RoboBoat: Unmanned Surface Vehicle

by

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Mechatronics Engineering

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Abstract

This report discusses about the usage of an Unmanned Surface Vehicles (USVs) named, RoboBoat that can be used for observation purposes in military applications. Given a number of way points RoboBoat would travel from one way point to the other way point. It would use a PID algorithm to adjust its course while travelling from one way point to the other. The GPS would constantly check the current position of the boat along with positions of the way point during the total course and the digital compass provides the heading of the boat with respect to north. The speeds of the two motors are adjusted to control the boat and guide it on its course. The design of the boat is a mono- hulled design made of plastic.

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Chapter 1

Introduction

1.1 Overview

Drones is a common buzzword among the tech community since past few years. Drones have become extremely popular over the past few years. Though, it was used mostly for military and observatory purposes at the beginning, the commercialization of drones and using it for multitude of purposes have made them insanely popular during the latter years.

Unmanned Vehicles are indispensable for various applications where human intervention is impossible, risky or expensive.Unmanned Vehicles can be categorized into Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs) and Unmanned Underwater Vehicles (UUVs). Although, USVs havent seen as much growth as UAVs and UUVs, the growth in USVs during past few years is substantial. During the past few years, the number of Unmanned Surface Vehicles (USVs) that were developed for military, environmental and robotics research applications saw a rapid increase. They are reliable, fast and highly maneuverable allowing them to conduct a wide range of missions, including patrols of the coast, without endangering the Navy personnel.

Even though, the history of USVs date back to World War II, it is only in the 1990s that a drastic improvement was seen in this field. This was largely due to the technological progress in the late 90s and the increase of terrorism activities worldwide.(Sharma et al. (2012))

Figure 1.1: Protector USV of the US Navy developed by General Dynamics Robotics Systems.

Sri Lanka suffered a thirty year old war which is considered to be one of the bloodiest in the modern day warfare. The conflict which spanned from 1983 to 2009 between Sri Lankan government and the separatist terrorist organization, LTTE re-defined military strategies with the introduction of suicide bombers and suicide vessels into warfare. The passenger carrier ships of the Sri Lankan Navy were often attacked by terrorists using autonomous suicide vessels and hundreds of lives were lost to the nation. The inspiration for RoboBoat was from the Unmanned Surface Vessels (USVs) which were used by the LTTE suicide vessels against the Sri Lankan Navy. As a person who has eye-witnessed the atrocities of war an idea was generated inside my mind to develop a boat that could counter attack the threat from terrorists and protect the valuable lives of innocent civilians and reduce the damage caused to the property.

Figure 1.2: A suicide boat used by the LTTE terrorists during Sri Lankan civil war

However, the intended application of Robo Boat is observation and it would not be utilized for direct military applications. It would be used to observe the path before a Navy ship starts its course. Robo Boat would follow a set of pre-programmed waypoints and is guided by GPS autopilot to find its course.The bearing of the boat with respect to the north is given by the digital compass. The boat will adjust its course according to the data provided by the GPS and the compass and will travel from one way point to the other.

1.2 Problem Statement

The RoboBoat is an Unmanned Surface Vessel (USV) that can be used for observatory purposes. It would travel along a set of given way points and can be utilized to observe a given terrain. Due to its small size and as there are no human lives involved in the process its a relatively safe method to operate especially during military operations. During the Sri Lankan civil war Navy vessels carrying passengers and supplies to the Northern peninsular of Sri Lanka were constantly attacked by suicide vessels carrying explosives and controlled autonomously. The traditional procedure was to dispatch a Navy boat to patrol along the course of the ship before it begins the trip and observe the terrain . However, this could be very dangerous as the patrol boat is highly prone to get attacked by terrorists. Since the protection of the ship which carries many civilian lives and essential supplies to the northern peninsular of the country was at stake the Navy had no option but risk the lives of its sailors in order to save the lives of civilians. RoboBoat is developed to provide an effective solution to this problem and save the lives of many civilians and navy personnel and reduce the damage caused to the property. RoboBoat will travel on a predefined path with the aid of GPS and digital compass. Since this observatory USV is small in size a better understanding about terrorist activities could be obtained in this way and allows the boat to travel in relatively small areas which could be impossible otherwise. Also, as its unmanned the threat caused to the lives of sailors is also nullified.

1.3 Objectives

Overall Objective

The prime objective is that the boat travels along a set of way points given by the user with the guidance of GPS autopilot and the digital compass.

Specific Objectives

In order to achieve the overall objective a number of other primary objectives have to be achieved.

- The RoboBoat should balance itself on water.
- The RoboBoat should travel from one way point to another without much deviation in its path and should eventually stop at the final way point.
- The RoboBoat should constantly check its current position against the correct position by a feedback loop and adjust its course
- The RoboBoat should adjust the speed of the two motors on either sides of the boat in order to maintain its course

1.4 Limitations and Scope

The scope of the project is limited to following a set of predefined way points using GPS and the digital compass. However, while carrying on the project it was understood that it is necessary to use a Radio Frequency module in order to analyse information about the output to adjust the PID algorithm as there was no device to acquire the feedback send by the boat according to its present situation. Thus, additionally a RF module was used although it was not thought about in the initial project proposal. However, the project is limited only to making the boat travel along a given set of way points. It does not include any observatory devices like a camera which allows a controller to get a visual image of the terrain and allows to take necessary actions. In the future the project could be developed further to a fully complete military- observatory vessel.

Chapter 2

Literature Review

Unmanned surface vessels (USVs) are also called autonomous surface craft (ASC). As the name implies they operate remotely of an operator. With Global Positioning Systems (GPS) becoming minimal, powerful and moderate unmanned surface vehicles have become possible to be developed easily. Additionally, Affordable, long range and higher bandwidth wireless data systems have also been significant to the rapid growth on USVs for its wide range of applications.At present, USVs are developed and demonstrated by academic labs, corporations and governments.(Manley (2008))

Unmanned vehicles are considered very important components of future naval activities. Significant research and development has been done on Unmanned Underwater Vehicle (UUVs) and Unmanned Aerial Vehicles (UAVs), yet only a little effort has taken place with respect to Unmanned Surface Vehicles (USVs). With future battles happening mainly in coastal areas against enemies who possess more sophisticated weapons . Hence, placing people in contingency areas is not a feasible option.(Yan et al. (2010)) Unmanned Surface Vehicles adds additional strength to the fleet of the Navy and it could be deployed in missions where its too risky to employ humans.The reliability and the ability to control the motion allows USVs to be used in a vast number of different missions.

The most recent 15 years have seen ground breaking research and development of unmanned underwater vehicles (UUVs) all through the world.(Ullah (2014)) The naval requirements for stealthy reconnaissance in the coast and the possibilities of driving down the expenses of civil seabed survey operations have combined with the intrinsically interesting technical challenge of producing cost effective UUVs to generate a vibrant research group.

In the mean time, research on unmanned surface vehicles (USVs) has continued silently in the background.The history of USVs dates back to the second world war,where a number of radio controlled USVs were built and used in operations. These early USV systems were mainly used as cannon and missile target systems.A number of mine detecting applications were developed in the 1950s and 1960s and research and military devices have been developed from time to time.(Roberts and Sutton (2006))

Unmanned Surface Vehicles (USVs) have been developed for a number of activities such as civil, military and research purposes. Over the last decade a number of different autonomous surface craft (ASC) prototypes have been developed.(Caccia et al. (2008)) Although,there is a broad scope of potential applications of the USVs, three primary applications have been the most important: research, oceanography, and military.(Calce et al. (n.d.))

The USVs must have the capacity to recognize environment, distinguish targets, and avoid obstacles, autonomously correct its path, and self-sufficiently finish the mission. At present the USV technology requires constant supervision to make sure that the boat avoids obstacles. One of the more troublesome issues identified with autonomy is working in a highly dynamic environment with different vehicles worked by people. People are capable of generating highly unusual practices. Subsequently, a self-ruling vehicle must be sufficiently adaptable to manage flighty occasions or circumstances furthermore sufficiently deft to react rapidly to evolving conditions.Thus, for high speed intelligent USV intelligence will be the most basic and also the most difficult feature.

Since USV is unmanned, the movement of the hull is difficult to be controlled by the automatic control systems in rough sea conditions. However, stability and anti-capsizing are big issues for USVs. The stabilization system of USV should be able to stabilize the hull and prevent excessive deck motion or capsizing and determine the optimal course and speed for the given wave, wind, and current environment. In the worst case scenario, the boat may turn upside down, hence a device for recovering the vehicle back to normal is essential.(Yan et al. (2010))

In this background, the design and implementation of an accurate and reliable navigation, guidance and control system, which has the ability to operate with only linear and angular position measurements, is a major factor for the development of relatively cheap remotely controlled vehicles for above mentioned applications.(Hasnan et al. (2012)) Since USVs need to navigate safely to complete a certain task in a variety of marine environments, especially when the vessel is beyond the sight and when remote control is unable to reach, the vessel must be able to operate independently of constant operator supervision. The main feature of intelligent USVs is the capability of independent operation, thus it is very important to research how to improve the intelligent level of USVs. In recent years, some researchers did work to improve USVs intelligence, including intelligent architecture design, mission planning, sensing and environmental monitoring. however, there are still many problems to be solved.

Although a number of different manufacturers of USVs exist, only a very few of them are targeted at the lower end of the research/experimental market. Given the lack of such vehicles an attractive alternative approach, especially for research applications, is to modify water crafts as autonomous devices. Both vessels which are originally intended for human operation as well as radio-controlled (RC) vehicles have been re purposed. Although a number of such projects exist, much of the technical details associated with these projects should be started from scratch. The basic structures used in this project can be easily adopted to other applications and the basic electronic components used are standard devices that are easily sourced.(Calce et al. (n.d.))

With the speed of USVs increasing, new and innovative hull forms are required to take maximum advantage of the fact that the vehicle is unmanned. It is different from the traditional drainage- type the dynamic lift, surface attack, and other issues that are only available to high speed movement, must be resolved.Through the joint efforts of the researches around the world, it is believed that the development of the unmanned vessel (boat) will enter a new phase in the near future, the intelligence level of the unmanned vessel and the work it can be engaged in will go further, it can be applied widely both in military and civilian service.Common trends are the modularity and easiness of transport of USVs, since logistical constraints are usually very narrow, as well as the introduction of constructive materials such as the introduction of constructive materials such as fibre-glass in order to built robust and light hulls.(Yan et al. (2010)) A new technology that has emerged in this field is the usage of liquid robotics has been instrumental in allowing the boat to generate energy from the wave action for it's propulsive needs. Also, solar panels are fixed that allows the boat to carry missions that last for a long duration.(Manley (2008)) This, long endurance has allowed the USV's to be considered seriously for surveillance missions and scientific purposes.

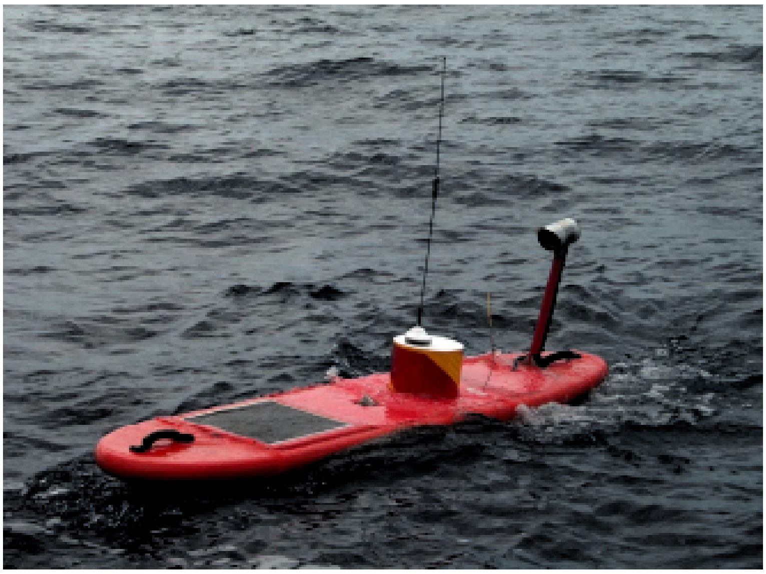

Figure 2.1: a USV that uses liquid robotics and solar panels

Unmanned Vehicles (UVs) as a whole is one of the most interesting research topics at present. Present developments in fluid dynamics, structural,propulsion and and electro mechanical systems is adequate to satisfy the requirements of future USVs. Even though, the technological potential of USVs is bright, there could be a possible change in policy about USVs in the near future. Unlike UUVs, which does not take into consideration the issue of competing users of the sea, USV s must be ready to interact with research and development programs are addressing the technical questions posed by the interaction of USVs and the nautical rules of the road.Also, despite having the adequate technology efforts should be made to increase intelligence, gain more control, make the devices highly stable, and reduce the costs in the future.(Yan et al. (2010))

Chapter 3

Methodology

The methodology of the RoboBoat is can be summarized as below. The way point latitudes and longitudes are selected using Google Maps and they are transferred to the Arduino micro controller.The current position of the boat is given by GPS data in latitudes and longitudes. The current heading of the boat is given by the digital compass. The boat takes into consideration the current position,current heading and calculates the speed by which the motors should rotate in order to maintain its course. There are two DC motors in the boat which are used to navigate the boat along its path and to alter the speed of the motor when it reaches a way point. The speeds of the motors are controlled by two MOSFETs.

It could be better explained by the following layout diagram. As mentioned before, first the GPS and the digital compass are initialized. Then depending on the data they acquire they DC motors are started to rotate. The GPS calculates the actual position and the the digital compass calculates the actual heading of the boat. Depending on these data distance to the next way point and bearing to the next way point (β) are calculated. Then the PID algorithm will consider to reduce the error of the measurement and depending on this the PWM value of the motors are changed in order to bring back the boat to it's correct position by changing the bearing and to control the speed in order to reach the way point.This process happens repeatedly until the error is minimized and until the boat is at its correct speed and heading. When the boat approaches the current way point values are switched to the next way point. This process is repeated until the last way point is reached and after that the PWM signal given to the motors are cut off and the boat will stop at the final way point.

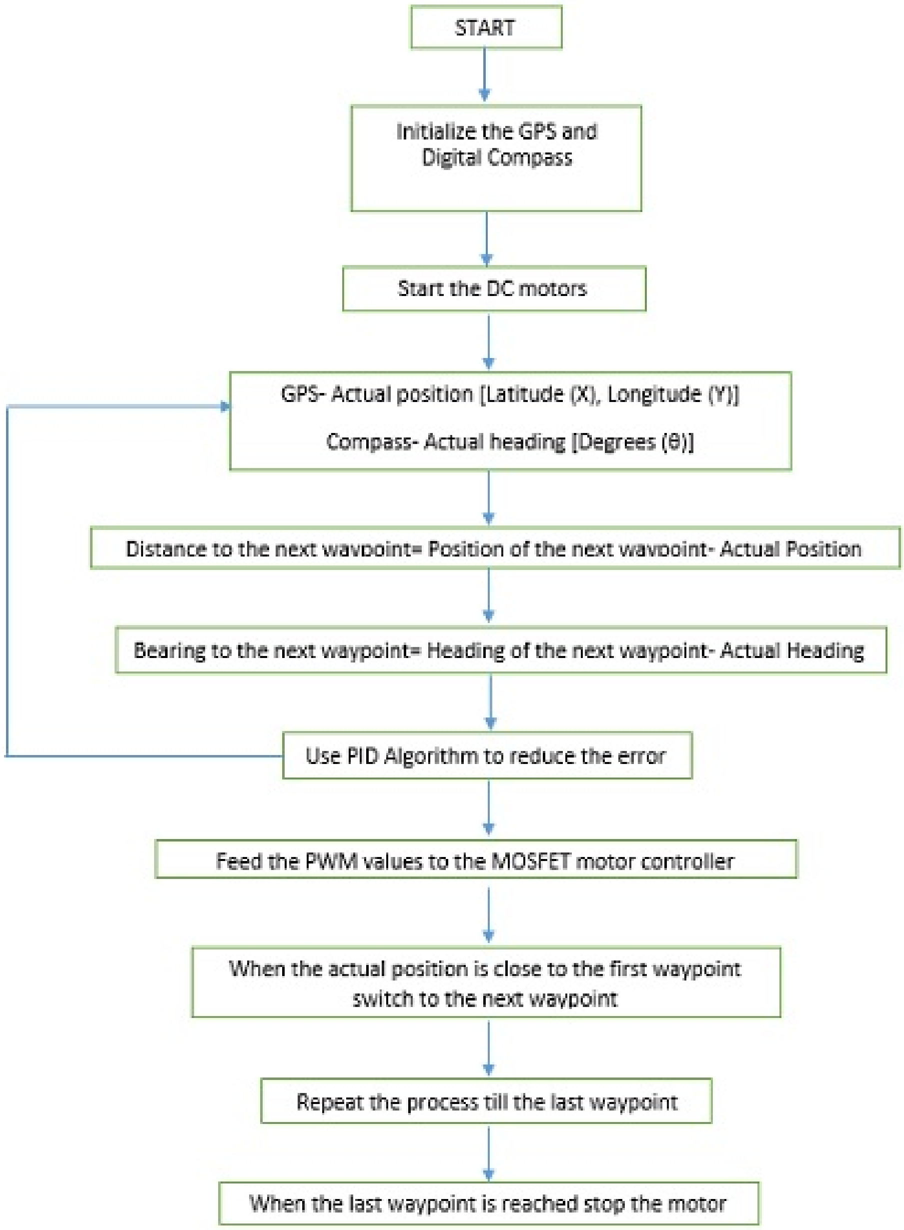

Figure 3.1: Layout diagram of the RoboBoat

3.1 Design

When considering the design of the boat the most important factor is to consider the forces which act on the boat. It was identified that the following forces are acting upon the boat while its travelling on water.

1. Thrust from the boat
2. Drag forces of water and air
3. Roll, pitch and yaw

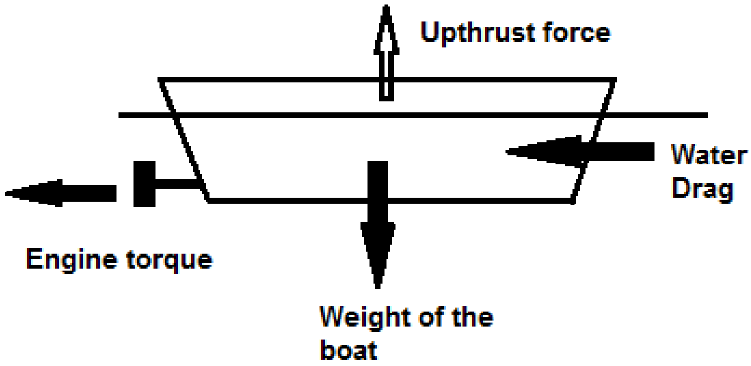

Figure 3.2: The forces which are acting upon the boat

Upthrust force

According to Archimedes Principle when a body is partially or totally immersed in a fluid there is an upthrust that is equal to the weight of the fluid displayed.

mg = $V\rho g$
V = Volume of the fluid displaced
ρ = Density of the fluid

Drag force

The drag force is the force which follows up on a solid object toward the relative stream velocity.Drag forces are reliant on velocity. Drag forces dependably diminish fluid velocity with respect to the solid object in the fluid's way.
Types of drag forces

1.Parasitic Drag
2.Lift-induced drag
3.Wave drag or wave resistance

Parasitic drag is generally used as a component of aero-dynamic and lift induced drag is just noteworthy when wings and lifting body are available . Wave drag happens when a strong object is going through a fluid at or near to the rate of sound in that fluid.

Drag depends on upon the properties of the fluid and on the size, shape and the rate of the thing. One way to deal with express this is by drag equation.

Drag Equation

$F_d = \frac{1}{2}\rho u^2 C_d A$

F_d = Drag Force
ρ = Density of the fluid
u = Speed of the object relative to the fluid
A = Cross sectional area
C_d = Drag coefficient
A dimensionless number and for streamlined flows C_d =0.04

The drag co-efficient depends on the shape of the object and on the Reynolds number.

Roll, pitch and yaw forces

There are three axes in any vessel called vertical, lateral and longitudinal axes. The movements around them are known as pitch, roll and yaw.

Yaw axis extends from top to bottom, and its perpendicular to the other two axes. The yaw axis is perpendicular to the body of the boat. A yaw motion is is a left-right movement of the hull.

Pitch axis is perpendicular to the yaw axis and is parallel to the body of the boat. A pitch motion is an up or down movement of the hull.

Roll axis is drawn through the body of the boat from tail to top, parallel to waterline. Rotation about the longitudinal axis is called roll motion. Roll changes the orientation of the boat with respect to the downward force of gravity.

The resultant force acting on the boat can be obtained as follows

$F_T - F_d = ma$
F_T= Force due to the torque of the motors
F_d= Force due to the drag force

$F_T - \frac{1}{2}\rho u^2 C_d A = ma$

Finally an equation for the torque required by the boat can be obtained by the below equation.

$F_T = ma + \frac{1}{2}\rho u^2 C_d A$

Also, a number of additional factors should be considered when considering about the design of the boat.

Center of Gravity

The center of gravity of a distribution of mass in space, is the point where the weighted relative position of the distributed mass sums to zero. The dispersion of mass is balanced around the average of the weighted position coordinates.

The center of mass is a useful reference point for calculations in mechanics that involve masses distributed in space,such as the linear and angular momentum of planetary bodies

Center of Buoyancy

The center of buoyancy depends on the center of gravity. When an object is fully or partially submerged in a liquid, some of that liquid is displaced.This volume of this liquid displaced is equal to the volume of the object that is below the surface of water. Adiitionally, the shape of the volume of displaced liquid is same to the shape of the part that is below the surface of water.

The center of buoyancy of the object is located at the center of gravity of the volume of the displaced liquid. It is the point through which the upward buoyant force acts.

The diagram below shows a a cross section of the boat The center of gravity (G) is at the geometric center of the boat.The center of buoyancy (B) is at the center of gravity of the displaced water.

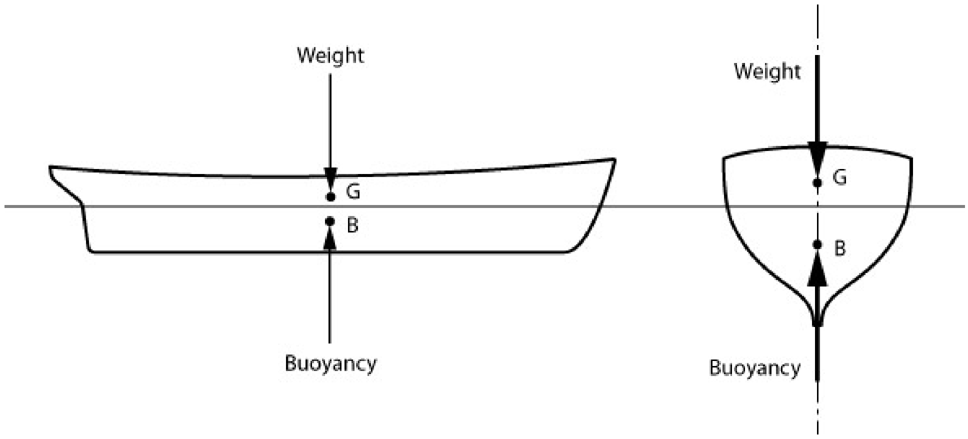

Figure 3.3: Center of gravity and center of buoyancy acting upon the boat

Meta center and Meta centric height

The point where the intersection of vertical lines through the center of buoyancy of a floating body when it is in equilibrium and when it is floating at an angle is called as the meta center.

At the point where the ship is heeled, the center of buoyancy of the ship moves horizontally. The meta center is directly above the center of buoyancy regardless of the tilt of the floating body. In the diagram to the right the two B s show the center of buoyancy of a ship in the upright and heeled condition, and M is the meta center. The meta center is considered to be fixed for small angles of heel but at larger angles meta center is no longer fixed.

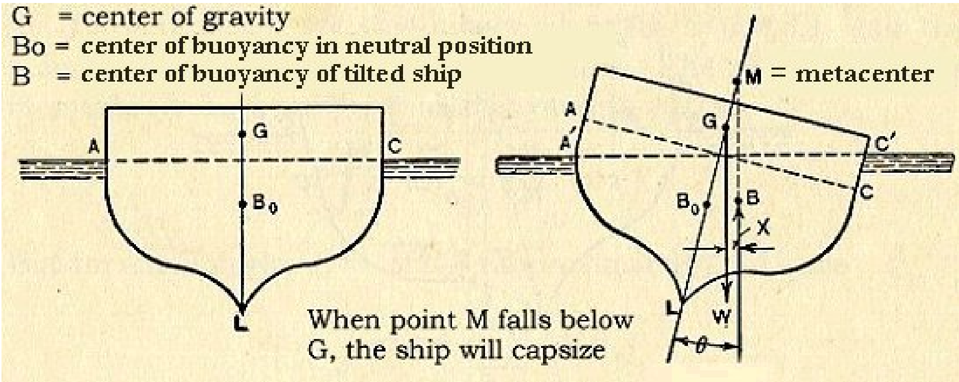

Figure 3.4: How center of gravity, center of buoyancy act on the boat

Meta centric height is a measurement of stability of a floating body. It is the distance between the center of gravity and its meta center. The meta center could be calculated using the following equation. Here a known mass is placed at the midpoint of the cross section of the boat at the place where the center of gravity lies.Then this weight is moved by a known distance. Due to this the boat will be tilted by an angle and this angle is measured. This data are applied to the following equation to obtain the meta centric height.

$GM = \frac{wd}{Wtan(\theta)}$

GM= Meta centric height
w = weight of the known object
d = distance moved
W = Total weight
θ = Angle between the initial and final positions

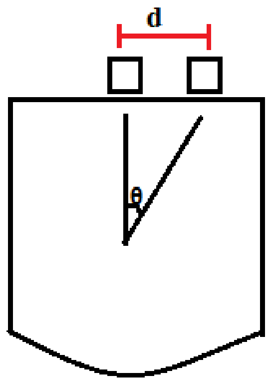

Figure 3.5: Meta centric height calculation

3.1.1 Initial Design

Figure 3.6: Initial Design

The initial design of the boat was to use a mono-hulled fiberglass boat that has one propeller connected to a brush less motor for controlling the speed and a rudder for controlling the angle by which the boat should rotate. An ESC (Electronic Speed Controller) was used to control the brush less motor. The angle of the rudder was controlled by a servo motor. The mechanism was the angle by which the boat should rotate in order to adjust its course (angle) is controlled by the servo motor and the speed by which the motors should rotate in order to reach the way point is controlled by the ESC. However, this design was a failure and the boat drowned during the testing stage unable to provide sufficient upthrust force to bear the weight of the components. Also, another reason for failure was the placement of the rudder aligned to the right side of the boat instead of placing the rudder in the center of the boat.This created a moment around the center of gravity of the boat that resulted the boat to topple during the testing stage.

3.1.2 Final Design

Figure 3.7: Final Design

The finalized design of the boat is much bigger in size with comparison to the initial design and it too is a mono-hulled boat made of plastic. This design includes two DC motors controlled by MOSFETs and they control the speeds by which the motors should rotate.The speed of rotation of motors are adjusted in order to navigate the boat to its intended heading from its current heading and to control the speed by which the boat is moving when it approaches a way point . However, this design does not include a rudder to change heading of the boat by an exact angle, but the two DC motors differentiate its speed to carry out a similar function. The speed controlling algorithm when approaching a way point however, is similar to the initial algorithm. This design is more balanced than the initial design and provides sufficient upthrust force to balance the weight of the components.

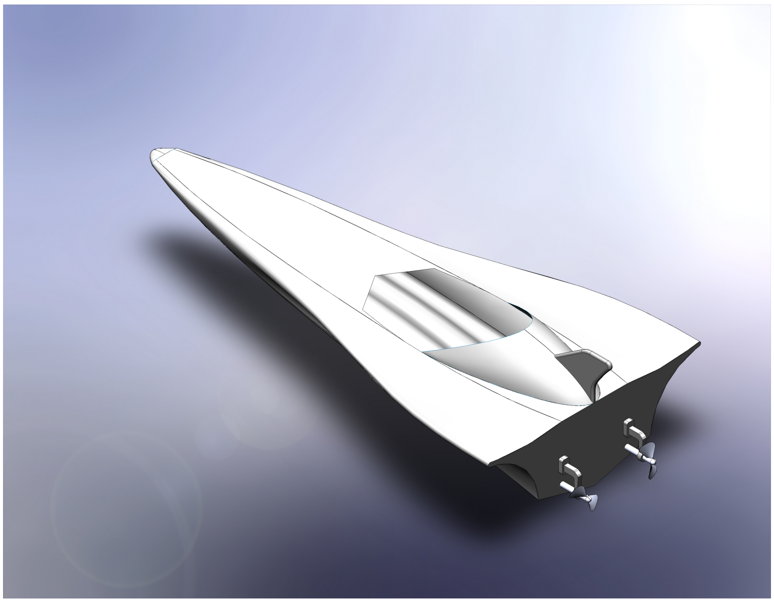

Figure 3.8: Final Design-Rear View

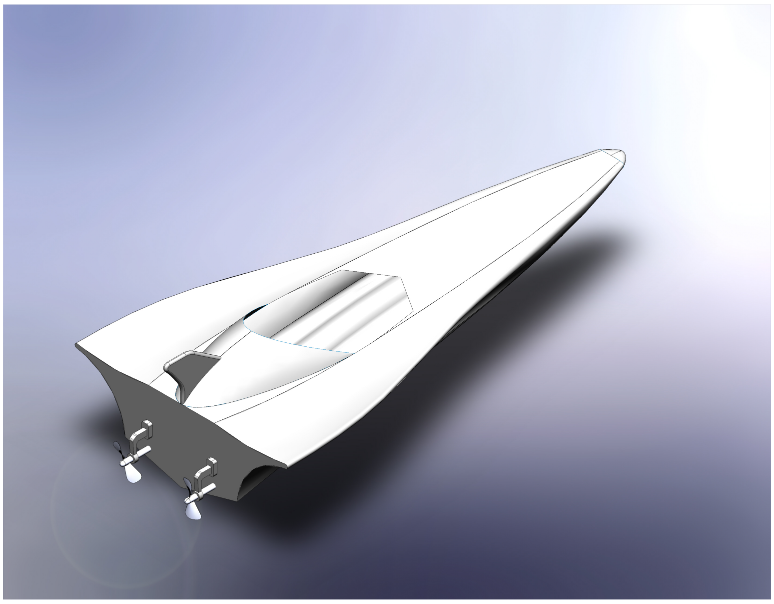

Figure 3.9: Final Design-Side View

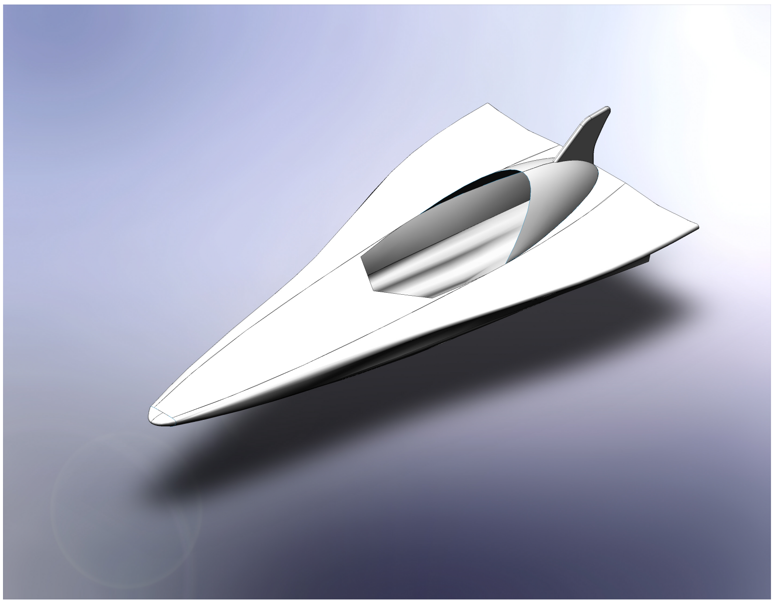

Figure 3.10: Final Design-Front View

3.2 Components

The functionality of the components could be summarized as below.

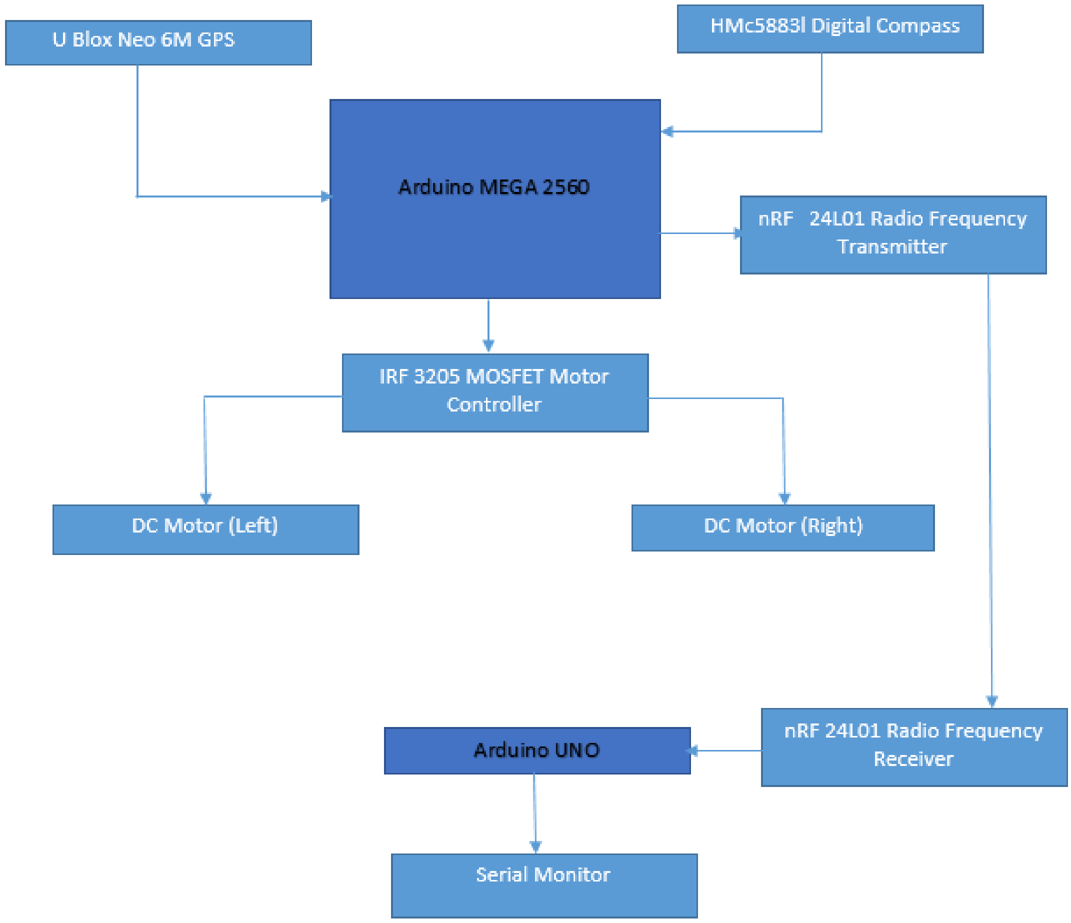

Figure 3.11: Components of the system

3.2.1 Arduino MEGA 2560

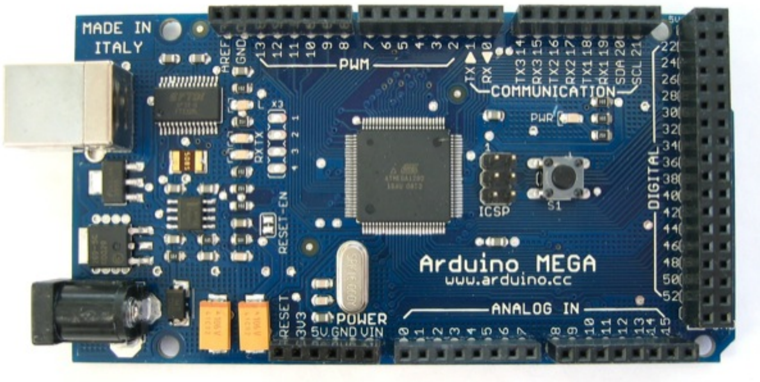

Figure 3.12: Arduino MEGA 2560

Arduino MEGA 2560 is the main micro controller used in RoboBoat. Arduino MEGA 2560 is board based on ATmega 2560 micro controller. The operating voltage is 5V and the board consists of 54 Digital Input/Output pins.The Arduino MEGA is usually powered by an USB connection or by an external power source.The ATmega 2560 micro controller contains 256 KB of flash memory for storage.

The functionality of the Arduino micro controller can be described as below. First the GPS and digital compass are initialized. Then the DC motors are started and they are rotated using a varying PWM signal depending on the feedback it receives. By this varying motor speeds the course of the boat is adjusted and it is navigated to reach the desired way point. The actual position is given by the GPS as latitudes and longitudes and the actual heading is given by the digital compass in degrees. (latitudes(X), longitudes(Y), heading(θ)).

3.2.2 IRF 3205 MOSFET Motor Controller

Two IRF 3205 Mosfets are used in the motor controller. MOSFET (Metal-Oxide-Semiconductor Field Effect Transistors) are a type of transistors that is used for amplifying or switching electronic signals. Eventhough theoretically a MOSFET consists of four components namely Source(S), Gate(G), Drain (D) and Body(B) in most occasions the body is connected to the source. The main advantage of the MOSFET transistor over a regular transistor is that the current required to turn on is relatively low (Mostly, less than 1mA), although it can deliver a much higher current to a load (10A-50A or more). This was the main reason behind using MOSFET instead of a more traditional L298 motor controller as it was measured the stall current drawn by the motors is about 12 A when the boat is on water.

The 2 DC motors are connected to the Ardunio in the following manner

Table 3.1: Right motor Pins to Arduino MEGA

Signal	Arduino MEGA pin
PWM	5
GND	GND

Table 3.2: Left motor Pins to Arduino MEGA

Signal	Arduino MEGA pin
PWM	6
GND	GND

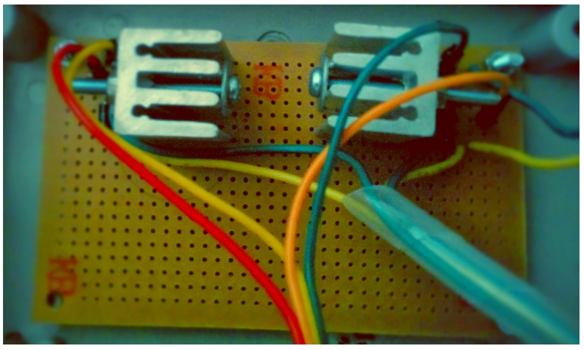

Figure 3.13: Motor Controller

3.2.3 U blox Neo 6 GPS Module

Figure 3.14: GPS Module

U blox NEO 6M is the GPS device used for getting the latitudes and longitudes of the current position of the boat and to carry out angle calculations. This GPS device is highly compatible with Arduino and the library used for GPS calculations was the TinyGPS library. The U blox NEO 6M GPS can function as a standalone GPS receiver as it comes with a built-in GPS antenna and it consists of a 50 channel positioning engine with more than 2,000,000 effective correlates. The U blox 6M device comes with 4 pins which are connected to Arduino MEGA 2560 as follows.

Table 3.3: GPS pins to Arduino MEGA

Signal	Arduino MEGA pin
GND	GND
TX	RX1(19)
RX	TX1(18)
VCC	5V

The baud rate of this device is set to 9600. The device is connected to UART TTL socket and uses EEPROM to store data.

Global Positioning System (GPS) is system that is based on satellites and can be used to locate positions anywhere on the earth. Anyone with a GPS receiver can access the system. and it can be used for any application that needs coordinates of a location.

The GPS system consists of three segments
1. The space segment which consists of the satellites
2. The control system controlled by the US military
3. The user segment which includes the users and the GPS receivers

There are four satellites in each of the six orbital planes. Every plane is slanted 55 degrees relative to the equator, implying that satellites cross the equator tilted in a 55 degree edge. GPS satellites finish a rotation in almost 12 hours, which implies that they pass through a certain point on earth twice a day.

GPS satellites continuously show satellite position and timing information by means of radio flags on two frequencies (L1 and L2). The radio signals travel at the speed of light and take roughly 6/100 th of a second to reach the earth

The satellite signs require a direct line to GPS recipients and can't penetrate to water, oil, or different obstacles. In these occasions, it will stop locating positions.

Two types of code are broad casted on the L1 frequency (C/A code and P code) C/A-Coarse Acquisition code is accessible to regular citizen GPS clients and gives Standard Positioning Service (SPS). Utilizing the Standard Positioning Services one can attain to 15 meter exactness 95 percent of the time, which implies 95 percent of the time, the directions read from the GPS will be inside 15 meters of the genuine position of the earth. The P-Precise Positioning Service (PPS) is accessible exclusively to the military. Due to this a military beneficiary can accomplish preferred precision over regular citizen recipient.

3.2.4 HMc5883l Digital Compass

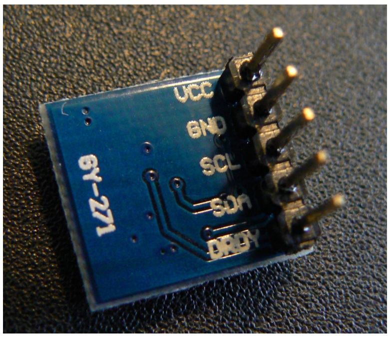

Figure 3.15: Digital Compass

HMc5883l digital compass is a 3 axis low field magnetic sensor with a digital interface. It has a considerably wide magnetic range of +/- 8 gauss. The communication is done through I^2C digital interface. it has about 1 to 2 degree compass accuracy.

The HMc5883l digital compass comes with 5 pins and they are connected to the Arduino as follows.

Table 3.4: Digital Compass pins to Arduino MEGA

Signal	Arduino MEGA pin
GND	GND
SCL	SCL
SDA	SDA
VCC	3.3V

The current heading of the boat is given by the digital compass. This angle is measured as theta (θ). Certain factors should be considered when measuring the current heading.

Magnetic compass does not always point to North. In fact there are only a few locations on earth which points exactly to the true north. The direction in which the compass needle points is Magnetic North, and the angle between magnetic north and true north is called magnetic declination.Magnetic north is determined by the earths magnetic field and is not the same as true north. The location of the magnetic north pole changes slowly over time.

If the compass points clockwise with respect to true north, declination is positive or east and if the compass points anti-clockwise with respect to true north, declination is negative or west.

3.2.5 nRF24L01 Radio Frequency Module

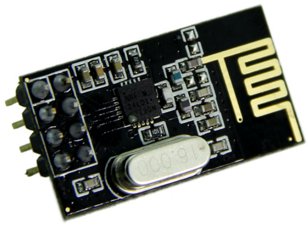

Figure 3.16: nRF24L01 RF module

nRF24L01 is a 2.4 GHz radio module which is based on Nordic Semiconductor nRF24L01+ chip. The nRF24L01 RF Module is connected to the Arduino as follows.

Table 3.5: RF Module pins to Arduino MEGA

Signal	Arduino UNO pin	Arduino MEGA pin
GND	GND	GND
VCC	3.3 V	3.3 V
CE	9	9
CSN	10	53
SCK	13	52
MOSI	11	51
MISO	12	50
IRQ	2	as per library

The Radio Frequency module is a pivotal device in order to determine the PID constants as it gives a feedback of the status of the boat in water. The Latitude, Longitude of the boat, the angles and are transmitted through the RF module to the serial monitor. However, A separate 3.3 V power supply should be provided to the RF module and 1F capacitor should be connected directly to the module. This is specially noticeable when the 3.3 V power comes from the MEGA which has only 3.3V of 50 mA power available.

Even though, initially it was not intended to use a Radio Frequency module and obtain data, during the testing stage it was understood that in order to tune PID smoothly for the boat it was essential that an output of the data is obtained and analysed.

3.3 Algorithm

3.3.1 Initial Algorithm

Initially the boat consisted of one propeller connected to a brush less motor and was controlled by an ESC.

Distance Calculation

Distance to the way point was calculated by the following equation.

Distance to the next way point = Position of the next way point - Actual position

The principle of the equation is based on the principle of Pythagoras

$$\text{Distance}=\sqrt{(X - WaypointLat)2 + (Y - WaypointLon)2}$$

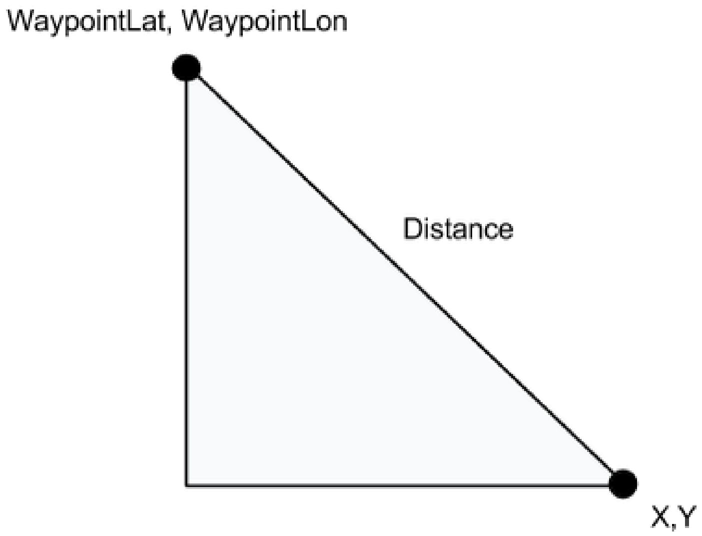

Figure 3.17: Initial Distance Calculation Algorithm

Since the terrain we are considering is the AIT swimming pool, due to its relatively less surface area, the Pythagoras theorem is applied to find the distance between the current point and the way point.

Here the distance is given as a difference of latitudes and longitudes and its needed to convert this value into metric units as when the boat approaches less than one meter to the way point instructions should be given for the boat to move to the next way point. Hence, it was necessary to convert this value into metric units. The following conversion was used to convert the distance obtained from degrees into metric units.

$1^\circ = 111km$

Since degrees of latitudes are parallel, the distance between two degrees remain almost constant. However, since longitudes are farthest apart at the equator and converge at the poles, the distance among two longitudes varies.Each degree of latitude is around 111 km apart from one another. But, due to the slightly ellipsoid shape of the earth, the range varies at the equator and at the poles. A degree of longitude is widest at the equator and gradually shrink to zero at the poles.

Thus the final calculation of the distance between the current location and the way point could be obtained as,

$$Distance = \sqrt{(X - WaypointLat)^2 + (Y - WaypointLon)^2} * 111000$$

Bearing Calculation

The bearing to the next way point is calculated by the following equation

Bearing to the next way point= Heading of the next way point - Actual heading

A PID algorithm is used to reduce the error of the distance to the next way point and the error of bearing to the next way point. These instructions are fed to the rudder servo and the servo is rotated in such a way that the distance and bearing to the way point are reduced. PID algorithm is used to bring the boat as much as close to the way point. When the actual position is close to the way point, the co-ordinates of the next way point are fed into the boat. This process is repeated as the boat travels from one way point to the other throughout its course. Finally, when the last way point is reached the motor is stopped.

Although the latitudes and longitude coordinates obtained directly from the GPS may initially seem as acceptable values for finding distances and angles between way points, its not very accurate. As the Earth is a sphere , latitude and longitude cannot be used as a coordinate system on a Cartesian plane. There are a number of distance approximations and co-ordinate transformations which should be taken into consideration,but not considered.

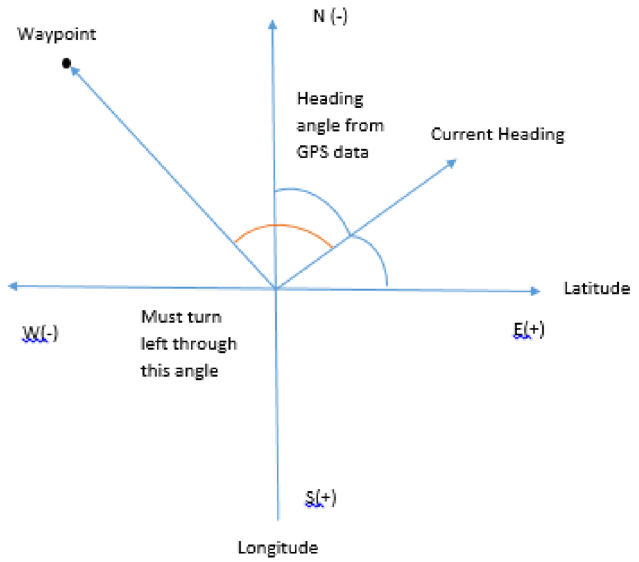

Figure 3.18: Initial bearing calculation algorithm

To calculate α (the Angle between current position and next way point), find the gradient between the two and calculate the arc tangent of the answer.

$\alpha = atan2(\frac{x - waypointLat}{waypointLon - Y})$

atan2 is the arc tangent function with two arguments. The objective of using two arguments instead of one is to use the data about the signs of the inputs in order to obtain the correct quadrant of the computed angle, which is not possible if the single argument arc tangent function was used.

Since, the resultant angle, α is in radians, the angle is converted to degrees first

$\alpha = (\frac{360}{2\pi}) * \alpha$

Here, we calculate the angle from the horizontal plane in the anticlockwise direction. However, in order to obtain the bearing from the north, the following calculation is done.

$\alpha = \alpha + 90°$

If the resulting α is less than 0, 360° is added to α

$\alpha = \alpha + 360°$

The current heading of the boat is given by the digital compass. This heading is recorded as θ .

Thus,The angle (β) by which the boat must turn,
$\beta = \alpha - \theta$

3.3.2 Final Methodology

Since it was understood that there are numerous errors in the initial methodology, a new methodology was developed minimizing the errors in the initial methodology

Distance Calculation

The Great circle distance method is used to calculate the distance between the current position and way point.It is a more scientific method of finding the distance between two points of a sphere as unlike in the Pythagoras theorem as we do not assume that the earth is flat and latitudes and longitudes do not converge. Great circle distance is the shortest distance between two points of a sphere when measured along the surface of the sphere.

$\Delta\sigma = arccos(sin(\phi1)sin(\phi2) + cos(\phi1)cos(\phi2)cos(\Delta\lambda))$

$\Delta\sigma$ = The central angle between the two points
$\phi1$, $\phi2$ =Latitude of point 1 and point 2
$\lambda1$, $\lambda2$ =Longitude of point 1 and point 2

Thus, the arc length(d) of a sphere of radius r and central angle $\Delta\sigma$ is given by

$d = r\Delta\sigma$

However, for smaller distances calculations Haversine formula can be used.

The Haversine formula states that for any two points on a sphere, the havesine of the central angle between them

$haversine(\frac{d}{r}) = haversine(\phi2 - \phi1) + cos(\phi1)cos(\phi2)haversine(\lambda2 - \lambda1)$

Haversine is the haversine function which is defined as,

$haversine(\theta) = sin2(\frac{\theta}{2}) = \frac{1-cos(\theta)}{2}$

d= distance between the two points
r= radius of the sphere
$\phi1, \phi2$= latitude of point 1 and latitude of point 2
$\lambda1, \lambda2$= longitude of point 1 and longitude of point 2

The distance between the two points can be expressed as

$d = 2rarcsin(\sqrt{\sin^2(\frac{\phi2-\phi1}{2}) + \cos(\phi1)\cos(\phi2) + \sin^2(\frac{\lambda2-\lambda1}{2})})$

Bearing Calculations

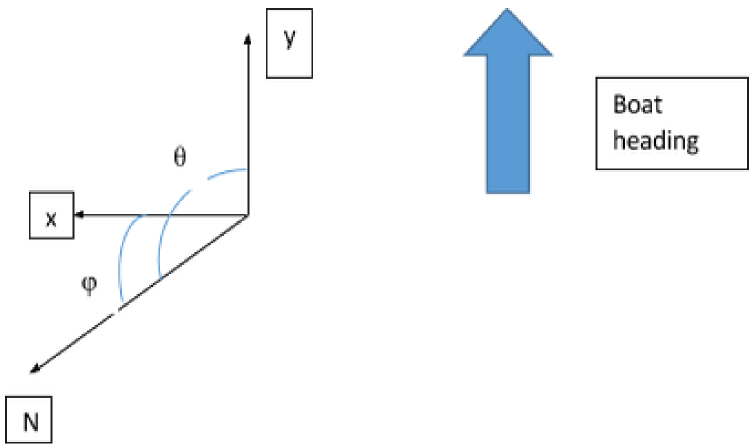

Figure 3.19: Final bearing calculation algorithm

Similar algorithm as the initial methodology is used to find α.

However, the algorithm used to find the boat heading is changed in order to obtain a more accurate value.Boat heading direction is parallel to y axis of the compass module. Take the course of boat heading with respect to north as θ and that of x axis as φ and earth magnetic field strength at a point as H, its components measured by compass in x and y axis as H_x and H_y respectively. Then we can write following equations.

$H_x = Hcos(\varphi)$
$H_y = -Hsin(\varphi)$

From these two equations we get

$tan(\varphi) = \frac{-H_y}{H_x} \, (providedH_x \neq 0)$

$\varphi = atan2(-H_y, H_x); -\pi \leq \varphi \leq \phi$

To change φ to a value between 0 and 2π

$\varphi = \varphi, \varphi \geq 0 + 2\pi, otherwise$

We can have the value θ (course of heading of the boat) as,
$\theta = (\varphi + \frac{\pi}{2})mod2\pi$

3.4 PID Algorithm

PID controllers are utilized commonly as a part of control systems. PID controller takes into consideration the error as the difference between the procedure variable and the set point. PID controller is designed to minimize the error by modifying the methodology. Thus, simply the function of the PID algorithm is to calculate the error value as the difference between the measured input and a desired set point.The PID controller minimizes the error by adjusting the output. PID incorporates three parameters.

Proportional
Integral
Derivative

P is depend end on the present error, I is depend end on the sum of the past errors and D predicts future errors.

In the Robo Boat project we use PID controller in two occasions.

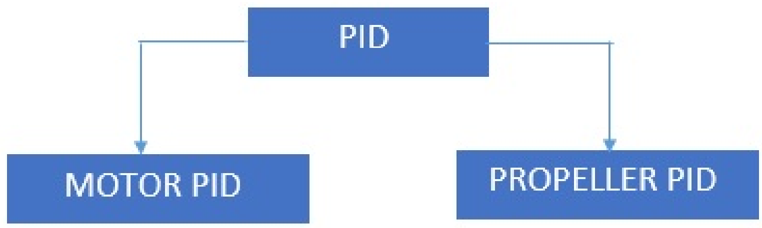

Figure 3.20: PID Algorithm

Firstly, the motorPID function is used to control the speeds of the two motors in order to navigate the boat along its path. The current heading of the boat (θ) is taken as the input. The desired angle, or the angle of the way point (α) is taken as the set point . The difference between angle of the way point and the current heading is the error. After measuring the current heading, and then calculating the error, the controller changes the speeds of the two motors accordingly to navigate the boat along the path.

$error(\beta) = Setpoint(\alpha) - Input(\theta)$

Here, a proportional controller is used where the speeds of the motors are changed with proportion to the error.

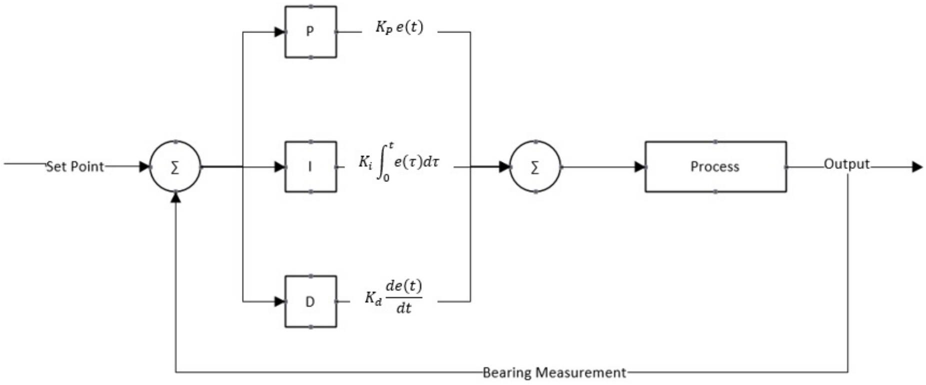

Figure 3.21: motorPID

Secondly, the propellerPID function is used to make sure that the boat does not overshoot from a pre defined way point. The current position of the boat is taken as the input. The position of the way point is taken as the set point. The difference between these two positions is the distance that the boat should travel and this is the error. After obtaining the current position and the position of the way point, the controller changes the speeds of the two motors to make sure that the boat reaches the desired way point location. When the distance to the way point is closer than 0.5m the base speeds of the two motors are changed according to the distance it has to travel in order to reach the way point. When the final waypoint is reched the two motors are cut off making the boat stop.

$error(Distance) = Setpoint(waypointLat, waypointLon) - Input(X, Y)$

Here too a proportional controller is used where the base speed of the two motors are changed proportional to the distance to the way point.When the distance to the way point is less than 0.25m the two motors are shut off.

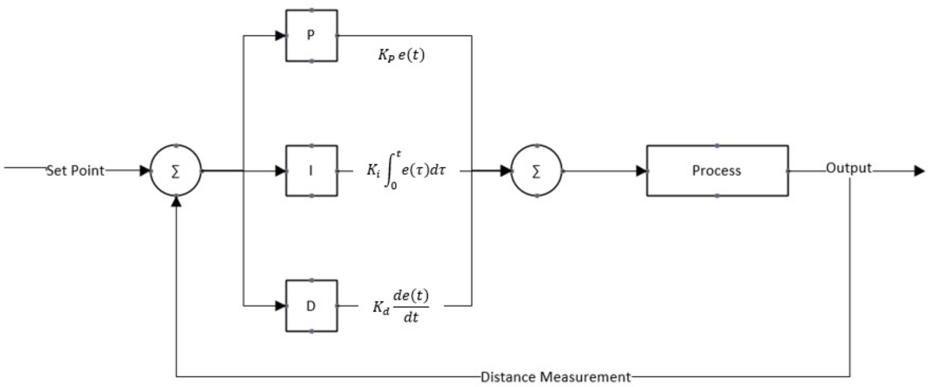

Figure 3.22: propellerPID

The PID scheme is named after its three correcting terms, proportional, integral and derivative terms and they are summed to calculate the output of the PID controller. Defining u(t) as the control output, the final form of the PID algorithm is,

$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$

K_p= proportional gain
K_i = integral gain
K_d = derivative gain
e = error
t = Time
τ= Integration; values from 0 to t are taken into consideration

Proportional term

Proportional value produces an output value that is proportional to the current error value. The proportional response is balanced by multiplying the error by a constant K_p, proportional gain constant.

In the motorPID function the error or the difference in angle between α and θ is multiplied by the gain constant and in the propellerPID function the error or the difference in distance between the current position and the way point position is multiplied by the gain constant to get this value.

$P = K_p e(t)$

Integral term

The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. This accumulated error is then multiplied by the integral gain (K_i) and it is added to the output.

$I = K_i \int_0^t e(\tau) d\tau$

Derivative term

The derivative of the process error is calculated by determining the slope of the error over time and multiplying the rate of change by the derivative gain (K_d)

$D = K_d \frac{d}{dt} e(t)$

Chapter 4

Experimental Results

4.1 Design Testing

Table 4.1: Weights of the components of the boat

Component	Weight of component
2 DC motors (200g each)	400g
Battery (Nickel Cadmium)	200g
Arduino MEGA board	50g
RF Transmitter module	10g
GPS sensor	15g
Digital Compass	10g
MOSFET motor controller	50g
Power Bank	200g
Other components	50g
Total weight of the boat	**985g**

From the Archimedes principle

$v\rho g = mg$
$v\rho g = 0.985 * g$
$v * 9.81 * 10^3 = 0.985 * 9.81$
$v = Ah = 0.985 * 10^-3m^3$

Thus, the volume of fluid displaced by components of the boat is $v = 0.985 * 10^-3m^3$

Assuming that the total height of the boat is H we get the following equation.

$h = \theta * H$
θ= Allowable co-efficient =0.5

Hence, the Archimedes equation could be re-arranged as below.

Weight of the boat without masses = $W_b = V\rho_b g$
The weight of the displaced mass= $W_m = \theta V\rho_w g$

Here V refers to the total volume of the boat

Total weight of the boat $W_T = W_m + W_b$
$W_T = \theta V\rho_w g + V\rho_b g$

$W_T = Vg(\theta\rho_w + \rho_b)$

The total volume of the boat was found to be $388950.87cm^3$ from the SolidWorks design. Hence, the total weight on the boat could be calculated as,
$W_T = 0.5 * 388950.87mm^3 * 1gcm^{-3} * 9.81ms^{-2} + 388950.87mm^3 * 3.9gcm^{-3} * 9.81ms^{-2}$
$W_T = 16.788675N$

Thus, the upthrust force acting on the boat should be higher than the weight of the boat, if the boat is to float.

A grapgh could be drawn as to how the RPM of the motors change with changing PWM values.

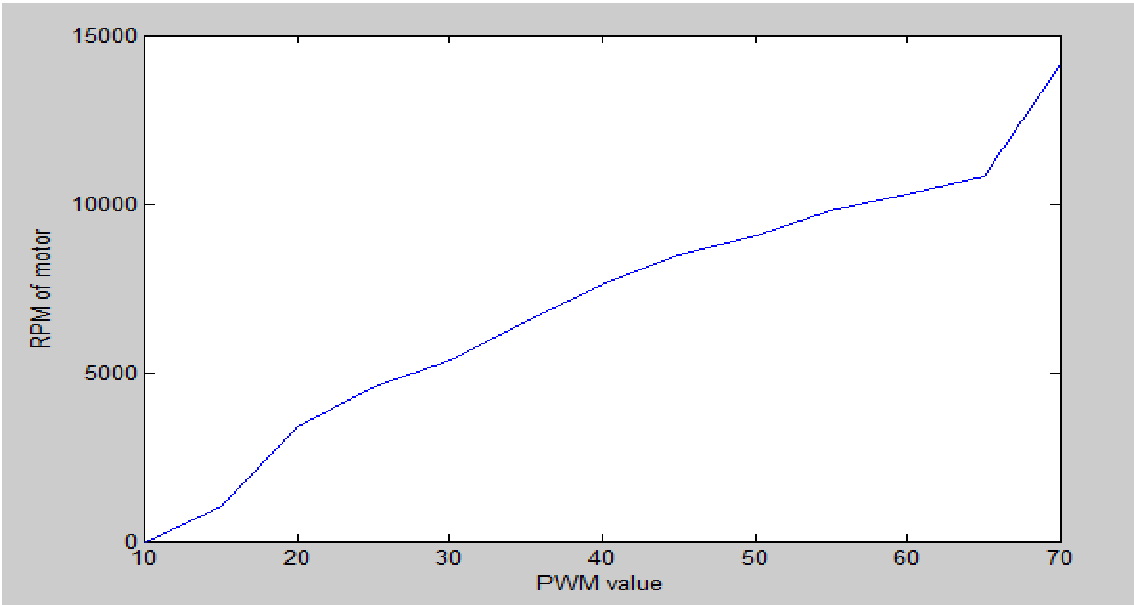

Figure 4.1: PWM v. RPM graph

It could be observed that when the PWM signal given to the motors are increased the RPM values of the motors are also increased.

The center of gravity of the boat was found using the Solid Works design. The center point of the base of the boat where propellers are placed is considered as the reference point.

The following results were obtained.
X = -170.64mm
Y = -22.76mm
Z = -0.02mm

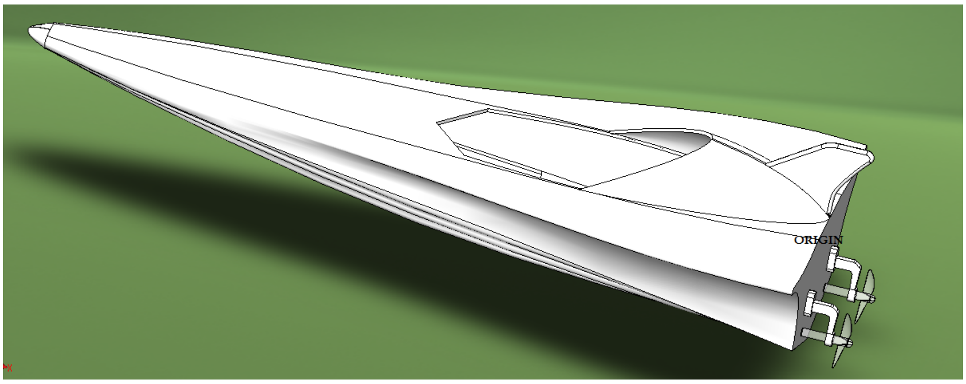

Figure 4.2: Finding the COG

4.2 GPS Testing

GPS could be considered as the most important component in the setup as the entire algorithm of navigating the boat is dependent on the data received by the GPS. Hence, it was pivotal that the data received by the GPS are taken as accurately as possible. GPS readings of several locations inside AIT were taken as an initial step. The results are as below. These readings were taken keeping the GPS module stable as possible and the objective was to get an idea about the variation of the GPS data.

```
Lat/Long:14.08,100.61
Alpha:139.50
Lat/Long: 14.07662, 100.60605
distance to waypoint:0.00
```

Figure 4.3: AIT Grocery GPS reading

```
Lat/Long: 14.07761, 100.61237
Lat/Long: 14.07761, 100.61236
distance to waypoint:0.00
```

Figure 4.4: AITIS GPS reading

```
Lat/Long: 14.07836, 100.61453
Lat/Long: 14.07836, 100.61453
distance to waypoint:0.01
Theta:0.00
```

Figure 4.5: UFM Bakery GPS reading

The error of the GPS measurement could be identified by checking the latitudes and longitudes of a known location by using both Google Maps and the GPS receiver. Google Maps is used to enter the way point locations, and these way points are reached using navigation from the GPS. Thus, it is essential to understand the error that could occur when obtaining latitudes and longitudes.

For an example the latitudes and longitudes of the front door of Chalerm Prakiat building is taken from the Google Maps and this value is compared with the values obtained for latitudes and longitudes from the GPS.

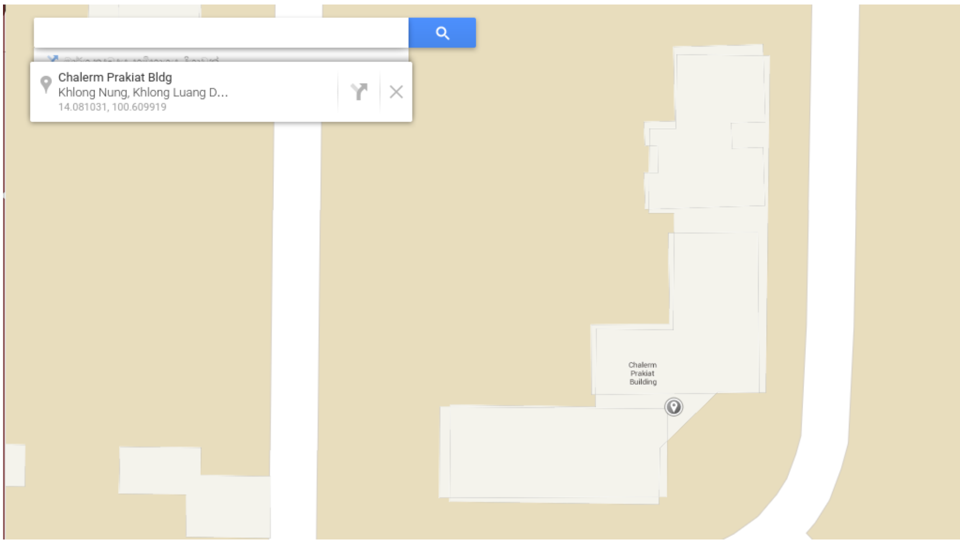

Figure 4.6: ISE building location on Google Maps

The values obtained from the Google Maps are 14.081033 and 100.609919

```
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
Lat/Long: 14.08096, 100.61003
distance to waypoint:11276556.000000
```

Figure 4.7: ISE building location on GPS module

However, the values obtained from the GPS is not exactly the same as the value from Google Maps.

Values from GPS read as 14.08096 and 100.61003 respectively.

The error that can occur by the two methods can be calculated

Error in Latitudes= $\frac{14.081033-14.08096}{14.08096} * 100 = 0.00052\%$

Error in Longitudes= $\frac{100.609919-100.61003}{100.61003} * 100 = 0.00011\%$

It was understood that there is a discrepancy in the results from the GPS and Google Maps. Also, there is no method to verify whether the values given from the GPS sensor are accurate.This could be considered as the largest challenge faced during the development of the boat as the total error of the system would be the error of the GPS module and the error of the Google Maps API. Since the way points are given by Google Maps and the latitudes and longitudes of the current position are given by the the GPS module the error that occurs is reflected in the distance calculation and the angle calculation. This was the main obstacle that was faced during the development of the boat. In an ideal situation the way point latitude longitudes and the current latitude longitudes should be obtained from a more accurate sensor.

There are various sources of possible errors that will influence the accuracy of positions calculated by a GPS receiver. The travel time of GPS satellite signals can be influenced by ecological factors; when a GPS signal passes through the ionosphere and troposphere it is refracted, subsequently, making the velocity of the signal to be unique in relation to the speed of a GPS motion in space. Sunspots also cause impatiences in GPS signals.

Another source of error is noise, or distortion of the signal. This is caused by electrical interference or errors inherent in GPS receiver itself. Errors in the ephemeris data (the information about satellite orbits) will also cause errors in computed positions, becasue the satellites werent really where the GPS receiver thought they were (based on the information it received) when it computed the positions. Small variation in the atomic clocks (clock drift) on board the satellites can translate to large positions errors; a clock error of 1 nanosecond translates to 1 foot or 0.3 meters user error on the ground. Multipath effects arise when signals are transmitted from the satellites bounce off a reflective surface before getting to the receiver antenna. When this happens, the receiver gets the signal in straight line path as well as delayed path (multiple paths)

4.3 Compass Testing

The current heading of the boat is also a very important parameter in the algorithm. Thus, the heading angle provided by the digital compass should be as accurate as possible. In order to achieve this objective the angles given for 4 main directions, North, South, East and West given by a normal compass were compared with the values given by the digital compass.

Figure 4.8: Carrying out compass testing with a manual compss

Table 4.2: Weights of the components of the boat

Direction	Expected Angle	Actual angle
North	0	1.43
East	90	91.45
South	180	185.55
West	270	275.85

4.4 RF Module Testing

It was important to make sure that the data send by the RF transmitter module is received properly by the RF receiver module. However, initially this was not successful due to the difficulty in transmitting a large number of characters in a single transmission. Due to this unusable data was received along with useful data as seen in the figure below.

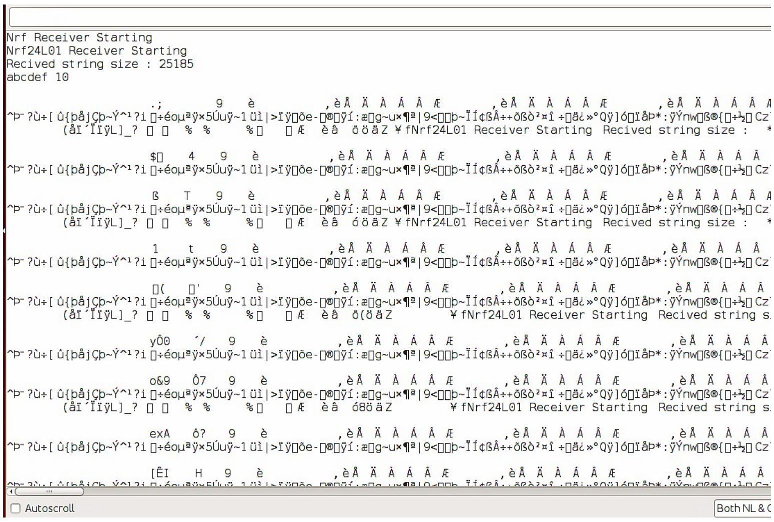

Figure 4.9: Initial data received by RF Receiver displayed on the serial monitor

However, this problem was mitigated by transmitting an array consisting of these data to the receiver.

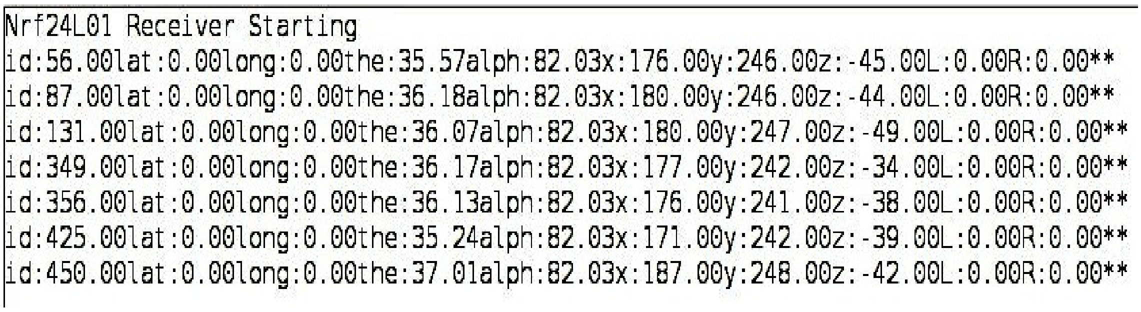

Figure 4.10: Final data received by RF Receiver displayed on the serial monitor

4.5 Methodology Testing

Initial Methodology

The methodology was tested using theoretical and actual values. A theoretical calculation was done using two theoretical values for X and Y and checking this with the latitude and longitude values of the waypoint the angles could be calculated.

X= 14.081085
Y= 100.609846

Waypoint Lat = 14.079056
Waypoint Lon = 100.614936

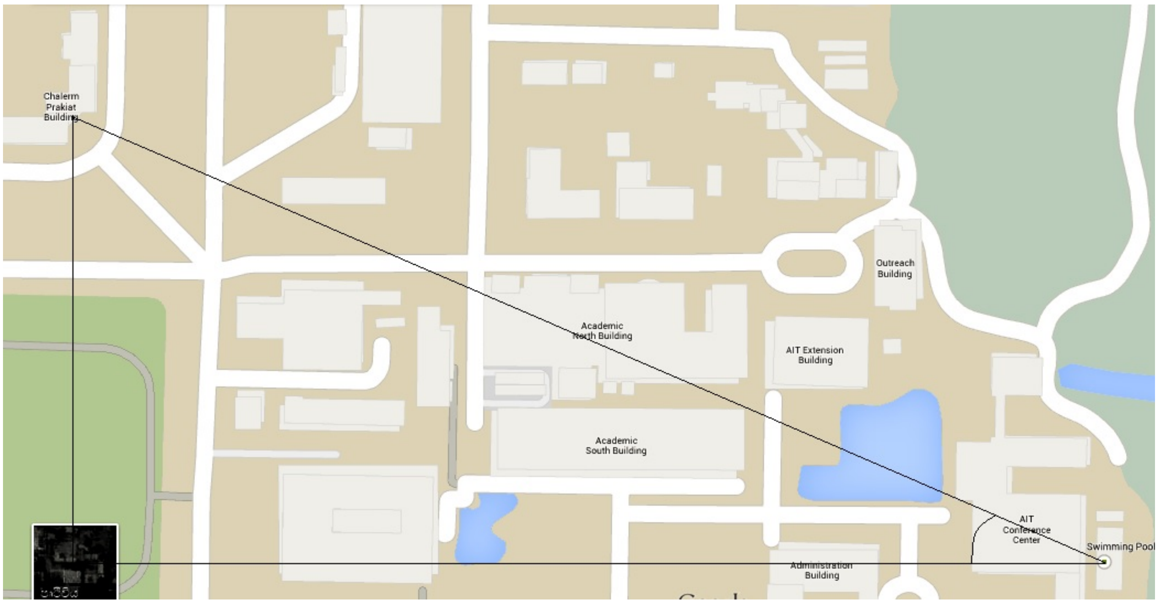

Figure 4.11: Testing in two locations in AIT

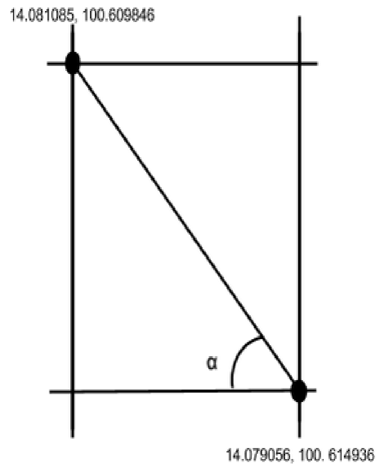

Figure 4.12: ISE and swimming pool co-ordinates

The methodology was also tested by using the position of a known location. ISE building is located on latitude 14.081165 and longitude 100.609948. A way point in the AIT Swimming pool was selected which has latitude 14.079056 and longitude 100.614936.

$Distance = \sqrt{(14.081165 - 14.079056)^2 + (100.609948 - 100.614936)^2}$
$Distance = 0.00541838905$

When this value was multiplied by 111000 to convert into meters, 601.4411m as the distance between the ISE bulding and the swimming pool.

the α angle could be calculated by atan2 equation. Thus,

$\alpha = atan2(\frac{x - waypointLat}{waypointLon - Y})$

$\alpha = atan2(\frac{14.081165 - 14.079056}{100.614936 - 100.609948})$
= 0.40002

Converted to degrees this become $\alpha = 22.9193°$

Thus, taking the angle from North, this become
$90° - 22.9193°$
$= 67.08064134°$

Suppose that the current heading of the boat is given by the compass as $60°$ Thus, (β) could be calculated by the following equation

$\beta = \alpha - \theta$

Thus, β in this instance equals to
$\beta = 67.08064134° - 60°$
$= 7.08064134°$

Thus, the boat should rotate in an angle of $7.00864134°$ in order to adjust its course with the way point.

Final Methodology

The same two locations of the ISE building and the swimming pool could be used for testing the new methodology as well.

X= 14.081085
Y= 100.609846

Way point Lat = 14.079056
Way point Lon = 100.614936

By applying the Haversine Formula

$$d = 2rarcsin(\sqrt{\sin^2(\frac{\phi2-\phi1}{2}) + \cos(\phi1)\cos(\phi2) + \sin^2(\frac{\lambda2-\lambda1}{2})})$$

$$d = 2*6.37*10^6 arcsin(\sqrt{\sin^2(\frac{14.079056-14.081085}{2}) + \cos(14.079056)\cos(14.081085) + \sin^2(\frac{100.614936-100.609846}{2}$$
$d = 594.2621m$

For finding the bearing we can do the following calculation,

The same methodology used in the initial algorithm is used to calculate α. However, a different approach is taken to find θ which is more accurate.

Since we consider the compass reading for the calculation, we consider an instance where $\theta = 35.24, \alpha = 82.03, X = 171, Y = 242, Z = -39$ are given by the RF module.

The real magnetic field strength is proportional to the value given by the Y and Z compass values

$H_x = Hcos(\varphi)$
$H_y = -Hsin(\varphi)$

Thus,

$171 = Hcos(\varphi)$
$242 = -Hsin(\varphi)$

$tan(\varphi) = \frac{-H_y}{H_x} = \frac{-242}{171} = -1.4152$
$\varphi = atan2(-242, 171); -\pi \leq \varphi \leq \pi$
$= -0.955646836$

To convert this into a value in between 0 and 2π we add $2\pi$to the value.
therefore,

$= -0.955646836 + 2\pi$
$= 5.327536947$

From this, we can obtain the value for the heading of the boat (θ)
$\theta = (5.327536947 + \pi/2) mod 2\pi$
$\theta = 0.6151479666$

Thus, when converted to degrees,
$\theta = 35.24538226°$

This value is verified by the answer returned by RF module

```
id:425.00lat:0.00long:0.00the:35.24alph:82.03x:171.00y:242.00z:-39.00L:0.00R:0.00**
```

Figure 4.13: RF module value of theta

4.6 PID Testing

Trial and error method was used for PID testing and after numerous attempts it was found that motorPID constants
$K_p = 0.3$
$K_i = 0$
$K_d = 0$

and PropellerPID constants
$K_p = 2.0$
$K_i = 0$
$K_d = 0$

Depending on the data received from the RF module, the following graphs could be plotted about how the error beta(β) changes with time. This could be used to get an idea as to how much the orientation of the boat changes with time.Here only a P controller is used and in the motorPID function value of P is tuned to 0.3. There is an oscillation that is observed, since only a P controller is used for the boat.

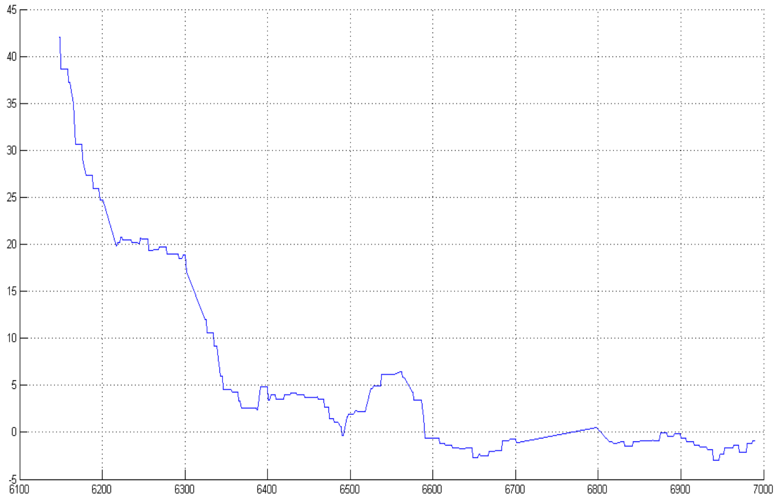

Figure 4.14: Error vs. Time graph 1-motorPID

Also, from the data of the RF module the following graph is plotted about how the error $Distance$ changes with time. The base speeds of the motors are changed proportional to the distance to the way point. When the distance to the way point is less than 0.25m the two motors are turned off and the co-ordinates of the next way point are given. The PWM value for the minimum base speed is set at 20 and the PWM value for the maximum base speed is set at 50. Here, only a P controller is used and in the propellerPID function value of P is tuned to 2.

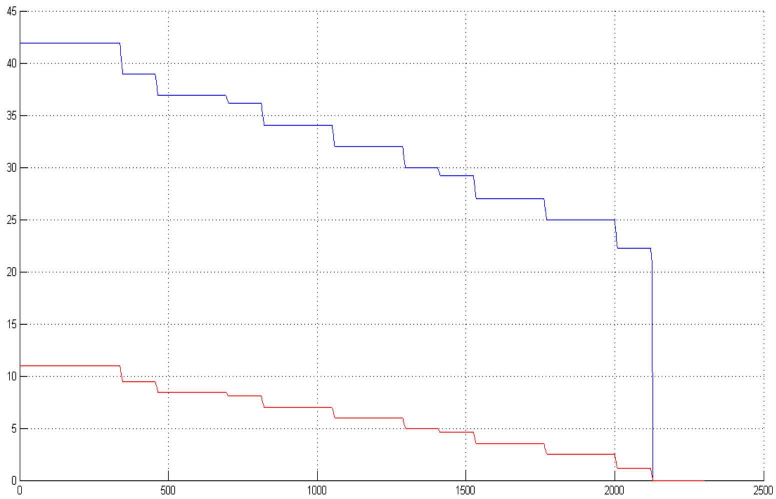

Figure 4.15: Error vs. Time graph 1-propellerPID

Here, the blue line represents the distance to the way point and the red lines represents the base speed of the motors. When the distance to the way point is less than 0.25 m the motors are shut off. The reason to get an output in this manner is the low sensitivity of the GPS sensor and the inability of the RF sensor to receive signals from the GPS properly.

Depending on the data received by the GPS the path followed by the boat could be mapped as below. However, again the same problem arises due to the less sensitivity of the GPS and the inability of RF sensor to receive signals from the GPS constantly.

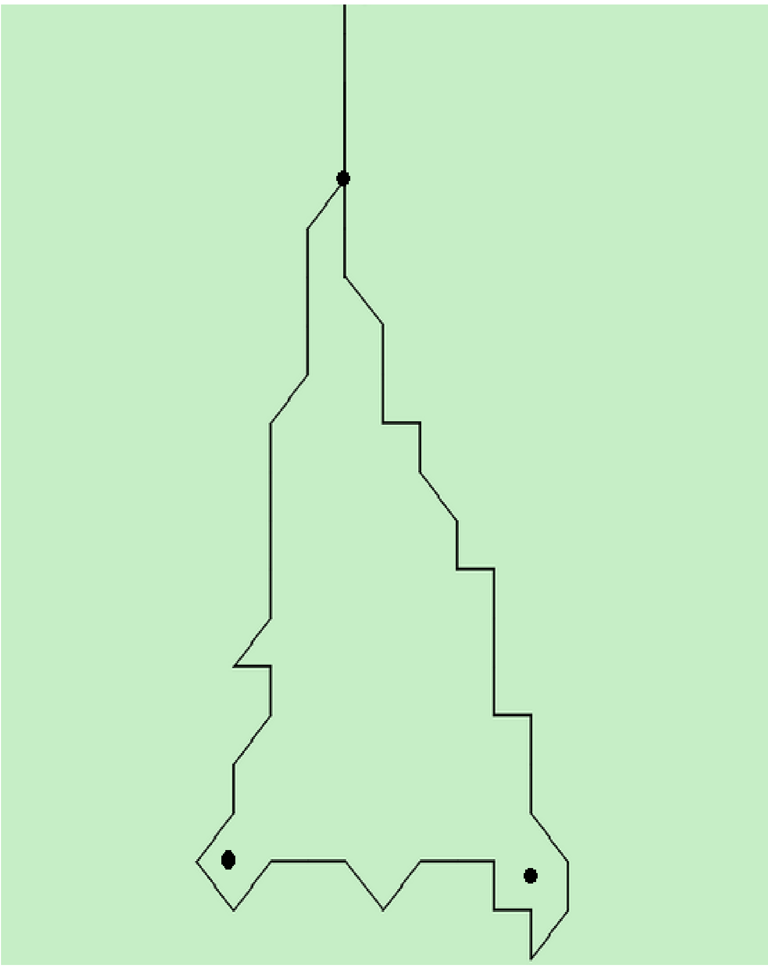

Figure 4.16: The path followed by the boat

From the above figure it could be seen that there is a large deviation of the boat when reaching a way point from the actual intended path it should take.

The deviation of the boat from an actual straight line while travelling from way point 2 (14.078861,100.614935) to way point 3 (14.07904,100.61495) is plotted in the following graph. The maximum deviation the boat has is 1.382m. It's assumed that in an ideal situation the boat should travel in a straight line from way point 2 to way point 3. The current path is compared with the straight line path to obtain the graph

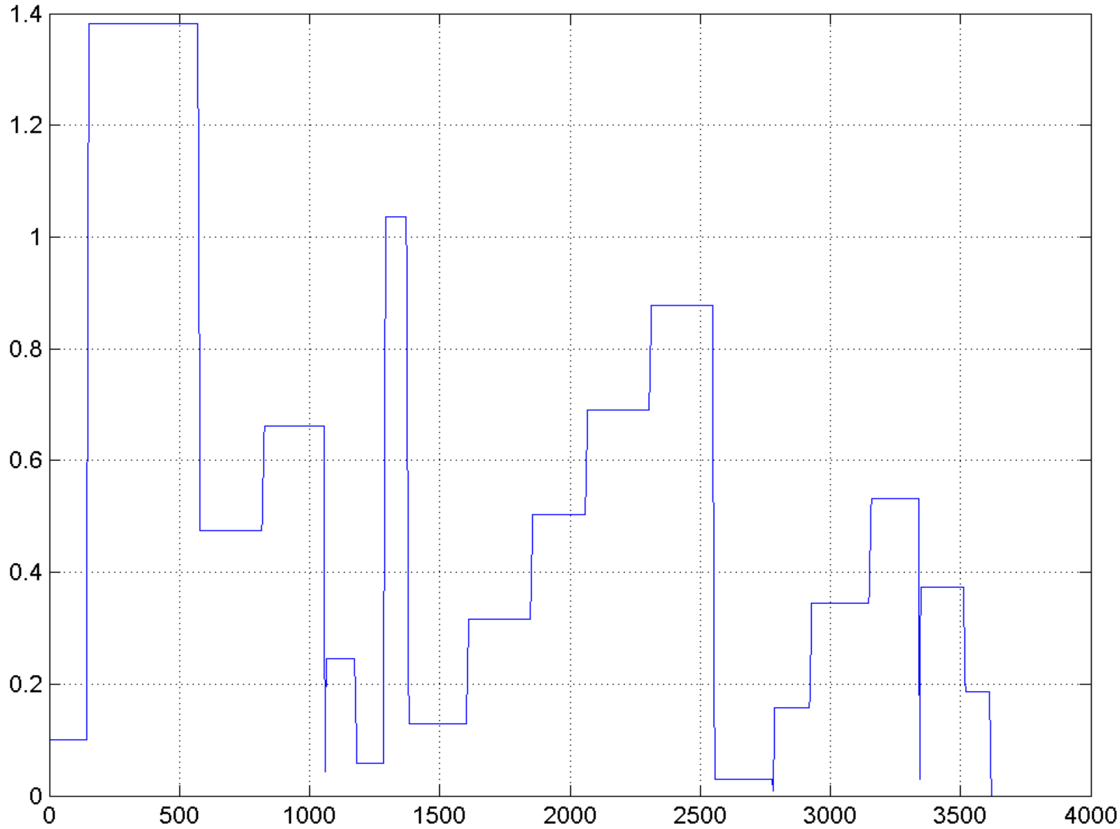

Figure 4.17: Deviation of the boat

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

The aim of this project was to design an autonomous boat that would follow a given a set of way points. In this report an algorithm is presented as to how the boat was automated in order to meet this objective. A GPS and a digital compass are used by the boat to identify it's current position and heading. Two PID feedback loops are used to adjust the course of the boat. Several attempts were done to make a stable design for a boat that would gain sufficient upthrust force to balance the weight of the components and finally a design where varying PWM signals are used to differentiate the speeds of the motors was adopted. The algorithm used can be divided into two main sections as the distance calculation and the bearing calculation where the Haversine formula is used to calculate the distance of the boat from the expected way point and in the bearing calculation the current heading of the boat given by the digital compass is taken into consideration to decide the angle by which the boat should rotate in order to reach the expected way point. The PID algorithm is used in two occasions, firstly to control the angle by which the boat should rotate in order to correct it's course and secondly the distance at which the base speeds of the boat should changed in order to reach the waypoint as precisely as possible without an overshoot. Several tests were done in order to make the path of the boat as smooth as possible and the data obtained by the sensors are accurate as possible hence the algorithm is depending on these data.

5.2 Recommendations

- This project is still in the initial stages and a lot of further modifications should be done in the future if it needs to be developed into a complete military observatory vessel.
- The most important modification that needs to be done is using a GPS device which has a higher accuracy than the present device. Due to the error of the GPS, at present it is a fairly difficult task to navigate the boat to a set of precise pre-defined locations. In order to achieve this a higher accuracy from the GPS a military GPS device should be used which indicates the precise current location of the boat.
- Another main modification would be the current maximum deviation from the path, 1.382m should be minimized and the boat should travel in a straight line.
- Also, the project could be further modified to include a device such as a video camera which could be used to transmit a live feed of the terrain observed.
- A higher resolution digital compass could be used which can indicate the current heading of the boat more accurately than in present. Also a more sensitive RF module should be used which can transmit data values at a higher frequency.

  By conducting these modifications a complete military observatory vessel could be developed.

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