS

V_u	is the pressure resisting displacement below the line of flotation in cubic meters
V_o	he pressure resisting displacement above the line of flotation in cubic meters
T_u	is the content of the ballast tanks below the line of flotation in cubic meters
T_o	is the content of the ballast tanks above the line of flotation in cubic meters
P	is the weight of the boat in M_P
γ	is the density of sea water in $[M_P/m^3]$
$F_{\delta yx}$	the hydroplane force for one blade for x-configuration
$F_{\delta y+}$	the hydroplane force for one blade for +-configuration
$\delta_{r\times}$	The horizontal manoeuvring variable
$\delta_{s\times}$	The vertical manoeuvring variable

CHAPTER ONE

INTRODUCTION

1.1 Overview

A Submarine is a watercraft capable of independent operation underwater deriving its origin from Bathyscaphe‖, which is evolved from the Diving Bell and is commonly, refers to Remotely Operated Vehicles (ROVs) and Robots, as well as medium sized or smaller vessels, such as the Midget Submarine and the Wet Sub. Submarines were first widely used during World War-1(1914-1918), and now figure in many Navies large and small. Civilian uses for Submarine include marine science, salvage, exploration and facility inspection and maintenance. Submarines can also be modified to perform more specialized functions such as search and rescue missions or underwater cable repair. Military usage includes attacking enemy surface ships, submarines, aircraft carrier protection, blockade running and ballistic missile submarines as a part of nuclear strike force, reconnaissance, conventional land attack and covert insertion of Special Forces. Submarines are also used in tourism and for undersea archeology.

1.2 Research Problem

A suitable controlling method of underwater vehicles is very challenging due to the nature of underwater dynamics and parameter uncertainties. Human cannot work effectively underwater. Dangerous underwater area and toxic water more, furthermore the period is also limited for human to work underwater unless for professional diver. Nonetheless, in any works, due to many issues for human, it was always a troublesome matter. Hence, in doing any jobs underwater will gives a huge trouble.

1.3 Research Objectives

•To understand the design and previous models of ROV.

•Control the speed of the motors.

•Measure the temperature and pressure of water.

•To give pictures from water.

1.4 Research Methodology

•Preliminary study of ROV structure and sensors.

•Interface the ROV hardware development with the firmware arrangement to complete the task.

•Design and development of Arduino system to control ROV.

•Hardware and software setting and testing.

•Finalize and upgrading program.

1.5 Research Structure

This project contains an abstract and five chapters: Chapter one is about the introduction; it presents an overview of the project. Chapter two presents Submarine systems, Introductions, History, Types of Submarines, Submarine purpose. Chapter three introduces the Submarine control systems, Submarine diving and floating system, Control fundamentals of submarine, Control surfaces and communication. Chapter four demonstrates components. Putting the parts together, Execution, testing and results. Chapter five includes the conclusion and further recommendations.

CHPATER TWO

SUBMARINE SYSTEM

2.1 Introduction

A submarine (or sub) is a watercraft capable of independent operation underwater. It differs from a submersible, which has more limited underwater capability. It is also sometimes used historically or colloquially to refer to remotely operated vehicles and robots, as well as medium-sized or smaller vessels, such as the midget submarine and the wet sub. Submarines are referred to as "boats" rather than "ships" irrespective of their size. Although experimental submarines had been built before, submarine design took off during the 19th century, and they were adopted by several navies. Submarines were first widely used during World War I (1914–1918), and are now used in many navies large and small. Military uses include attacking enemy surface ships(merchant and military),or other submarines, aircraft carrier protection, blockade running, ballistic missile submarines as part of a nuclear strike force, reconnaissance, conventional land attack (for example using a cruise missile), and covert insertion of special forces. Civilian uses for submarines include marine science, salvage, exploration and facility inspection and maintenance. Submarines can also be modified to perform more specialized functions such as search-and-rescue missions or undersea cable repair. Submarines are also used in tourism and undersea archaeology. Most large submarines consist of a cylindrical body with hemispherical (or conical) ends and a vertical structure, usually located amidships, which houses communications and sensing devices as well as periscopes. In modern submarines, this structure is the "sail" in American usage and "fin" in European usage. A "conning tower" was a feature of earlier designs: a separate pressure hull above the main body of the boat that allowed the use of shorter periscopes. There is a propeller (or pump jet) at the rear, and various hydrodynamic control fins. Smaller, deep-diving and specialty submarines may deviate significantly from this traditional layout. Submarines use diving planes and also change the amount of water and air in ballast tanks to change buoyancy for submerging and surfacing. Submarines have one of the widest ranges of types and capabilities of any vessel. They range from small autonomous examples and one- or two-person subs that operate for a few hours to vessels that can remain submerged for six months such as the Russian Typhoon class, the biggest submarines ever built. Submarines can work at greater depths than are survivable or practical for human divers. Modern deep-diving submarines derive from the bathyscaphe, which in turn evolved from the diving bell.

2.2 History

According to a report in Opusculum Taisnieri published in 1562: Two Greeks submerged and surfaced in the river Tagus near the City of Toledo several times in the presence of The Holy Roman Emperor Charles V, without getting wet and with the flame they carried in their hands still alight. In 1578, the English mathematician William Bourne recorded in his book Inventions or Devises one of the first plans for an underwater navigation vehicle. A few years later the Scottish mathematician and theologian John Napier wrote in his Secret Inventions (1596) that "These inventions besides devises of sayling under water with divers, other devises and strategems for harming of the enemyes by the Grace of God and worke of expert Craftsmen I hope to perform." It's unclear whether he ever carried out his idea. The first military submersible was Turtle (1775), a hand-powered acorn-shaped device designed by the American David Bushnell to accommodate a single person. It was the first verified submarine capable of independent underwater operation and movement, and the first to use screws for propulsion. The submarine became a potentially viable weapon with the development of the Whitehead torpedo, designed in 1866 by British engineer Robert Whitehead, the first practical self-propelled or 'locomotive' torpedo. The spar torpedo that had been developed earlier by the Confederate States Navy was considered to be impracticable, as it was believed to have sunk both its intended target, and probably H. L. Hunley, the submarine that deployed it. In 1878, John Philip Holland demonstrated the Holland I prototype. Discussions between the English clergyman and inventor George Garrett and the Swedish industrialist Thorsten Nordenfelt led to the first practical steam-powered submarines, armed with torpedoes and ready for military use. The first was Nordenfelt I, a 56-tonne, 19.5-metre (64 ft) vessel similar to Garrett's ill-fated Resurgam (1879), with a range of 240 kilometres (130nmi; 150mi), armed with a single torpedo, in 1885. A reliable means of propulsion for the submerged vessel was only made possible in the 1880s with the advent of the necessary electric battery technology. The first electrically powered boats were built by Isaac Peral y Caballero in Spain (who built Peral), Dupuy de Lôme (who built Gymnote) and Gustave Zédé (who built Sirène) in France, and James Franklin Waddington (who built Porpoise) in England. Peral's design featured torpedoes and other systems that later became standard in submarines. In 20th century submarines were not put into service for any widespread or routine use by navies until the early 1900s. This era marked a pivotal time in submarine development, and several important technologies appeared. A number of nations built and used submarines. Electric propulsion became the dominant power system and equipment such as the periscope became standardized. Countries conducted many experiments on effective tactics and weapons for submarines, which led to their large impact in World War I figure (2.1):

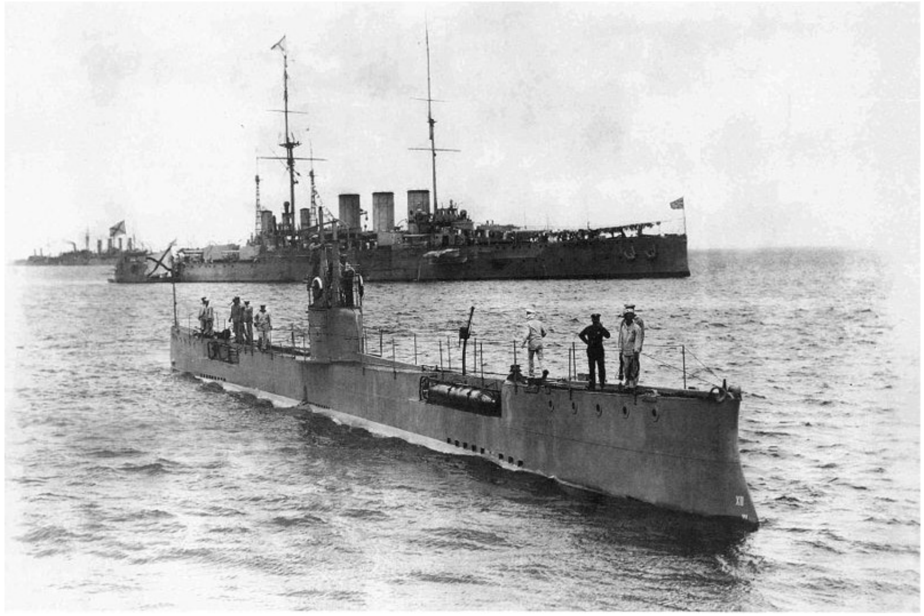


Figure 2.1: Akula launched in 1907

The Irish inventor John Philip Holland built a model submarine in 1876 and a full-scale version in 1878, which were followed by a number of unsuccessful ones. In 1896 he designed the Holland Type VI submarine, which used internal combustion engine power on the surface and electric battery power underwater. Launched on 17 May 1897 at Navy Lt. Lewis Nixon's Crescent Shipyard in Elizabeth, New Jersey, Holland VI was purchased by the United States Navy on 11 April 1900, becoming the Navy's first commissioned submarine, christened USS Holland. Commissioned in June 1900, the French steam and electric Narval employed the now typical double-hull design, with a pressure hull inside the outer shell. These 200-ton ships had a range of over 100 miles (161 km) underwater .The French submarine Aigrette in 1904 further improved the concept by using a diesel rather than a gasoline engine for surface power. Large numbers of these submarines were built, with seventy-six completed before 1914. The Royal Navy commissioned five Holland-class submarines from Vickers, Barrow-in-Furness, under license from the Holland Torpedo Boat Company from 1901 to 1903. Construction of the boats took longer than anticipated, with the first only ready for a diving trial at sea

on 6 April 1902. Although the design had been purchased entirely from the US Company, the actual design used was an untested improvement to the original Holland design using a new 180 horsepower (130 kW) petrol engine. These types of submarines were first used during the Russo-Japanese War of 1904–05. Due to the blockade at Port Arthur, the Russians sent their submarines to Vladivostok, where by 1 January 1905 there were seven boats, enough to create the world's first "operational submarine fleet". The new submarine fleet began patrols on 14 February, usually lasting for about 24 hours each. The first confrontation with Japanese warships occurred on 29 April 1905 when the Russian submarine Som was fired upon by Japanese torpedo boats, but then withdrew.
Military submarines first made a significant impact in World War I. Forces such as the U-boats of Germany saw action in the First Battle of the Atlantic, and were responsible for sinking RMS Lusitania, which was sunk as a result of unrestricted submarine warfare and is often cited among the reasons for the entry of the United States into the war. At the outbreak of the war, Germany had only twenty submarines immediately available for combat, although these included vessels of the diesel-engined U-19 class, which had a sufficient range of 5,000 miles (8,000 km) and speed of 8 knots (15 km/h) to allow them to operate effectively around the entire British coast. By contrast, the Royal Navy had a total of 74 submarines, though of mixed effectiveness. In August 1914, a flotilla of ten U-boats sailed from their base in Heligoland to attack Royal Navy warships in the North Sea in the first submarine war patrol in history figure(2.2):

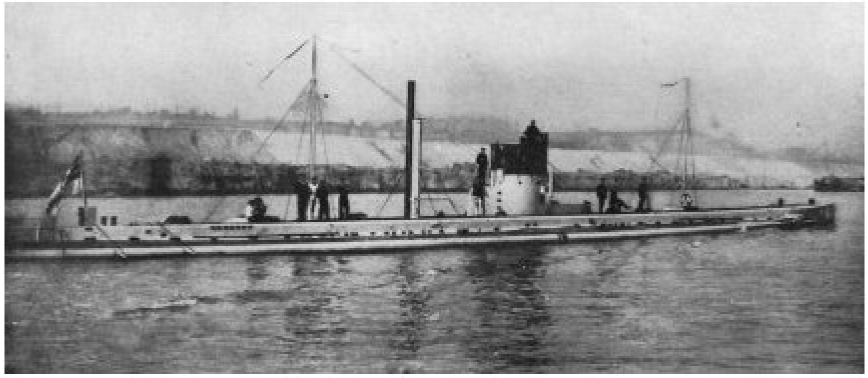


Figure 2.2: The German submarine SM U-9

The U-boats' ability to function as practical war machines relied on new tactics, their numbers, and submarine technologies such as combination diesel–electric power system developed in the preceding years. More submersibles than true submarines, U-boats operated primarily on the surface using regular engines, submerging occasionally to attack under battery power. They were roughly triangular in cross-section, with a distinct keel to control rolling while surfaced, and a distinct bow. During World War I more than 5,000 Allied ships were sunk by U-boats. During World War II, Germany used submarines to devastating effect in the Battle of the Atlantic, where it attempted to cut Britain's supply routes by sinking more merchant ships than Britain could replace. (Shipping was vital to supply Britain's population with food, industry with raw material, and armed forces with fuel and armaments.) While U-boats destroyed a significant number of ships, the strategy ultimately failed. Although the U-boats had been updated in the interwar years, the major innovation was improved communications, encrypted using the famous Enigma cipher machine. This allowed for mass-attack naval tactics (Rudeltaktik, commonly known as "wolfpack"), but was also ultimately the U-boats' downfall. By the end of the war, almost 3,000 Allied ships (175 warships, 2,825 merchantmen) had been sunk by U-boats. Although successful early in the war, ultimately Germany's U-boat fleet suffered heavy casualties, losing 793 U-boats and about 28,000 submariners out of 41,000, a casualty rate of about 70%. The Imperial Japanese Navy's I-400-class submarine is shown in figure (2.3):

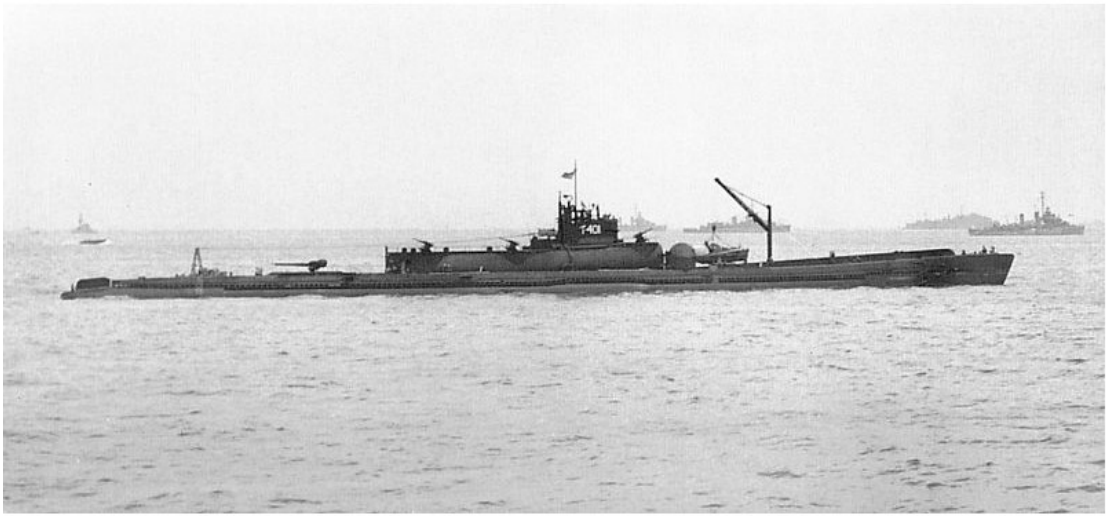


Figure 2.3: The Imperial Japanese Navy's I-400-class submarine

The Imperial Japanese Navy operated the most varied fleet of submarines of any navy, including Kaiten crewed torpedoes, midget submarines (Type A Ko-hyoteki and Kairyu classes), medium-range submarines, purpose-built supply submarines and long-range fleet submarines

2.3 Types of Submarines

Submarines are vessels which carry out underwater operations and duties. The usage of submarines has been quite prominent especially during war times when they are used as stealth weapons to destroy opponents' naval vessels. Over the years, however, the usage of submarines has extended to a number of areas. This extension in the scope of usage has led to the innovation and development of newer submarine technology. Some of the types of submarines that have originated over the years can be enumerated and listed down as follows:

- **U-Boat:** The German war-vessels used during the Second World War, the U-boats were of extreme importance to the German naval forces. The development of the U-boat technology was testimony to the German forces' single-minded determination to win the World War. The first U-boat was launched in the year 1939 and was called the U-27 figure(2.4):

Figure 2.4: Submarine U-27

- **Midget Submarine:** The word 'Midget' refers to anything being small in stature. The midget submarine technology empowers big naval ships to allow these smaller vessels into the water to carry out required underwater operations. The midget submarine is often referred to as the submersible Example in Figure (2.5):

Figure 2.5: Midget submarine

- **Personal Submarine:** Also known as the recreational submarine, the personal types of submarine is that which is used for recreational or research purposes. First created by Graham Hawkes in the 1970s, these types of submarines were initially utilized as naval vessels. In contemporary times, they have become exceedingly important in the marine research and recreational arena. Nowadays, even super yachts and large cruise ships have personal recreational submarines, shown in figure (2.6):

Figure 2.6: Personal submarine

- **Deep-Sea Submergence Vehicle:** Known as the DSV, the deep sea submergence vehicle is a submarine used for deep water research purposes. DSVs can either be manually operated by pilots or controlled through robotic operations. The Deep Sea Submergence Vehicles are sometimes also referred to as the Deep Submergence Research Vehicles. DSV is shown in figure (2.7):

Figure 2.7: DSV

- **Deep Submergence Rescue Vehicles:** Referred to as the DSRV, these types of submarines are used for underwater naval rescue operations. Predominantly used in the United States, this submarine technology was developed as a result of the naval accident caused to the USS Thresher in the 1960s. Over the years, the usage of these types of submarines has extended to other countries of the world as well. DSRV is shown in figure(2.8):

Figure 2.8: DSRV

- **Naval Submarines:** Last but not the least, the main usage of submarine is during the war time. Used extensively during war time, naval submarines are used today by almost all countries around the world in their defense systems. Naval Submarine is shown in figure (2.9):

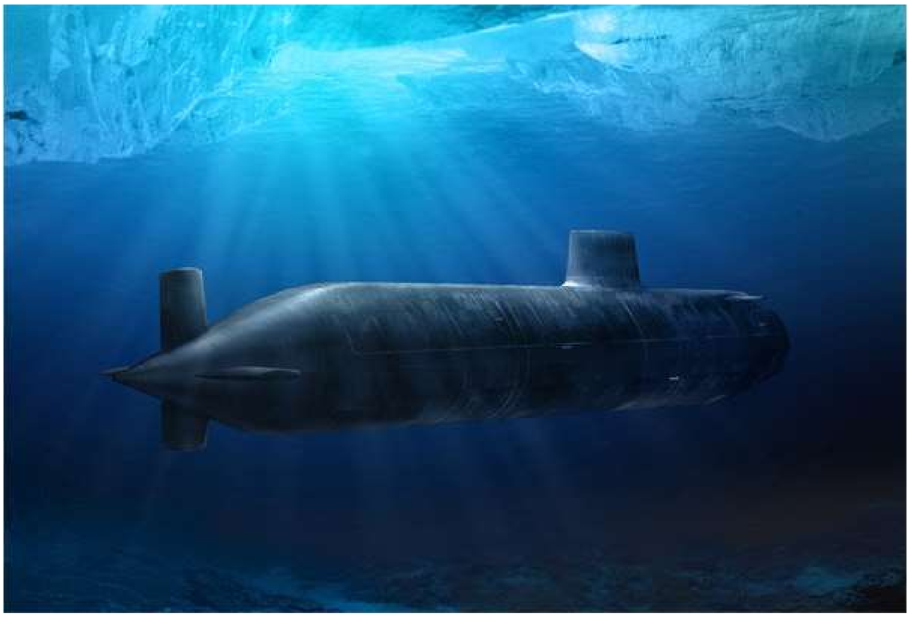


Figure 2.9: Naval Submarine

2.4 Submarine Purpose

Submarines monitor the air, land and sea (both above the surface and below it). Submarines are force multipliers: compelling foreign militaries to launch numerous vessels in response to even the threat of a single submarine. During times of war, submarines are crucial in controlling the seas. They detect and destroy hostile submarines and surface ships, blockade foreign ports and restrict ocean transport. They provide intelligence and underwater protection for surface ships, and are able to detect and lay mines more efficiently than any other navy vessel. Submarines provide a means to land Special Forces in hostile regions and, if fitted with suitable weapons, are able to strike land targets. Submarines are also used for a variety of functions in the private sector. The most common are scientific submarines, which explore the world's oceans to further research and to locate sunken ships. Submarines can also be used for tourism, while unmanned submarines (which are very small and operated remotely from the surface) are used to perform work which is too deep or too dangerous for divers, such as on an oil rig.

CHAPTER THREE

SUBMARINE CONTROL SYSTEMS

3.1 Introduction

A submarine control system is complicated and has a lot of elements depends on many factors. In the control room there is a steering system, floating and diving system, sonar system, water leak and fire detector sensor, and other depends on the type of the Submarine. Control room can be shown in figure (3.1):

Figure 3.1: Control room

3.2 Submarine diving and floating system

The submarine has two floating conditions one on the surface and the other submerged. In either case, Archimedes principle has to be applied. The transition from surface to submerged cruising is achieved by flooding the ballast tanks. They are empty for surface cruising and completely flooded for submerged cruising.

The diving process may be interpreted in two ways. In the first interpretation, the water used to flood the ballast tanks may be considered as ballast, increasing the weight of the submarine by the weight of the water. At the same time, the volume of the submarine increases. The center of buoyancy and, in most cases, the center of gravity shift with respect to height as well as length. The diving process is completed when the ballast tanks are filled and the vessel is submerged. The vessel is now heavier and displaces its own weight. This interpretation is common in foreign countries. Submarine above water is shown in figure (3.2):

Figure 3.2: Submarine above water

The second interpretation has been used in Germany since about 1938. The water used to flood the ballast tanks during the dive is not considered part of the submarine weight, and so the weight of the submarine is the same on the surface as when submerged. Figure (3.3) represents Buoyant.

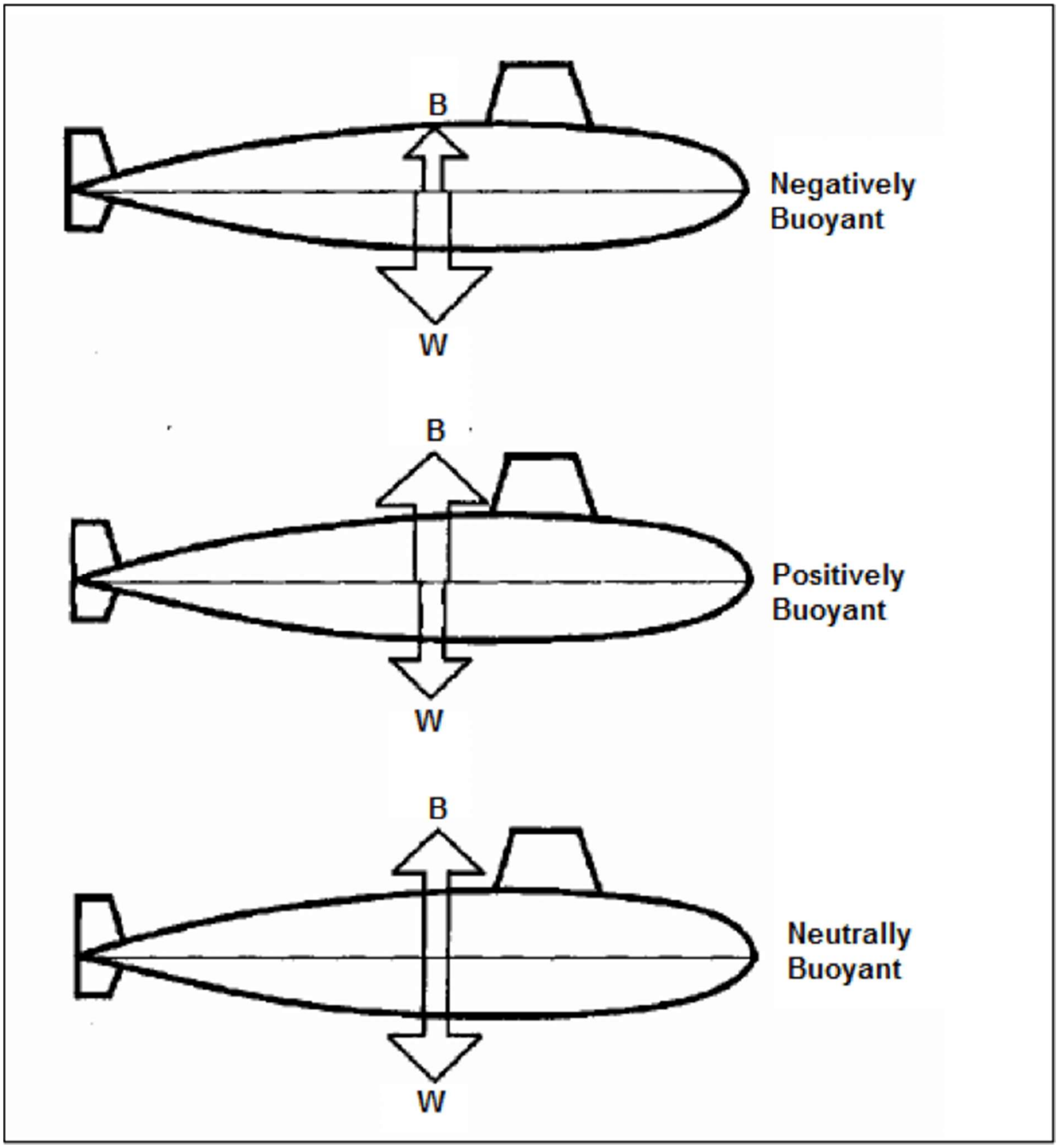


Figure 3.3: Buoyant

The center of gravity also remains the same with respect to height and length on the surface as when submerged. During surface cruising, the ballast tanks are empty, when the boat sub- »" merges they are filled. Thus on diving, the only change is the center of buoyancy with respect to height, and usually with respect to length, because the pressure-resisting parts above the waterline are submerged and the displacement of the content of the ballast tanks is eliminated. This interpretation is easier to use during the design phase. Unless otherwise indicated, this is the interpretation that will be used in what follows. The pressure-resisting displacement (V + V) includes Figure (3.4) represent the displacement of the pressure hull at the outer edge of the hull and additionally outside the pressure hull, all structural members making up the ballast tanks, fuel tanks and free-flooding areas, as well as the stern tube, propeller, pressure-resistant piping (ventilation ducts), compressed air flasks, retractable equipment (periscopes, antennas, etc.) and, finally, the fuel tanks outside the pressure hull.

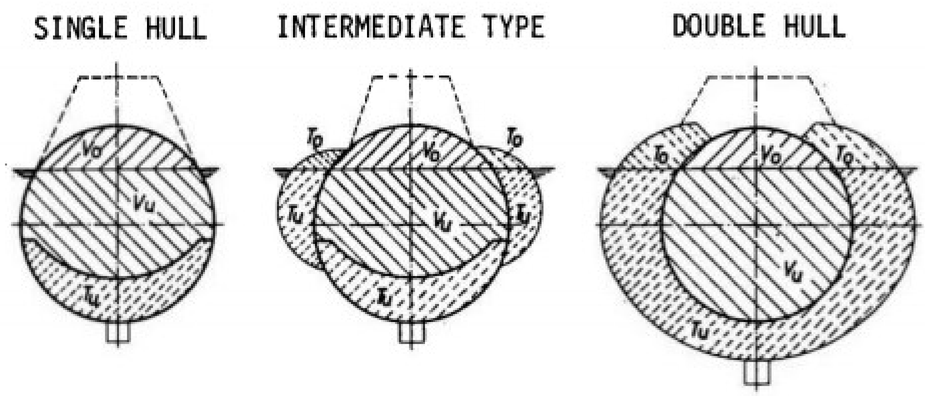


Figure 3.4: Displacement Relationships for Submarines

Thus, the following relation is valid:

For surface cruising:

$$P = \gamma(V_u + T_u) \tag{3.1}$$

For submerged cruising:

$$P + \gamma(T_u + T_o) = \gamma(V_u + T_u + V_o + T_o) \tag{3.2}$$

From these:

$$\gamma(V_u + T_u + T_u + T_o) = \gamma(V_u + T_u + V_o + T_O) \tag{3.3}$$

And thus:

$$T_u = V_o \tag{3.4}$$

V_u is the pressure resisting displacement below the line of flotation in cubic meters,

V_o is the pressure resisting displacement above the line of flotation in cubic meters,

T_u is the content of the ballast tanks below the line of flotation in cubic meters,

T_o is the content of the ballast tanks above the line of flotation in cubic meters,

P is the weight of the boat in M_P.

γ is the density of sea water in $[M_P/m^3]$.

Thus, a submarine that is ready to dive must have an underwater '^ weight that corresponds to its displacement. The weight has to be varied only according to the density of the sea water. If the submarine dives in denser water, it should be made heavier.

Maximum and minimum densities that may be encountered must be established for design purposes in order to keep a submarine submersed. E.g., the oceans and their bordering seas have a sea water density of 1.025- 1.028. The Baltic Sea has a density of 1.012 but drops to 1.005 in the Eastern Baltic. Large areas near estuaries consist of almost pure fresh water. Submarine from the inside is shown in figure (3.5):

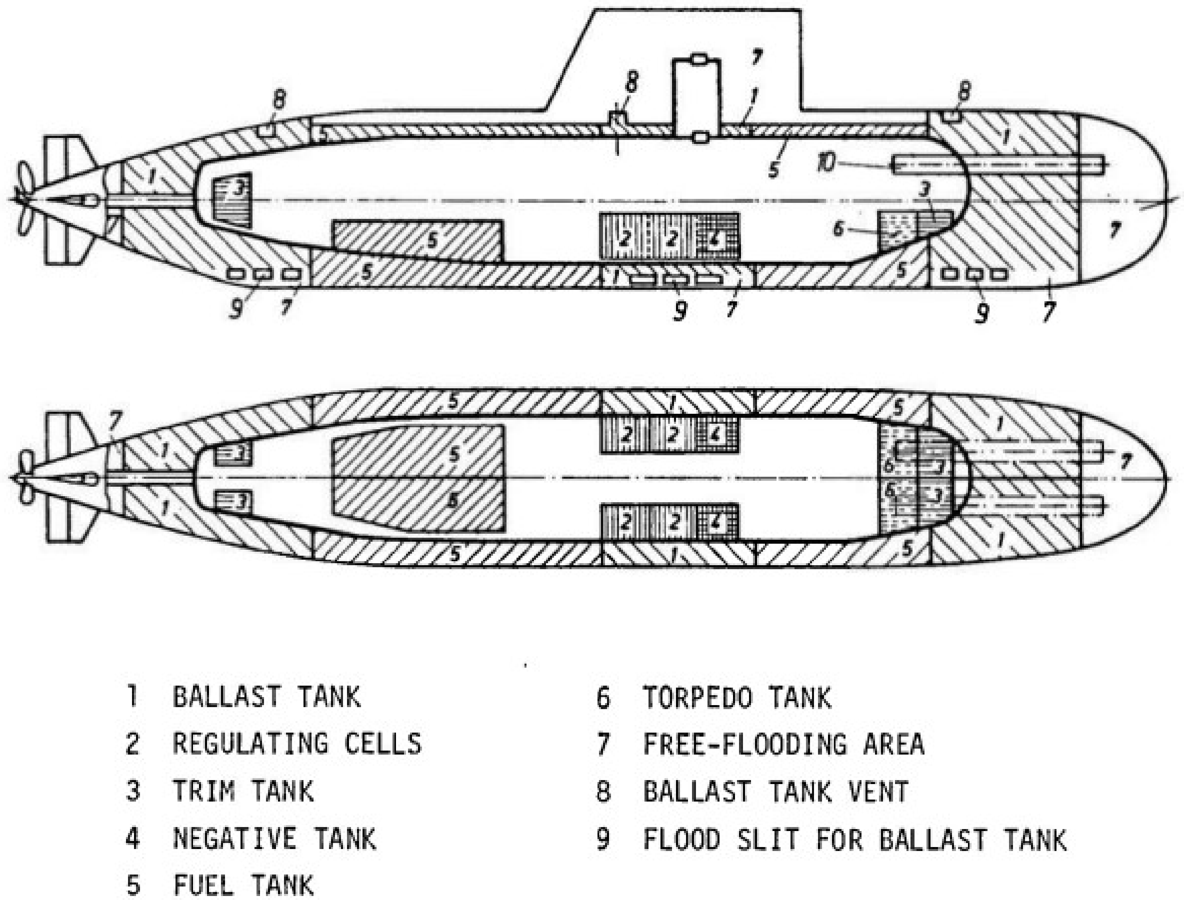


Figure 3.5: Submarine from the inside

When the submerged vessel is trimmed so that it floats on an approximately even keel without reserve or negative buoyancy, the submarine is said to have "neutral trim without reserve buoyancy." When a submarine of this type surfaces by blowing its tanks, i.e., by emptying its ballast tanks, it can float on the surface on a fixed trim only as long as the weight condition of the controlled state is maintained. This surface trim condition depends on the shape of the submarine and on the location and size of its ballast tanks. All the consumable items on board, such as stores, fresh water, and fuel, must be compensated for within the submarine by changing the counterweights. Thus, when a submarine is on the surface and "ready to dive," it is impossible to tell whether it is completely loaded with fuel and supplies or whether some of these items have been consumed.

3.3 Control Fundamentals of submarine

Controller design is about creating dynamic systems that behave in useful ways. Many target systems are physical; employ controllers steer ships, fly jets, position electric motors and hydraulic actuators, and distill alcohol. Controllers are also applied in macroeconomics and many other important of non-physical systems. It is the fundamental concept of controller design that a set of input variables acts through a given "plant" to create an output. Feedback control then uses sensed plant outputs to apply corrective inputs:

Table 3.1: Plants inputs and outputs

Plant	Input	Output	Sensors
Jet aircraft	Elevator, rudder,etc	Altitude, hdg	Altimeter, GPS
Marine vessel	Rudder angle	Heading	Gyrocompass
Hydraulic robot	Valve position	Tip position	Joint angle
U.S economy	Fed interest rate etc	Prosperity	Inflation, M1
Nuclear reactor	Fed	Power level	Temp. pressure

3.4 The classical submarine steering system

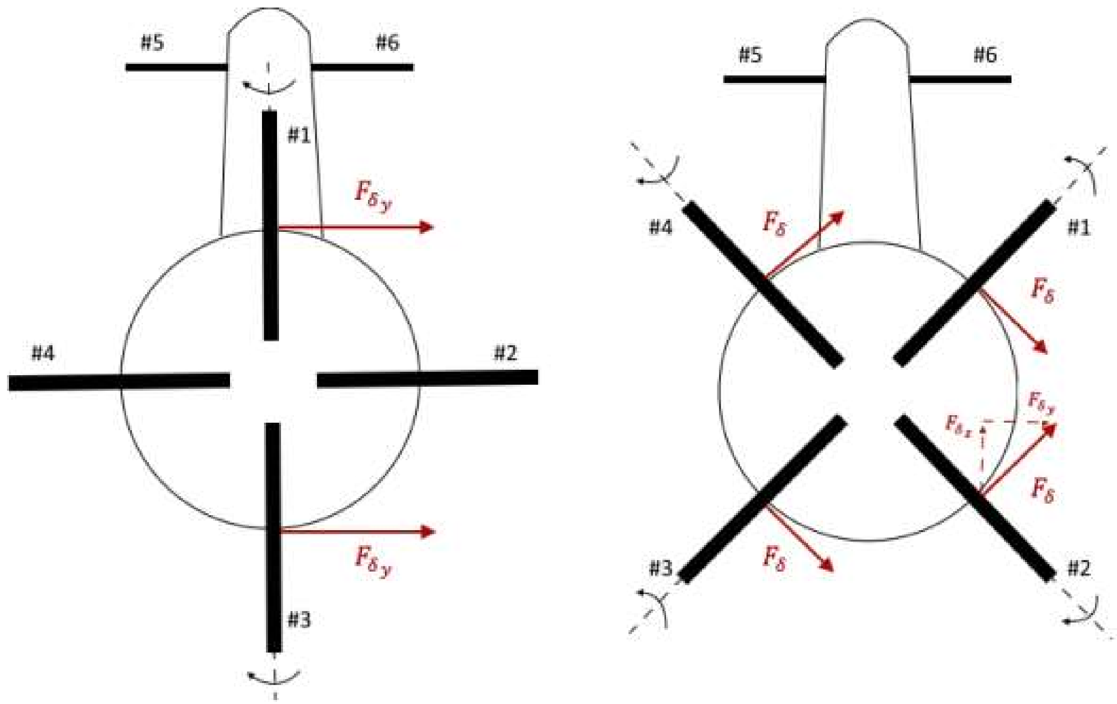
The classical steering system onboard of a submarine comprises of a one man or two man console operated by means of joysticks, stick wheels, levers or a combination of both. For all rudder configuration (e.g. X-Rudder, + - Rudder) it offers different modes of operation as manual operation, automatic mode and emergency mode. In manual mode the hydroplanes forward and aft and the rudders are steered by the helmsman. Typically the hydroplanes/rudders (forward and aft) are linked to each other so that the steering system takes care of acting on the rudders depending on actual speed and the demanded depth change given by the helmsman. In certain situations it is advantageous to decouple the hydroplanes/rudders forward and aft and operate them separately. In automatic mode a 3D Autopilot takes over and keeps the set depth and course. In a “mixed mode” the helmsman might steer and control course/heading in manual while the Autopilot keeps the set depth or vice versa. This was the task of legacy depth and course pilots as well whereas modern systems perform complex depth changes, preprogrammed maneuvers and dynamic predictions as well. All this in a preciseness and smoothness comparable to a well-trained helmsman. The emergency mode takes care of situations where the submarine has a loss of mains and has to operate as save as possible. Today the steering console of a conventional submarine is interfaced with the sensors and systems directly necessary to perform the task of steering the submarine, e.g. the depth sensors, essential navigation data, the actuators for the hydraulic rudder engines including the feedback from the rudder position transmitters and the engine control. This principle limits the submarine design and operation to a high degree as it does not take advantage of already available technologies in terms of data distribution onboard like on commercial vessels and even surface combat ships.

3.5 Advanced safety and alarm management for highly automated operation

Basic requirement for having multiple steering workstations onboard (such as the steering console and the navigation workstation or other multifunctional consoles) A is a common HMI. It is essential there is no “break” between the different steering workstations and its operation concepts, especially if an operator switches due to a changed mission profile from system A to system B. The acceptance of increasing the automation of submarine steering will also depend on increasing the safety and alarm management. This implies an advanced control (e.g. track control) which also considers dysfunction and drift of sensors over time while being submerged and, for example, not connected to GPS. In other words, an advanced control requires a highly reliable integrity monitoring. Furthermore, the respective alarm management shall take into account all relevant information being part of this process. From a functional point of view simulation and training capabilities must not be missed. Future steering will support the helmsman with a "virtual submarine" presentation – performing training sessions without interfering the real submarine. In addition, the safety and alarm management can be supported by specific safety features (e.g. safety envelope, bottom navigation, forward looking sonar), which among others prevents critical depth to the autopilot and/or helmsman. Another aspect is a reaching a higher level of redundancy by having more than one dedicated steering console onboard (e.g. steer the boat from the navigation workstation). Further, the aviation industry uses fly-by-wire technologies including additional features like "force feedback" joysticks or stick wheels, which provide vibration warnings in extreme maneuvers when reaching defined limits. This might be a future scenario for research projects regarding safety improvements in submarine steering consoles.

3.6 Control Surfaces

In the coefficient file, the stern hydroplanes are calculated assuming a cross-configuration (×−conf iguration), and each coefficient is considered for one hydroplane as shown in figure (3.6):



(a) (b)

Figure 3.6 control surfaces

(a) configuration (cruci) seen from behind.

(b) ×-configuration (cross) seen from behind.

Therefore, the coefficients regarding the stern hydroplanes must be multiplied with 4 before using in Equations 3.5-3.6 As presented in section 4.6, when using the cross-configuration all four stern hydroplanes are used to perform a manoeuvre, but for a cruci-configuration only two are used as shown in Figure 3.6, where the submarine is initiating a horizontal turn. Positive hydroplane deflection is with its trailing edge towards port side as the figure is portray. Assuming that the cross-configuration has a mounting of 45 degrees from the submarines vertical line, the hydroplane force for one blade for each configuration will be:

$$F_{\delta yx} = \frac{F_\delta}{\sqrt{2}} \tag{3.5}$$

$$F_{\delta y+} = F_{\delta} \tag{3.6}$$

One blade on the cruci-configuration will thus create a force of $\sqrt{2}$ times larger than a blade with a sweep of 45 degrees. If a cruci-configuration model submarine is used, each of the stern hydroplane coefficients should be multiplied with a factor of $\sqrt[2]{2}$since the cruci-configuration only uses two hydroplanes instead of four for a turn or a dive. In the EOM's, Equations, the stern hydroplanes are treated with two variables, except in the rolling moment equation, Equation 3.7, where each plane has its own variable. The horizontal manoeuvring variable is the rudder deflection δr calculated as:

$$\delta_{r\times} = \frac{\delta_1+\delta_2+\delta_3+\delta_4}{4} \tag{3.7}$$

$$\delta_{r\times} = \frac{\delta_1+\delta_2}{2} \tag{3.8}$$

Where δ1 −δ4 are the angles of the four different hydroplanes as seen in Figure 5.2. The vertical manoeuvring variable is the stern-plane deflection δs calculated as:

$$\delta_{s\times} = \frac{-\delta_1+\delta_2-\delta_3+\delta_4}{4} \tag{3.9}$$

$$\delta_{s\times} = \frac{-\delta_1-\delta_3}{2} \tag{3.10}$$

For this thesis, the deflection of the stern hydropanes are defined as positive when the trailing edge is towards port side of the submarine and negative towards starboard. On a submarine there are some dynamic movements that has to be considered to be able to get as good a model as possible. Such dynamics is considered with the hydroplanes. As the controller orders a deflection of the hydroplanes to execute a turn or dive, the planes will be rotating with a limited rate until the desired deflection is reached.

3.7 Submarine Hull

Modern submarines are cigar-shaped. This design, visible in early submarines, is sometimes called a "teardrop hull". It reduces the hydrodynamic drag when submerged, but decreases the sea-keeping capabilities and increases drag while surfaced. Since the limitations of the propulsion systems of early submarines forced them to operate surfaced most of the time, their hull designs were a compromise. Because of the slow submerged speeds of those subs, usually, well below 10 kt (18 km/h), the increased drag for underwater travel was acceptable. Late in World War II, when technology allowed faster and longer submerged operation and increased aircraft surveillance forced submarines to stay submerged, hull designs became teardrop shaped again to reduce drag and noise.

USS Albacore (AGSS-569) was a unique research submarine that pioneered the American version of the teardrop hull form (sometimes referred to as an "Albacore hull") of modern submarines. On modern military submarines, the outer hull is covered with a layer of sound-absorbing rubber, or anechoic plating, to reduce detection.

3.7.1 Single and double hulls

Modern submarines and submersibles, as well as the oldest ones, usually have a single hull. Large submarines generally have an additional hull or hull sections outside. This external hull, which actually forms the shape of submarine, is called the outer hull (casing in the Royal Navy) or light hull, as it does not have to withstand a pressure difference. Inside the outer hull there is a strong hull, or pressure hull, which withstands sea pressure and has normal atmospheric pressure inside.

3.7.2 Pressure hull

The pressure hull is generally constructed of thick high-strength steel with a complex structure and high strength reserve, and is separated with watertight bulkheads into several compartments. There are also examples of more than two hulls in a submarine, like the Typhoon class, which has two main pressure hulls and three smaller ones for control room, torpedoes and steering gear, with the missile launch system between the main hulls. The dive depth cannot be increased easily. Simply making the hull thicker increases the weight and requires reduction of onboard equipment weight, ultimately resulting in a bathyscaphe. This is acceptable for civilian research submersibles, but not military submarines. Pressure Hull is shown in figure (3.8):

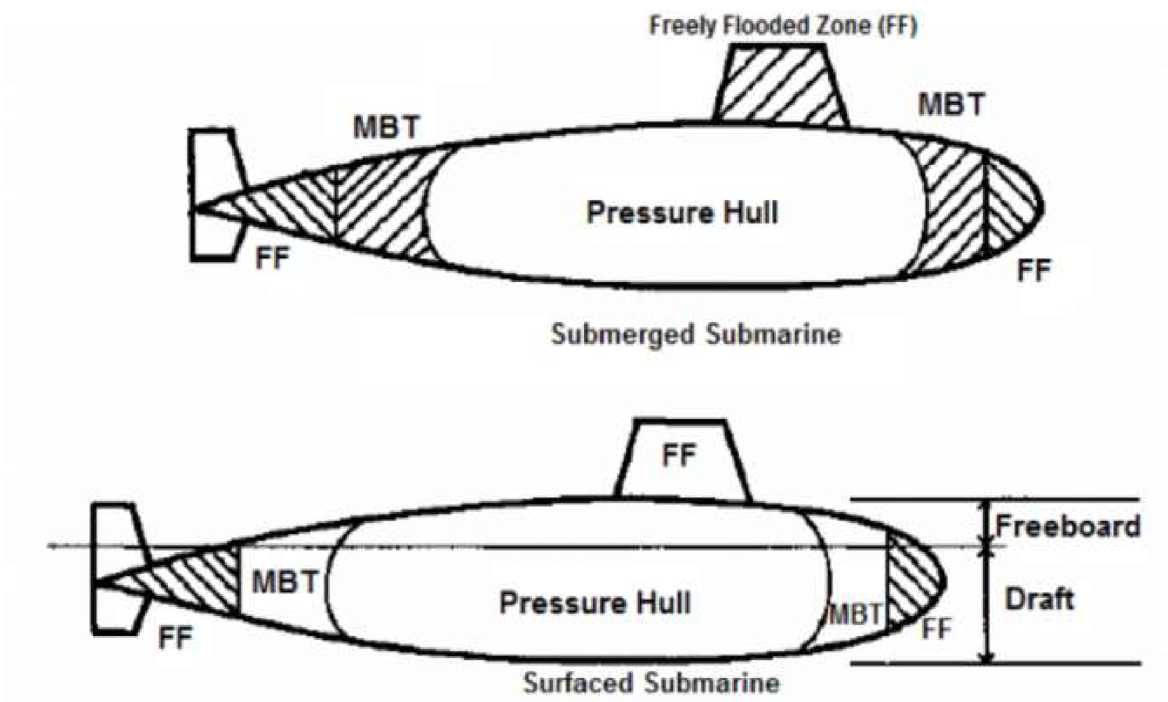


Figure 3.7: Pressure Hull

3.8 Navigation

Early submarines had few navigation aids, but modern subs have a variety of navigation systems. Navigation system is shown in figure (3.9):

Figure 3.8: Navigation System

Modern military submarines use an inertial guidance system for navigation while submerged, but drift error unavoidably builds over time. To counter this, the crew occasionally uses the Global Positioning System to obtain an accurate position. The periscope a retractable tube with a prism system that provides a view of the surface is only used occasionally in modern submarines, since the visibility range is short. The Virginia-class and Astute-class submarines use photonics masts rather than hull-penetrating optical periscopes. These masts must still be deployed above the surface, and use electronic sensors for visible light, infrared, laser range-finding, and electromagnetic surveillance. One benefit to hoisting the mast above the surface is that while the mast is above the water the entire sub is still below the water and is much harder to detect visually or by radar.

3.9 Communication

Military submarines use several systems to communicate with distant command centers or other ships. One is VLF (very low frequency) radio, which can reach a submarine either on the surface or submerged to a fairly shallow depth, usually less than 250 feet (76 m). ELF (extremely low frequency) can reach a submarine at greater depths, but has a very low bandwidth and is generally used to call a submerged sub to a shallower depth where VLF signals can reach. A submarine also has the option of floating a long, buoyant wire antenna to a shallower depth, allowing VLF transmissions by a deeply submerged boat. By extending a radio mast, a submarine can also use a "burst transmission" technique. A burst transmission takes only a fraction of a second, minimizing a submarine's risk of detection. To communicate with other submarines, a system known as Gertrude is used. Gertrude is basically a sonar telephone. Sonar is shown in figure (3.9):

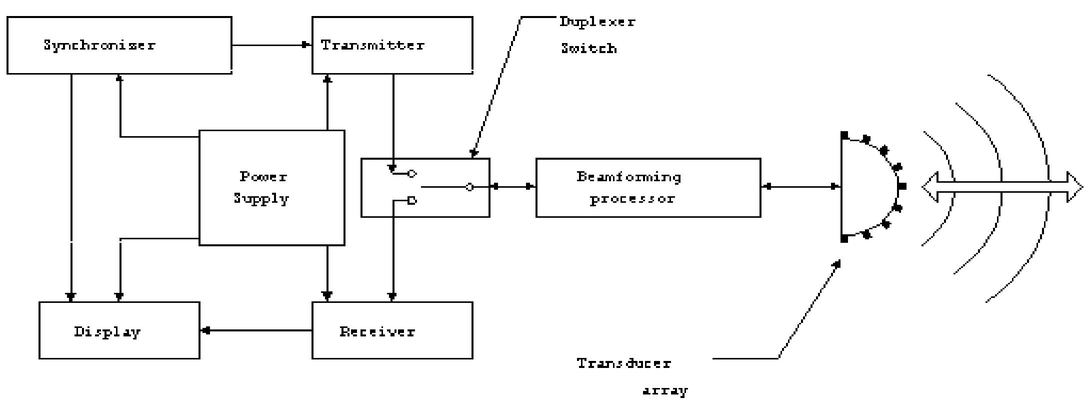


Figure 3.9: Sonar

Voice communication from one submarine is transmitted by low power speakers into the water, where it is detected by passive sonars on the receiving submarine. The range of this system is probably very short, and using it radiates sound into the water, which can be heard by the enemy.

CHAPTER FOUR

APPLICATIONS

4.1 Introduction

One type of submarine is the ROV (Remotely Operated Vehicle) whose movements are controlled directly by humans from the water surface. In this Chapter, ROV prototype has been designed and tested with three DOF (Degrees of Freedom) and controlled by a potentiometer .three brushless motor has been used in order to move the three direction.

4.2 The System Main Block Diagram

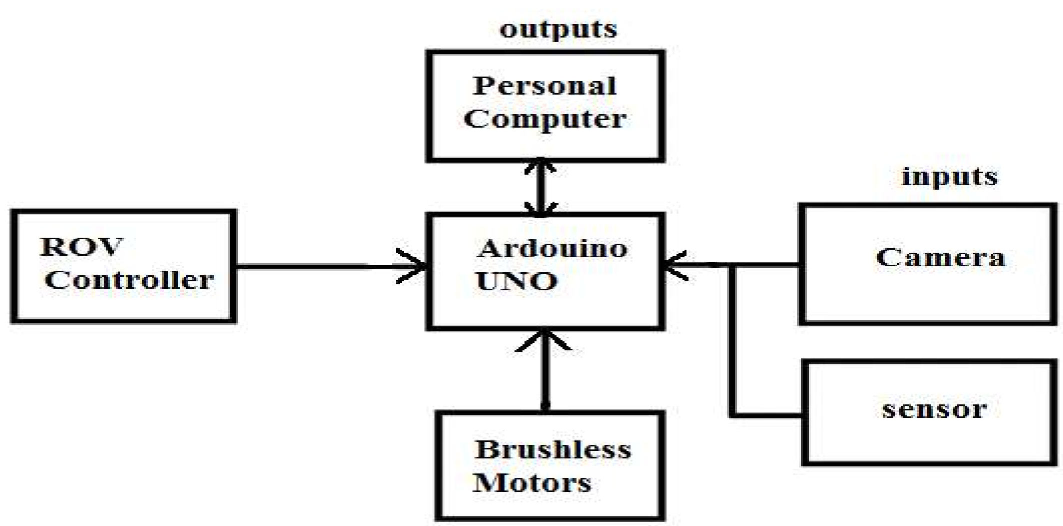


Figure 4.1: System Diagram

In this block diagram in figure (4.1) arduino is powered using a SUB from the laptop, the camera type Ov7670 and sensors connected to the arduino and have a feedback on the laptop. A three brushless motor are connected was an electronic speed control ESC to control it a speed, the esc connected to the arduino program. The microcontroller was used is a potentiometer to the arduino controlling the speed of the motors.

4.2.1 Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328 .It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. Arduino Uno pin Diagram is shown in figure (4.2):

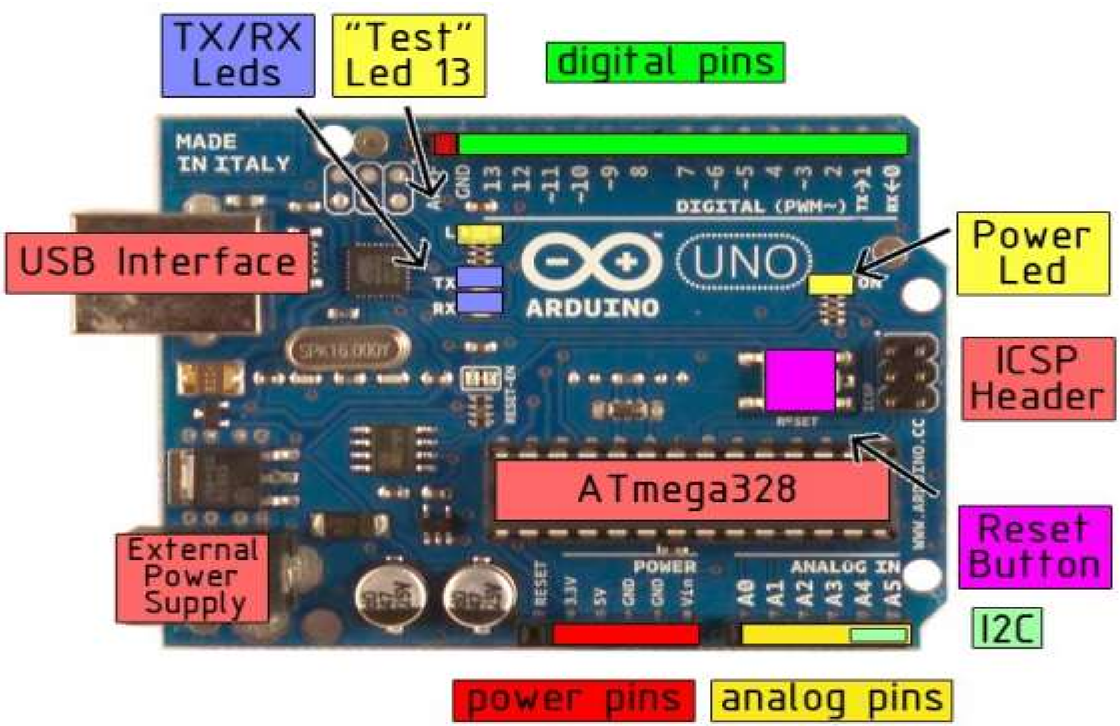


Figure 4.2: Arduino Uno pin Diagram

4.2.2 Brushless Motor

An a small yet powerful motor for planes up to 800 grams, using three li-poly cells 140 watts continuous power with short bursts up to 180 watts. An excellent higher-powered replacement for geared Speed 400-480 motors in slow-flying or 3D planes that require a larger 10" propeller. Use on sailplanes up to 28 oz, trainers up to 25 oz, aerobatic aircraft up to 18 oz and 3D airplanes up to 15 oz. Recommended prop is 10 x 5 on 3 li-poly cells. The motor features a 3.2mm hardened steel shaft, dual ball bearings, and has 3.5mm gold spring male connectors already attached and includes 3 female connectors for your speed control. Now includes collet type prop adapter and radial motor mount. Mounting holes have 16mm and 19mm spacing on centers and are tapped for 3mm (M3) screws. Brushless motor is shown in figure (4.3):

Figure 4.3: Brushless motor

4.2.3 Electronic speed control (ESC)

An electronic speed control (ESC) is an electronic circuit that controls and regulates the speed of an electric motor. It may also provide reversing of the motor and dynamic braking. Miniature electronic speed controls are used in electrically powered radio controlled models. Full-size electric vehicles also have systems to control the speed of their drive motors. ESC is shown in figure (4.4):

Figure 4.4: ESC

4.2.4 LM35 Temperature Sensor

The LM35 sensor shown in figure (4.5) is a temperature-measuring sensor with a voltage output proportional to the temperature of the Centigrade. LM 35 does not need to be reset every time as it happens in some sensors. The measured temperature range is (55 °C to 150 °C) at 0.05% accuracy.

Figure 4.5: LM35 temperature sensor

4.2.5 MS5540C Water Depth (Level) Sensor

The MS5540C pressure sensor measures Absolute water or air pressure. It also measure temperature at the same time. So you can use it for measuring water depth in sea or water level in tank. It can be also be used with different fluids measurements such as oil. You might use it also with air for measuring altitude (barometer) and temperature. MS5540C water depth (Level) sensor is shown in figure (4.6):

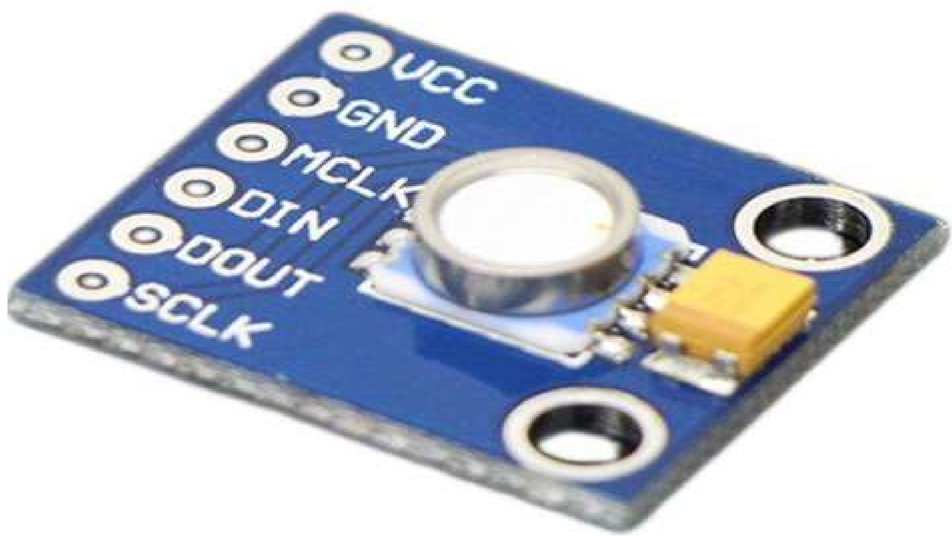


Figure 4.6: MS5540C water depth (Level) sensor

4.2.6 CAMERA Type OV7670

The CAMERACHIPTM type OV7670/OV7171 shown in figure (4.7) is a low voltage CMOS image sensor that provides the full functionality of a single-chip VGA camera and image processor in a small footprint package.

Figure 4.7: camera type OV7670

The OV7670/OV7171 provides full-frame, sub-sampled or windowed 8-bit images in a wide range of formats, controlled through the Serial Camera Control Bus (SCCB) interface. This product has an image array capable of operating at up to 30 frames per second (fps) in VGA with complete user control over image quality, formatting and output data transfer.

4.2.7 Power Supply (Battery type LiPo)

- Capacity: 3000mAh
- Voltage: 3S / 3 Cell / 11.1v
- Watt Hours: 33.30Wh

  Figure (4.8) represent battery type LiPo:

Figure 4.8: battery type LiPo

4.2.8 Potentiometer

A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat. The measuring instrument called a potentiometer is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle, hence its name. Potentiometer is shown in figure (4.9):

Figure 4.9: Potentiometer

4.3 Hardware Implementation

The physical characteristics of materials that were used in designing the ROV to operate in underwater conditions can be seen in figure (4.10). In this work, polyvinyl chloride (PVC pipe with steel bars inside) is used as a structural element since it complies with mechanical characteristics for the ROV to function properly Lengths of the pipes are in the table (4.1):

Table 4.1: ROV Frame Components.

Component Name	Materials	Lengths(mm)	Dimension (mm)
Hull robot	PVC pipe	400	114
Motor casing	PVC pipe	130	35
Bearing	Aluminium	-	5
Propeller	Plastic	-	48
electrical cover	Plastic	20	108
Hull cover	PVC dop	-	114
Shaft	Aluminium	40	5
Coupling shaft	Brass	18	6

After the right measurement were taken, pieces were cut and assemble together with a CPVC Cement, as shown in figure (4.10) below:

Figure 4.10: Pieces of PVC pipe

Figure (4.11) shows the ROV frame. The pressure hull is using PVC pipe with end cap for both side. To increase withstand of pressure to the PVC pipe, another PVC connector will be put. Waterproof silicon is used as the sealing method. From the ROV frame, the measurement of buoyancy force is carried out so that ROV can easily submerge as long as it follows set points. The weight will be used to overcome the buoyancy problem by playing around some buoyancy experiments.

Figure 4.11: ROV frame

As show in figure (4.12): The brushless motors are model QF-2611 manufactured by XCSOURCE with a turning speed of 1000 KV three-phase voltage, are connected in a star configuration. The brushless motors are controlled by an electronic speed controller (ESC), which generates a three-phase output signal, having as an input a pulse width modulation (PWM) signal generated by an Arduino UNO microcontroller. The motors were connected with a plastic propeller.

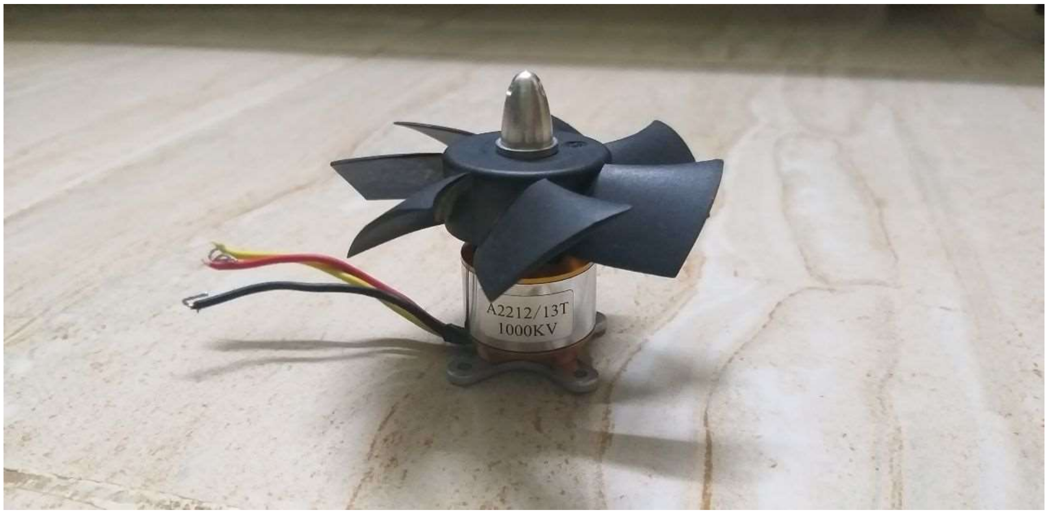


Figure 4.12: brushless motor with a propeller

After that the lights and camera were placed inside the pipe alongside with the Arduino UNO, the lights and the battery .the pipe were cover properly and sealed with a water proof silicon as show on in figure (4.12).

4.4 Operation System

Arduino UNO was used as microcontroller and Connect with three brushless motors, OV7670 camera and water depth sensor as show in figure (4.1). Arduino IDE program was installed and used to program the Arduino ESC was connected to the brushless motor in order to control the speed of the motor.

4.5 Electronic Elements Testing:

In order to make sure everything is working properly each items was test separately and then test to together to give a better result.

4.5.1 Camera Type OV7670:

After the cam was programed using Arduino IDE the cam give feedback in the laptop using a cable, pictures were saved as shown in figure (4.13), the pictures are unclear black and white.

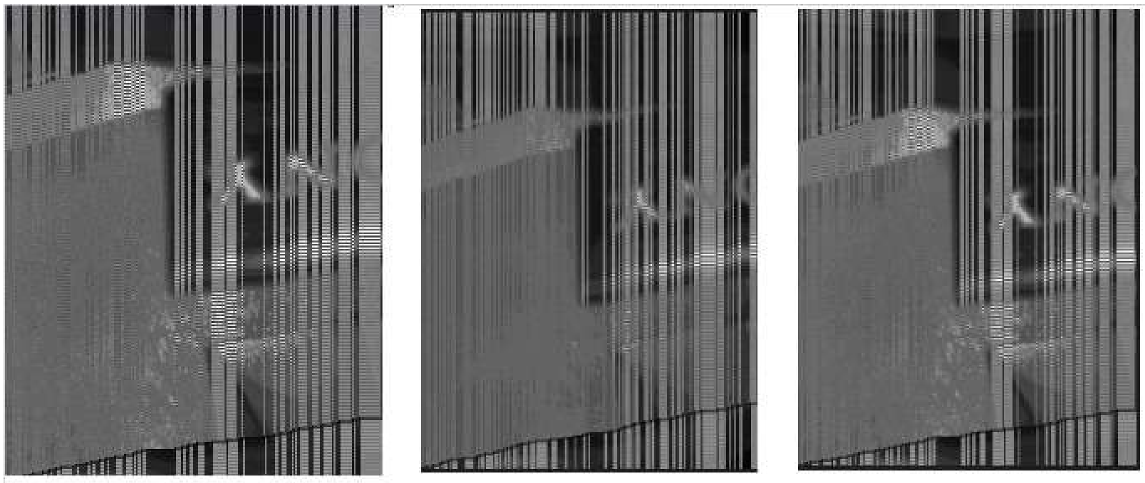


Figure 4.13: Camera Testing

4.5.2 Temperature and Pressure Sensor:

LM35 was used for temperature sensor and water depth sensor used as pressure sensor both of them were programed and give feedback in the laptop with a delay of 1000ms, water depth sensor give three parameters depth temperature and pressure but in the program it only give one of them which is the pressure due to manufacture errors, final result can be shown in figure (4.14):

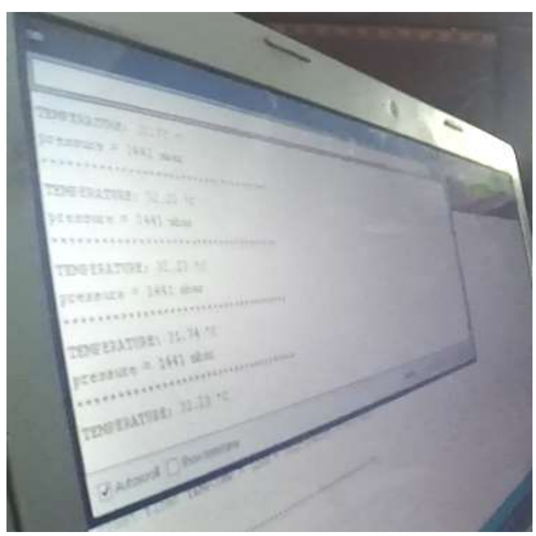


Figure 4.14: Sensors Testing

4.5.3 Brushless motor:

In this prototype there is three motors each of them were test separately and then programed together ,firstly it was connected to electronic speed control and then connected to the Arduino and potentiometer to control it speed ,each motor prove working properly , the result is shown in figure (4.15):

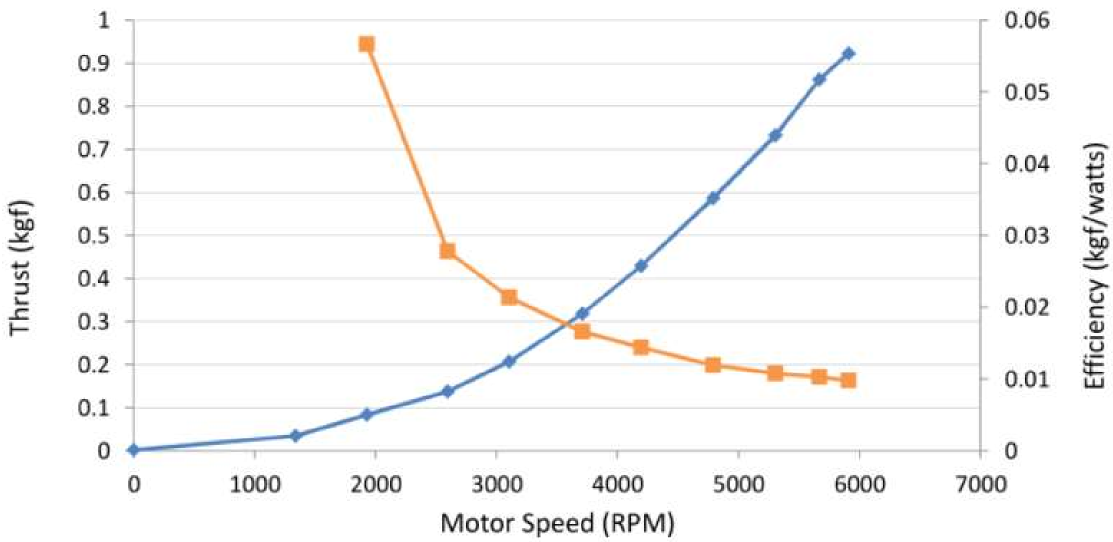


Figure 4.15: Motors Testing

4.5.4 Potentiometer

Three potentiometer were used, each one were tested alone with a brushless motor, after Arduino was programed, and the programed worked properly.

4.6 ROV Controller:

Potentiometer was used as Manual wire control method, Three of them were used each one control one brushless motor, which was connected to Arduino with Ethernet cable. Figure (4.16) shown the controller:

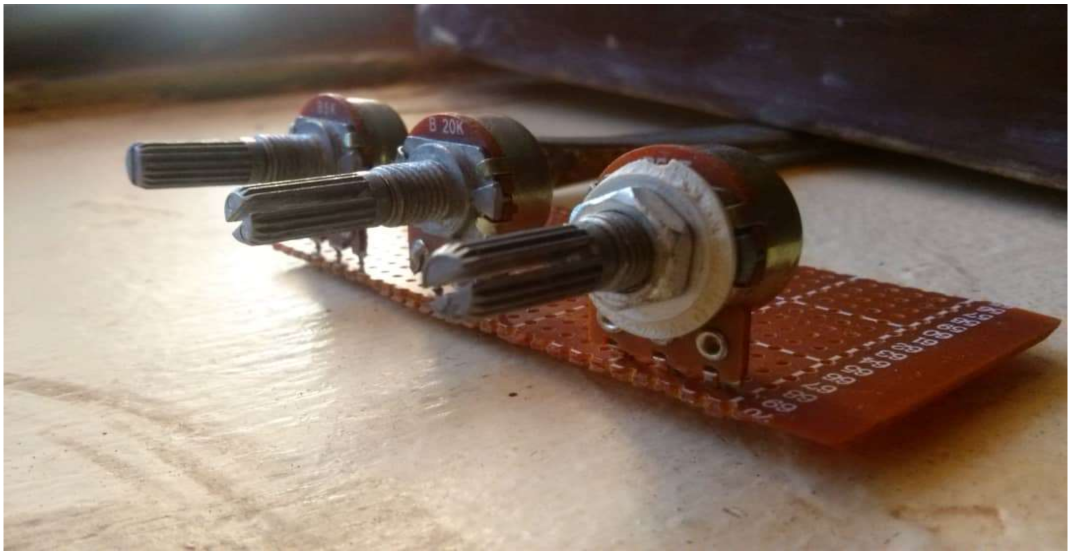


Figure 4.16: Controller

4.7 ROV Testing:

After a lot of research were made, ROV shown in figure (4.11) were made and it was sealed using silicon. Figure (4.17) shown the final look of the ROV while motors are spinning.

Figure 4.17: ROV Prototype

4.8 Water leakage Test:

The prototype was cheeked after been sealed with silicon and left to dry for one hour ,and then it was put in water as shown in figure (4.18):

Figure 4.18: ROV in Water

4.8.1 Test one:

failed after water went inside the pipe as the air bubbles was on the surface of the water, and the temperature sensor give a 87C degree indicting more heat ,so it was Opened again to let the water out and dry all the items. Figure (4.19) show the LM35 Sensor when water leakage happened.

Figure 4.19: LM35 in water

After all electronic items was dry, it was tested again outside of the water and it worked properly then it was test again under water.

4.8.2 Test Two:

This time a CMPT water prove was used and silicon, the body was cheeked again and then it was put in the water. Test two was a success water didn’t leak and sensors give a good result in the laptop.

4.9 Final Testing and Result:

All the items were put together for the final test, and it was properly sealed to prevent water leakage ,then tested in the water and on ground surface , it move left by increasing the speed of the left motor and decreasing the right motor , and move to the right by increasing the speed of the right motor and decreasing the left motor , the middle motor should have moved the ROV up from the water to let it out, but the ROV weight wasn’t balance so it didn’t move up, in order to get the right balance a five bottle of water has been used, and then were put a long side the bottom of the ROV Frame then tested again, it worked this time but due to the pressure of the water the silicon leaked. Figure (4.20) show all motors are working and can be controlled with the controlled in figure (4.16).

Figure 4.20: ROV Underwater

CHAPTER FIVE

CONCLUSION AND RECOMMNDATIONS

5.1 Conclusion

The development of Remotely Operated underwater Vehicle (ROV) and integrated sensor are used to operate the system in a good manner.

ROV using three brushless motors as the thrusters (propulsive devices used by watercraft for attitude control in the reaction control system). The camera type ov7076 is helpful in taking photos of targets underwater.

5.2 Recommendations

- Add a Wi-Fi as a wireless system.
- Add more sensors such as sensor type MPU6050 to optimize the system.
- Add of a pair of relays per motor in order to reverse the movement of the motors.
- Replace the camera type OV7076 with a higher quality camera that has video feedback.
- Finally, an arm can be added to pick up sample from the water using Servo motor.

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APPENDICES

Appendix (A)

Arduino IDE program for the ROV motors:

```
#include <Servo.h>

// Define the number of servos

#define SERVOS 3

// Create the servo objects.

Servo myservo[SERVOS];

// Attach servos to digital pins on the Arduino

int servo_pins[SERVOS] = {9,10,11};

// Analog pins used to connect the potentiometers

int potpins[SERVOS] = {A1,A2,A3};

// Variables to read the value from the analog pin

int potpin_val[SERVOS];


void setup() {


  for(int i = 0; i < SERVOS; i++) {

    // Attach the servos to the servo object

    myservo[i].attach(servo_pins[i]);

  }
```

```
}

void loop() {

  // For each servo
  for(int i = 0; i < SERVOS; i++) {
    // Read the value of the potentiometer (value between 0 and 1023)
    potpin_val[i] = analogRead(potpins[i]);
    // Scale value to between 0 and 180
    potpin_val[i] = map(potpin_val[i], 0, 1023, 0, 180);
    // Update servo position
    myservo[i].write(potpin_val[i]);
    // Wait 15 milliseconds for the servo to get to the position
    delay(15);
  }
}
```

Appendix (B)

Arduino IDE program for sensors:

```
 #include <SPI.h>

 int clock = 9;

void resetsensor() //this function keeps the sketch a little shorter

{

 SPI.setDataMode(SPI_MODE0);

 SPI.transfer(0x15);

 SPI.transfer(0x55);

 SPI.transfer(0x40);

}

void setup() {

 Serial.begin(9600);

 SPI.begin(); //see SPI library details on arduino.cc for details

SPI.setBitOrder(MSBFIRST);

 SPI.setClockDivider(SPI_CLOCK_DIV32); //divide 16 MHz to communicate
on 500 kHz

 pinMode(clock, OUTPUT);

 delay(100);

}

void loop()
```

```
{
 TCCR1B = (TCCR1B & 0xF8) | 1 ; //generates the MCKL signal
 analogWrite (clock, 128) ;
 resetsensor();//resets the sensor - caution: afterwards mode = SPI_MODE0!
 //Calibration word 1
 unsigned int word1 = 0;
 unsigned int word11 = 0;
 SPI.transfer(0x1D); //send first byte of command to get calibration word 1
 SPI.transfer(0x50); //send second byte of command to get calibration word 1
 SPI.setDataMode(SPI_MODE1); //change mode in order to listen
 word1 = SPI.transfer(0x00); //send dummy byte to read first byte of word
 word1 = word1 << 8; //shift returned byte
 word11 = SPI.transfer(0x00); //send dummy byte to read second byte of word
 word1 = word1 | word11; //combine first and second byte of word
 resetsensor();//resets the sensor
 //Calibration word 2; see comments on calibration word 1
unsigned int word2 = 0;
 byte word22 = 0;
 SPI.transfer(0x1D);
 SPI.transfer(0x60);
 SPI.setDataMode(SPI_MODE1);
```

```
word2 = SPI.transfer(0x00);
word2 = word2 <<8;
word22 = SPI.transfer(0x00);
word2 = word2 | word22;
resetsensor();//resets the sensor
//Calibration word 3; see comments on calibration word 1
unsigned int word3 = 0;
byte word33 = 0;
SPI.transfer(0x1D);
SPI.transfer(0x90);
SPI.setDataMode(SPI_MODE1);
word3 = SPI.transfer(0x00);
word3 = word3 <<8;
word33 = SPI.transfer(0x00);
word3 = word3 | word33;
resetsensor();//resets the sensor
//Calibration word 4; see comments on calibration word 1
unsigned int word4 = 0;
byte word44 = 0;
SPI.transfer(0x1D);
SPI.transfer(0xA0);
```

```
SPI.setDataMode(SPI_MODE1);
word4 = SPI.transfer(0x00);
word4 = word4 <<8;
word44 = SPI.transfer(0x00);
word4 = word4 | word44;


long c1 = word1 << 1;
long c2 = ((word3 & 0x3F) >> 6) | ((word4 & 0x3F));
long c3 = (word4 << 6) ;
long c4 = (word3 << 6);
long c5 = (word2 << 6) | ((word1 & 0x1) >> 10);
long c6 = word2 & 0x3F;
resetsensor();//resets the sensor
//Temperature:
unsigned int tempMSB = 0; //first byte of value
unsigned int tempLSB = 0; //last byte of value
unsigned int D2 = 0;
SPI.transfer(0x0F); //send first byte of command to get temperature value
SPI.transfer(0x20); //send second byte of command to get temperature value
delay(35); //wait for conversion end
SPI.setDataMode(SPI_MODE1); //change mode in order to listen
```

```
tempMSB = SPI.transfer(0x00); //send dummy byte to read first byte of value
tempMSB = tempMSB << 8; //shift first byte
tempLSB = SPI.transfer(0x00); //send dummy byte to read second byte of value
D2 = tempMSB | tempLSB; //combine first and second byte of value
resetsensor();//resets the sensor
//Pressure:
unsigned int presMSB = 0; //first byte of value
unsigned int presLSB =0; //last byte of value
unsigned int D1 = 0;
SPI.transfer(0x0F); //send first byte of command to get pressure value
SPI.transfer(0x40); //send second byte of command to get pressure value
delay(35); //wait for conversion end
SPI.setDataMode(SPI_MODE1); //change mode in order to listen
presMSB = SPI.transfer(0x00); //send dummy byte to read first byte of value
presMSB = presMSB << 8; //shift first byte
presLSB = SPI.transfer(0x00); //send dummy byte to read second byte of value
D1 = presMSB | presLSB;
const long UT1 = (c5 * 8) + 20224;
const long dT =(D2 - UT1);
const long TEMP = 200 + ((dT * (c6 + 50))/1024);
const long OFF = (c2*4) + (((c4 - 512) * dT)/4096);
```

```
 const long SENS = c1 + ((c3 * dT)/1024) + 24576;

 long PCOMP = ((((SENS * (D1 - 7168))/16384)- OFF)/32)+250;

 float TEMPREAL = TEMP/10;

Serial.print("pressure = ");

 Serial.print(PCOMP);

 Serial.println(" mbar");

 const long dT2 = dT - ((dT >> 7 * dT >> 7) >> 3);

 const float TEMPCOMP = (200 + (dT2*(c6+100) >>11))/10;

 Serial.print("temperature = ");

 Serial.print(TEMPCOMP);

 Serial.println(" °C");

 Serial.println("************************************");

 delay(1000);

}
```