

DESIGN AND FABRICATION OF UNDERWATER ROBOT



Manu Mishra

Design and fabrication of Underwater robot

A thesis submitted for award of

Dual Degree

**Bachelor of Technology in Mechanical Engineering with Master of
Technology in Mechatronics and Automation**

by

Manu Mishra

710ME4109

Under the esteemed guidance of

Prof. Dayal Ramakrushna Parhi



Department of Mechanical Engineering

National Institute of Technology Rourkela

Odisha (India)-769008

Index

Declaration.....	(iii)
Certificate.....	(iv)
Acknowledgements.....	(v)
Abstract.....	(vi)
List of Tables.....	(vii)
List of figures.....	(viii)
List of symbols.....	(x)
1. Introduction.....	(1)
2. Literature Review.....	(5)
3. Theory.....	(11)
3.1 Underwater robot Kinematics.....	(11)
3.2 Various factors affecting underwater robots.....	(15)
4. Experimental Fabrication and CAD modelling.....	(19)
5. Fuzzy Technique for navigation.....	(24)
6. Result and Discussion.....	(38)

7. Conclusion.....	(41)
8. References.....	(42)
9. Publications.....	(45)

Declaration

I hereby declare that this thesis is my original work and to the best of my knowledge and belief it does not contain any material that is prewritten by any person or published before by anyone.

Also it does not contain any material that is a part of any thesis or document that has been previously used for award of any degree or diploma by any institute or university except the references and acknowledgements made in the text.

(Manu Mishra)

Date /.../.....



NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA -769008, ODISHA, INDIA.

Certificate

This is to certify that this thesis entitled, “Design and fabrication of Underwater Robot”, submitted by Mr. Manu Mishra to the Department of Mechanical Engineering, National Institute of Technology, Rourkela, for the partial fulfilment of award of the Dual degree Bachelor of Technology in Mechanical Engineering and Master of Technology in Mechatronics and Automation, is a record of genuine research work done by him under my guidance and direction.

This theory as I would see it, is deserving for the award of Dual degree Bachelor of Technology in Mechanical Engineering and Master of Technology in Mechatronics and Automation as per the regulation of the institute. To the best of my insight, the outcomes epitomized in this thesis have not been submitted to any other University or Institute for the recompense of any degree or certificate.

Supervisor

Date: / /2015

Dr. Dayal Ramkrushna Parhi

Professor

Department of Mechanical Engineering

National Institute of Technology Rourkela, Odisha-769008

Acknowledgement

I would like to firstly thank the Almighty, with whose blessings, I am composing this thesis.

I want to express my heartfelt gratitude and indebtedness to Prof. Dayal Ramkrushna Parhi for his generosity and kindness in giving me a chance to work under his watch and direction. Amid this period, without his esteemed guidance, information, profound persistence, priceless direction and answers to my various inquiries, this research would have never been conceivable. He was never less than a father who teaches his son to help him pave his way in life.

I am highly obliged and grateful to Ms. Shubhasri Kundu for providing me the required guidance on every point of project. Without her helpful disposition it was unrealistic to complete this project. Unique thank goes to Mr. Maheswar Das, who helped me immensely in my project and was always like a brother to help in every problem.

I thank all the research scholars of Robotics Lab, especially Mr. Prases Mohanty, Mr. Anish Pandey, Mr. Adik Sahoo and who helped me and always encouraged me in different ways towards the fulfilment of my work. Their help and heaps of flawless memory with them can never be caught in words.

I would like to thank my guardians for boundless backing and support. Lastly I would like to thank all my professors for their valuable guidance. With their help only, I could pursue my Dual degree at NIT Rourkela.

Abstract

Underwater robot or vehicle refers to an autonomous robot equipped with suitable equipment, sensors and actuators which enable it to navigate in the underwater environment. In the recent years, under water robots have played an important role in many under water operations and research. There is an increase in the research in this area because of the wide application of the autonomous under water robots in many issues like exploring underwater life, environment and resources, carrying out scientific as well as military tasks under water. Underwater Robots are important and substantial tools for achieving various actions and these have increasing applications in various discovering and observing underwater environments. Due to the various uncertainties in the underwater environment and the dynamic behaviour, designing and fabrication of the underwater robot is difficult task. Various parameters are needed for monitoring and controlling during the implementation of a certain task with an underwater robot. Hence, research in this area of monitoring and designing of the underwater robots has become a challenge for engineers and has been also taken up by many researchers. The design is the most important step in manufacturing of an underwater robot, and its salient features play an important role whenever we have to choose an underwater robot for a specific mission or research purpose. These robots are continuously substituting the human divers for performing various tasks that over-risk our human life. This research focuses on the design and fabrication of an underwater robot having a PVC hull, a frame, motors and various sensors like depth sensor and sonar sensor have been incorporated as its main accessories. Fuzzy technique has been used for the control of thrusters and navigation purposes.

List of Tables

Table 5.1: Parameters for Obstacle distance.....	(27)
Table 5.2: Parameters for heading angle.....	(27)
Table 5.3: Parameters of elevation angle.....	(28)
Table 5.4: Parameters of Motors (forward and backward motion).....	(28)
Table 5.5: Parameters for Motors (for vertical motion).....	(28)
Table 6.1: Comparison of various Experimental and Simulation results.....	(40)
Table 7.1: The specifications of the developed Underwater Robot.....	(42)

List of figures

Figure 1.1: Some examples of commercial AUVs.....	(2-3)
Figure 1.2(a): AUV 150.....	(3)
Figure 1.2(b): Alister 100.....	(4)
Figure 3.1: A figure showing the various movements of an underwater object namely Roll, Pitch and Yaw.....	(12)
Figure 3.2: Figure showing the flow chart of various processes in an AUV	(13)
Figure 3.3: Effects of the buoyancy force and weight of the body on an underwater body.....	(15)
Figure 3.4: Stability and buoyancy.....	(16)
Figure 4.1: The Hull of Underwater robot.....	(20)
Figure 4.2: The aluminium frame for robustness.....	(21)
Figure 4.3: CATIA model for Motor.....	(22)
Figure 4.4: CATIA model for the underwater robot.....	(23)
Figure 5.1: Various inputs and outputs	(26)
Figure 5.2: Front obstacle distance.....	(29)
Figure 5.3: Left obstacle distance graph.....	(29)
Figure 5.4: Right obstacle distance graph.....	(30)

Figure 5.5: Heading Angle-Azimuth angle Graph.....	(30)
Figure 5.6: Heading angle – Elevation Angle graph.....	(31)
Figure 5.7: Target Angle – Azimuth angle graph.....	(31)
Figure 5.8: Target Angle- Elevation Angle graph.....	(32)
Figure 5.9: Motor 1 Graph.....	(32)
Figure 5.10: Motor 2 Graph.....	(33)
Figure 5.11: Motor 3 Graph.....	(33)
Figure 5.12: Motor 4 Graph.....	(34)
Figure 6.1: The fabricated underwater robot giving the CAD view of the robot made in the laboratory.....	(37)
Figure 6.2: Image of fuzzy Logic Controller results defuzzification.....	(39)

List of symbols

x_b - Surge

y_b - Sway

z_b - Heave

φ_b - Roll

ψ_b - Yaw

θ_b - Pitch

O_W- Origin of world frame

O_B- Origin of body frame

LOD: Left Obstacle distance

ROD: Right Obstacle distance

FOD: Front obstacle distance

HA- Heading angle

TA-Target angle

AA- Azimuth angle

EA-Elevation angle

1. INTRODUCTION

Underwater robot or vehicle refers to an autonomous robot which is equipped with suitable equipment, many sensors e.g. sonar, pressure etc. and actuators which enable and help it to navigate in the underwater environment. In the past few years, under water robots have played an important role in many under water operations and research. There is an increase in the research in this area because of the wide application of the autonomous under water robots in many issues like exploring underwater life, environment and resources, carrying out scientific as well as military tasks under water. Underwater Robots are important and substantial tools for achieving various actions and these have increasing applications in various discovering and observing underwater environments. Due to the various uncertainties in the underwater environment and the dynamic behaviour, designing and fabrication of the underwater robot is a difficult task. Various parameters are needed for monitoring and controlling during the implementation of a certain task with an underwater robot. Hence, research in this area of monitoring and designing of the underwater robots has become a challenge for engineers and has been also taken up by many researchers. If some parameter like the position and direction of motion of the robot could be controlled automatically, the underwater robot can be enormously facilitated. The design is the most important step in manufacturing of an underwater robot, and its salient features play an important role whenever we have to choose an underwater robot for a specific mission or research purpose. These robots are continuously substituting the human divers for performing various tasks that over-risk our human life.

Underwater Vehicles find various applications in oil industries, research and in various defense and research organizations. Some of these applications are as follows.

- Underwater Vehicles find applications in sea floor mapping and hydrographical surveys for the development of the subsea infrastructure or the layout of pipelines for oil or gas industries.
- Underwater Vehicles have also been employed for the leakage detection of oil/gas from the underwater pipelines as well.
- The usage of Underwater Vehicles offers large benefits in replacing the human operators thus avoiding the operating cost and the various risks in the extreme underwater environment like deep oceanic environments. Some of the Underwater Vehicles which are usually used for various commercial purposes are shown in the Figure 1. It is developed by Kongsberg Maritime and Forsvarets Forsknings Institutt (FFI) in Norway, Bluefin Autonomous Underwater Vehicle by Bluefin Robotics.



Figure 1.1(a)

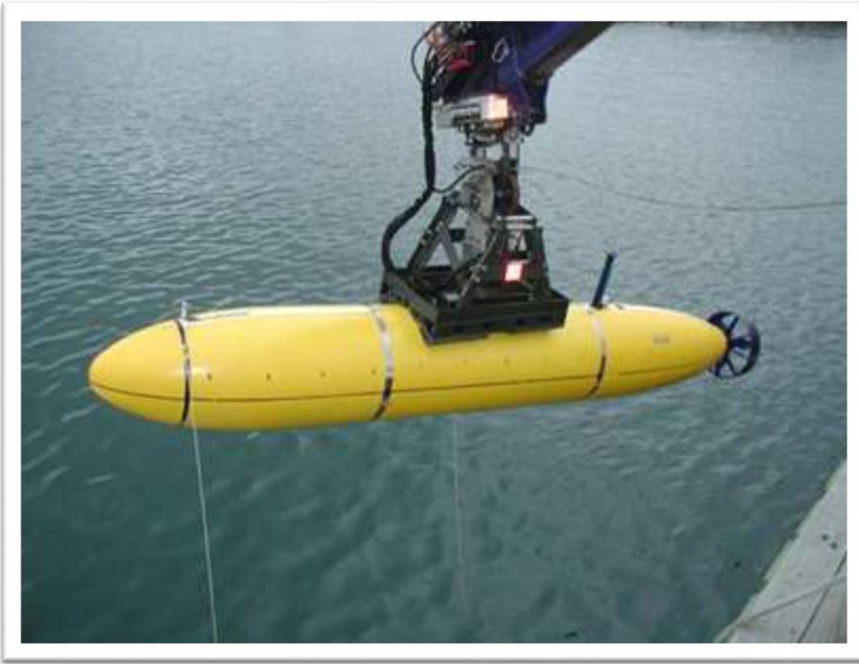


Figure 1.1(b)

Figure 1.1 (a) & (b): Some Examples of Commercial AUV's

- Underwater Vehicles are also suitable for various military applications and for underwater mine detection. AUVs can also be used as anti-submarine warfare and can also be employed in a protected area for the identification of unauthorized trespassing.
- In the recent years, Underwater Vehicles are being used as the means for providing warfare equipment and medicines in the affected areas. Few autonomous Underwater Vehicles which are known for their wide applications in defense and other military applications are the AUV150 made by CSIR CMERI, from India, TALISMAN robot made by the BAE Systems and the ALISTER 100 robot made by the eca Robotics. These are shown figures 2a and 2 b.



Figure 1.2.a AUV 150



Figure 1.2.b Alister 100

2. LITERATURE REVIEW

The configuration and advancement of the vehicle Mako comprised of actualizing a mechanical and electrical framework, and the joining of subsystems. The advancement of these frameworks has brought about a low-speed, base overwhelming, open-outline submerged vehicle named the Mako that displays high symmetry, particularity and dependability. The demonstrating of the Mako was then performed which included the utilization of the dynamic model of a submerged vehicle and the ensuing recognizable proof of the important parameters [1]. MIT's Orca AUV has two PVC tubes mounted on an aluminum outline. Batteries are arranged in the base tube to bring down the center of mass and expand the correcting snippet of the vehicle. Every tube has a sliding card mounted with electronic hardware. These cards use connectors to associate the electronic hardware to the PVC end plate. The end plate contains the outer connectors. This arrangement kills the requirement for disengaging links when expelling the cards from the tubes. Propulsion is given by means of two engines mounted on the sides for even development and two vertical engines for profundity control. These thrusters are fueled through six 12V, 3Ah batteries while the staying electronic gear uses four other 12V batteries. A locally available checking framework measures singular voltages and current for power administration purposes [2]. A biomimetic robot or a robot which mimics biological processes was made which propels the robot with the help of two fins which help in the smooth wave like motion of the robot and are symmetrical. The fins are driven by many servo motors and these motors are controlled by a cosine function wave. The two fins have been divided into a number of small parts and thus on each part the thrust is calculated and hence total thrust is calculated on the fin body [3].

A missile evasion system has been applied to an underwater robot in accord with the defense requirements of armed forces now days and for this fuzzy technique has been used. In this, fuzzy

technique provides the necessary decision making and the various requirements for evading a simple torpedo attack on a submarine system and various state variables have been used for the purpose of decision making process [4].

Underwater glider is an AUV that uses and applies the buoyancy and altitude for its navigation purpose. When these two parameters are changed, the vehicle's vertical movement could be easily attained. The identification of these various parameters like net buoyancy depth angle and the pitching angle of the glider has been observed when using ballast rate as an input. MATLAB has been used to analyze the mathematical model [5].

Instead of two inputs, single input has been used in single input fuzzy logic controller. This greatly eased the process of tuning of various factors/parameters and various rule inferences. A very simplified and easy approach for designing this foresaid fuzzy logic controller has been used to simplify a tedious method [6].

A hybrid fuel cell has been manufactured for more efficient, cleaner and easy to use source of power for the various underwater systems. Low emissions and longevity of operation are the major advantages of this hybrid fuel cell which uses a super-capacitor with two power levels. Also compact size is also a main feature in this cell [7]. Finite element methods for example ABAQUS and UNIDEX were used for the calculation of the various stress levels which were generated by an underwater explosion and the various stress waves were assumed to be spherical shaped in which various stiffeners have been incorporated and the response has been modelled [8]. The method, sliding mode control, because of its power against demonstrating imprecision and outer aggravations, has been effectively utilized to the dynamic situating of remotely worked submerged vehicles. So as to enhance the execution of the complete framework, the intermittence in the control law must be smoothed out to maintain a strategic distance from the

redundant impacts. A properly designed adaptive fuzzy algorithm has been described which could enhance the control strategy and avoid disturbances [9]. The point of this paper is to explain remotely worked framework (Remotely Operated Vehicle) outline. The correspondence and control of submerged vehicles is a mind boggling issue. This section starts with tending to the centre of these issues: source of power for the vehicle, level of self-governance, and correspondences linkage to the vehicle. It then moves to the talk of self-rule, with portrayal of an airplane similarity and afterward the vehicle in its water surroundings. This paper addresses the most basic ranges of a remotely operated vehicle configuration and operational contemplations by researching the reason that vehicle geometry does not influence the thought process execution of a ROV about as much as the measurements of the tie. Remotely Operated Vehicle frameworks are an exchange off of various elements, including expense, size, arrangement assets, and operational prerequisite. Yet, the tie outline can help make, or crush, the ideal Remotely Operated Vehicle [10].

The standard state of a submarine weight structure is as a ring-hardened round chamber, hindered by end tops. The weight structure is at times encompassed by a hydrodynamic frame, which is in a condition of free-surge and is in this way unrealistic to fizzle because of hydrostatic weight. The proposed outline is like the configuration of a submerged penetrating apparatus, as proposed by the creator and his previous understudy (Ross and Laffoley-Lane, 1998), furthermore to a submerged rocket launcher (Ross, 2005). The present structures have a superior hydrodynamic structure than those beforehand proposed by the creator; this new frame might likewise permit preferred mobility over the past structures. They will likewise yield much bigger inner volumes of the submarines, with the goal that they can store more. Issues may happen with the moderate develop of contaminants in the air and every now and then the vessel may need

cleansing. This will be decreased to some degree, as the team was most likely working in a few rota shifts. Contemplations were made so that the team does not experience the ill effects of physiological and mental issues. Outside backing of the vehicle from expert scaled down and different submarines wasn't so simple. These submarines ought to have the capacity of floating over the submerged vessels, so that their trapdoors can lock in. This drifting office can be accomplished through water plane impetus. The utilization of generally received trapdoor covers for submarines and submersibles ought to be given much thought to help salvage missions. Then again, such vessels ought to demonstrate suitable for guard purposes, as the foe will discover the vessels exceptionally hard to follow, as their marks will be miniscule. The arrangement perspective of the primary structure require not be a circular structure, but rather can be of oval shape, similar to a course, or of comparable structure. The utilization of atomic energy to create power for the vessel ought to demonstrate truly palatable. Crisis battery force ought to additionally be accessible. In the event that a GFRP composite is utilized, the vessel will have adequate store lightness to be brought and brought down up in the water. Furthermore, the great sound retention characteristics of a GFRP composite will make the vessel exceptionally hard to distinguish by the adversary and ought to additionally make clamor levels inside the vessel bearable. By and large, GFRP won't erode in salt water. The building of these new submerged vessels won't be simple [11].

A few key parts of submerged acoustic interchanges are examined. Distinctive architectures for two-dimensional and three-dimensional submerged sensor systems are examined, and the qualities of the submerged channel are definite. The primary difficulties for the advancement of productive systems administration arrangements postured by the submerged environment are point by point and a cross-layer way to deal with the mix of all correspondence functionalities is

recommended. Moreover, open examination issues are examined and conceivable arrangement methodologies are delineated [12].

Stabilizing of an underwater robot using internal rotors is discussed. Taking kinetic energy as a dynamic factor and design feedback using lyapunov function with use of general model and viscosity and hydrodynamic factors, the stability has been discussed [13]. An entirely newly arrangement of ideas, routines, and instruments that are adjusted to catch the joining of sensible orders, constant time development, and discrete occasion progress have been talked about. The re-view of three control ventures outlined at the Underwater Systems and Technology Laboratory, and examines the new difficulties from the dynamic streamlining perspective are talked about [14].

A remote-worked vehicle (ROV) created for examinations of the ocean depths more than a wide region can be worked as both a towed and a self-propulsive vehicle. Called DELTA, the shape is like that of a delta-wing flying machine. The vehicle has two propellers and weight shift mechanical assembly as actuators. The paper depicts the outline of the control framework for the vehicle. Non-straight movement comparisons of the towing link and DELTA are talked about. Depth control execution was enhanced by the powerful controller [15]. A three-level progressive structural planning is proposed so as to uncouple the execution of client characterized movement undertaking capacities regarding the working environment (direction), from straight and precise rate control and mapping of the obliged control activities onto the incitation framework. The presentation of PI-sort undertaking capacities empowers an ordinary Lyapunov-based direction framework to neutralize the impacts both of unmodelled, i.e. unmeasured kinematic collaborations between the vehicle and the earth, and of inclination in speed estimations. The vehicle progress are overseen by routine addition planning controllers performing speed control,

while a propelled actuator model, which considers propeller–hull connections, enhances the accuracy of the push to propeller rate mapping. Preparatory tests, completed in a high-jumping pool with an over-activated model ROV, demonstrated the framework's usefulness and indicated superior exhibitions as far as its exactness in finishing close base moderate movement assignments, e.g. height and floating control and direction following, notwithstanding when the mapping of the obliged control activities onto the incitation framework is reconfigured to face any kind of thruster shortcoming [16]. Spineless creatures that utilize a liquid filled hole encompassed by contractile tissue (a hydrostatic skeleton) move themselves proficiently submerged and enter districts blocked off to legged or wheeled gadgets. A hydrostatic robot would consequently be important for investigating marine environments. A three-section hydrostatic robot is developed that locomotes submerged. Every portion comprises of two strong roundabout plates associated by four equidistant shape memory compound springs. A liquid filled bladder in the focal point of every section gives hydrostatic skeletal backing. The 15.5 cm long robot moves and paces up to 0.6 cm/s, can swing up to 21°, and can switch its length by up to 16%. A model of the robot's kinematics has additionally been produced [17].

As an option methodology, of the high cost automated frameworks, the GARBI submerged robot has been outlined as an ease ROV created for submerged applications in shallow water situations. Depiction of the submerged vehicle and the blessed frameworks, the robot's objectives and its principle applications has been talked about. The robots movements have been restricted to 4 DoFs and some other reductions in navigation parameters also have resulted GARBI as a reduced cost underwater vehicle [18].

3. THEORY

3.1 Underwater robot kinematics

The Six degree of freedom underwater vehicle simulation is very important and quite useful in the fabrication of autonomous and non-autonomous underwater vehicle systems. Several forces are there which have to be taken into account which includes the hydrodynamics of the vehicle inside water, rigid body dynamics of the AUV etc.

There are several complex and various nonlinear forces acting on an underwater robot or vehicle, usually with open frame Autonomous UVs, making the control of underwater vehicle trickier. Several forces are there, for example: hydrodynamic drag force, damping forces, lift, Coriolis and centripetal force, gravity force and buoyancy forces, thruster forces, and environmental parameters. The various topics involved about the kinematics of the AUV will be the reference frames, the Euler angles and the state of space representation. The dynamics will include the dynamic models of AUV, with a description of the mass and inertia forces, Coriolis and centripetal force, hydro-dynamic damping and, gravitation force and buoyancy forces.

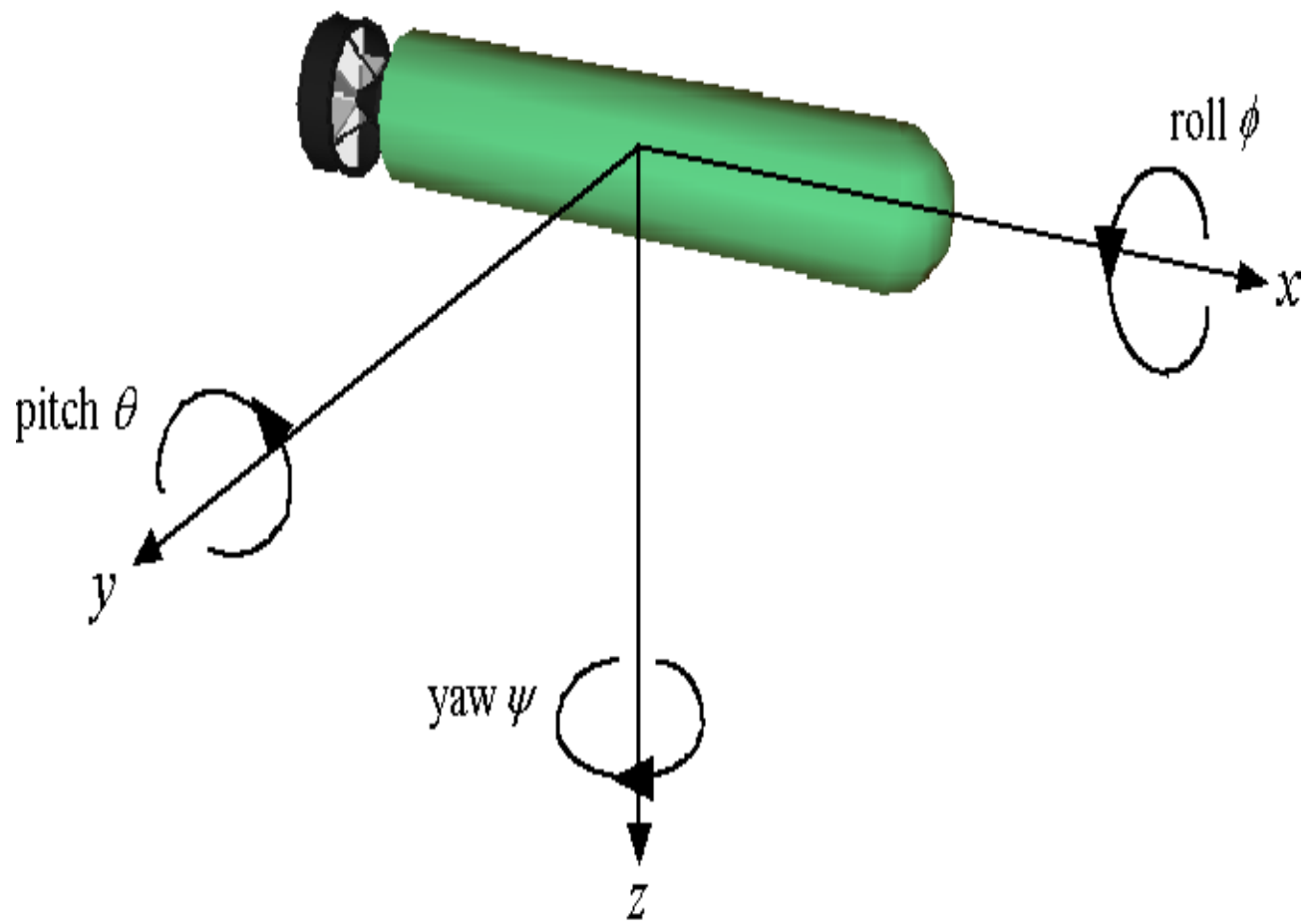


Figure 3.1: A figure showing the various movements of an underwater object namely Roll, Pitch and Yaw

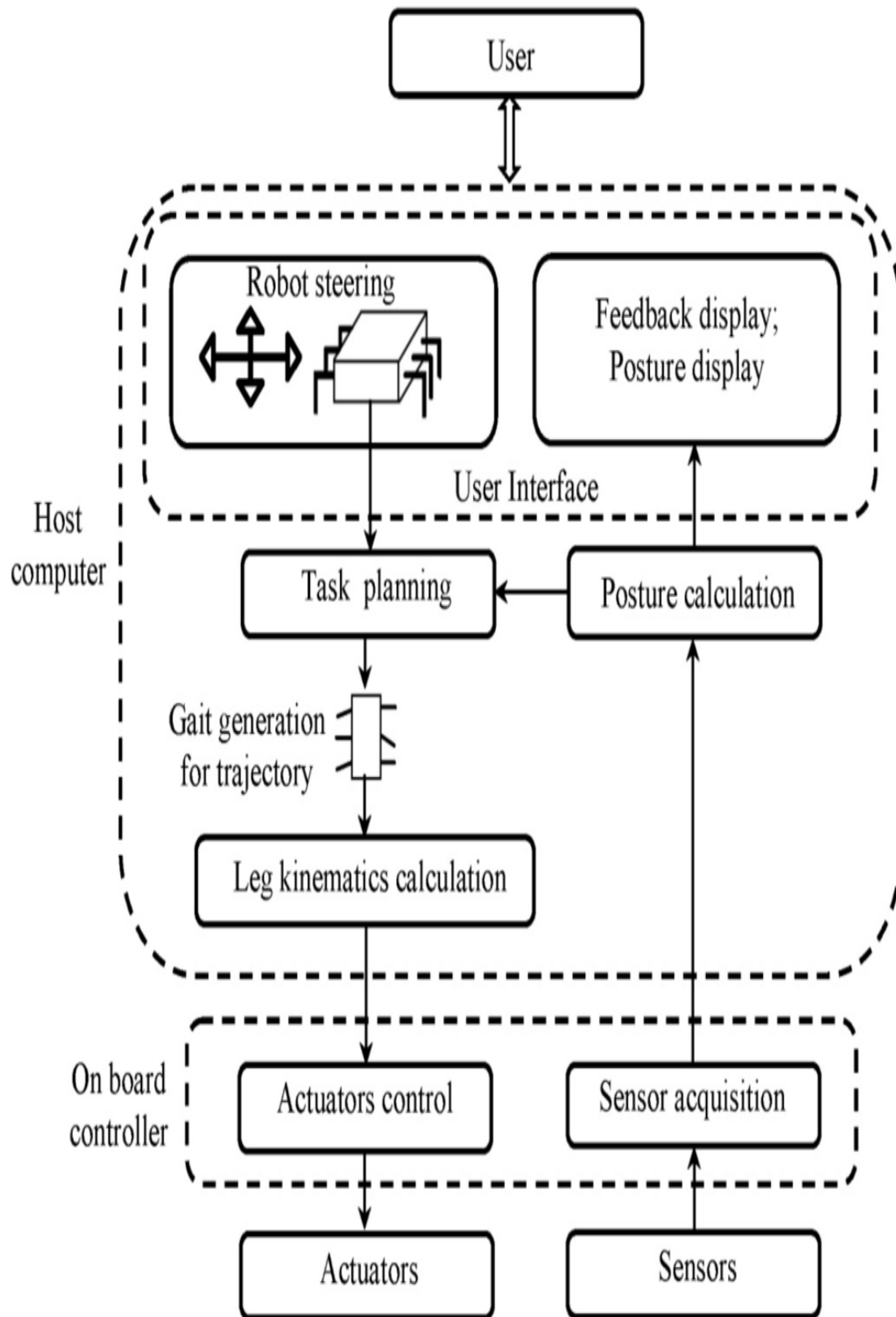


Figure 3.2: Figure showing the flow chart of various processes in an AUV.

Reference Frame

There are two types of reference frames introduced to model of AUV, a world-fixed or world reference frame (W) and a body-fixed or body reference frame (B). The W-frame is based on the world, where x-axis points towards the north, y-axis towards the east and the z-axis points to the centre of earth. The Body-frame is coupled to the concerned body or vehicle, where x-axis points towards the forward direction, y-axis points towards the right of vehicle and the z-axis points vertically down. The World-frame and Body-frame are depicted in Figure. The directions of every axis can be seen. The various notation, $x_b y_b z_b \varphi_b \psi_b \theta_b$ are named as Surge, Sway, Heave, Roll, Yaw and Pitch motions respectively. The origins of the World-frame and Body-frame are defined as O_w and O_b . All the DOF for the Body-frame and World-frame to be used in this report are listed in a vector form in

$$x = [Surge \quad Sway \quad heave \quad roll \quad yaw \quad pitch]$$

Or

$$x = [x_b \ y_b \ z_b \ \varphi_b \ \psi_b \ \theta_b] \quad \text{—————} \quad (1)$$

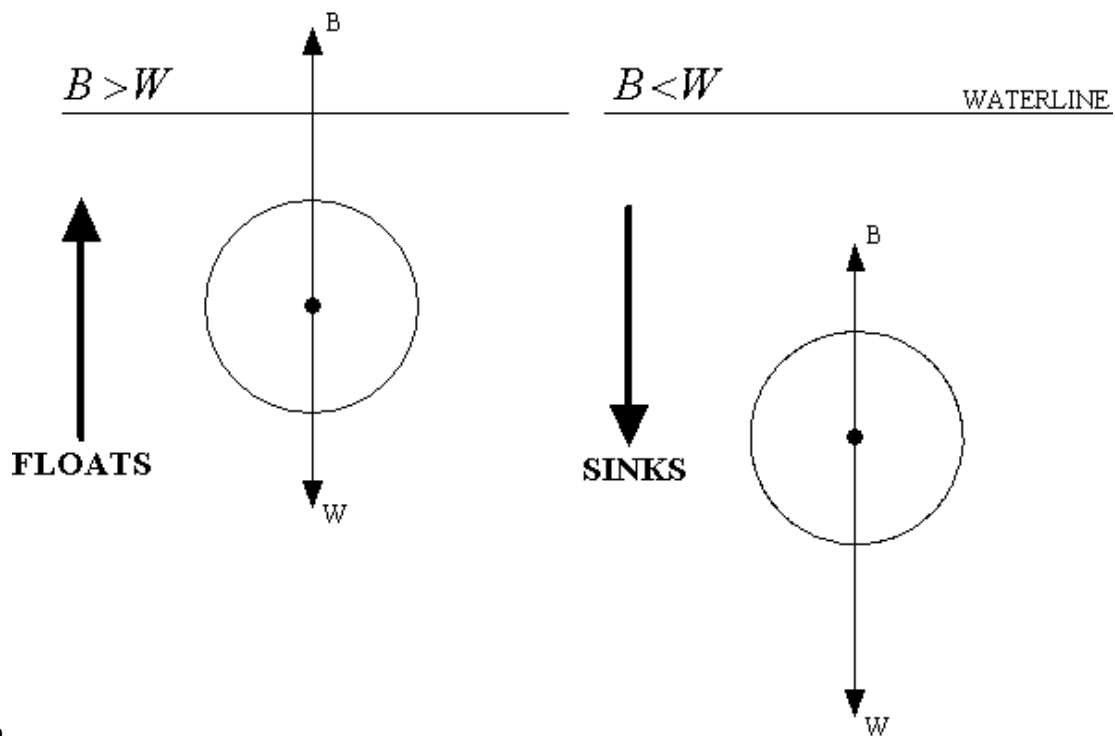
And

$$\eta = [x \ y \ z \ \varphi \ \psi \ \theta]^T \quad \text{—————} \quad (2)$$

3.2 Factors affecting the motion of an Underwater Vehicle or Robot

A. Buoyancy

According to fluid mechanics, the buoyant force, i.e. B , exerted on a body, which is floating or is submerged, is equal to the weight of the water volume displaced by the body. An object's ability to float depends on whether the magnitude of the weight of the body, i.e. W , is greater than the buoyancy force. If B is greater than W , then the body floats, but, if B is less than W , the body sinks. If buoyant force B and weight of the body W are equal, then the body remains in the same



position.

Figure 3.3: Effects of the buoyancy force and weight of the body on an underwater body.

B. Hydrodynamic Damping

At the point when a body is travelling through the water, the fundamental forces acting the other way to the movement of the body are hydrodynamic damping force or hydrodynamic force simply. These damping powers are fundamentally because of drag and lifting forces, and additionally lineal skin friction force. Damping strengths have a noteworthy impact on the progress of a submerged vehicle which prompts non linearity. Lineal skin contact can be viewed as immaterial when contrasted with drag powers, and accordingly, it is typically adequate to just consider the last when figuring damping strengths.

C. Stability

Expecting no water movement or development, the solidness or stability of a static body submerged is dominatingly influenced by the positions of the CoM or centre of mass, CM, and buoyancy, CB. The centre point of buoyancy is the centroid of the volumetric relocation of the body. If CM and CB are not adjusted vertically to one another in either the longitudinal or sidelong headings, then shakiness will exist because of the formation of a non-zero couple.

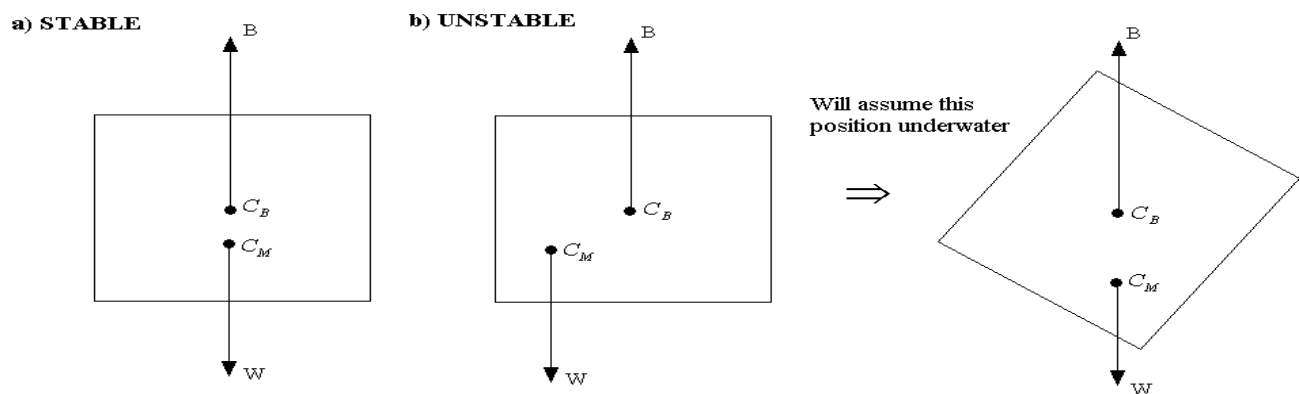


Figure 3.4: Stability and buoyancy

D. Coriolis

Coriolis is an inertial force that acts perpendicularly to the course of movement of a body. This force is corresponding to both the speed and the pivot of direction framework or coordinate system. The impact of the Coriolis power is that, the way of the body deflects. In viable circumstances, the way of the body is not in genuine diverted, but rather it has all the earmarks of being avoided. This is a direct result of the movement of the body and its organize framework or coordinate system. Since the direction arrangement of a self-governing submerged vehicle pivots concerning some other reference outline or coordinate system, the impact of coriolis force is for the most part considered and is incorporated in the different comparisons and equations of movement.

E. Included mass

Another wonder that influences submerged vehicles is included mass. At the point when a body moves submerged, the prompt encompassing liquid is accelerated alongside the body. This influences the elements of the vehicle in such a path, to the point that the power needed to accelerate the water can be demonstrated as an included mass. Included mass is a genuinely noteworthy impact and is identified with the mass and inertial estimations of the vehicle.

F. Natural Forces

Natural aggravations can influence the movement and strength of a vehicle. This is especially valid for a submerged vehicle where waves, streams and even wind can unstabilize the vehicle. At the point when the vehicle is submerged, the impact of wind and waves can be to a great extent disregarded. The most noteworthy unsettling influences then for submerged vehicles are streams. In a controlled environment, for example, a pool, the impact of these natural powers is insignificant.

G. Pressure

Similarly as with air, submerged weight is created by the heaviness of the medium, for this situation water, following up on a surface. Pressure is generally measured as an outright or encompassing pressure; total meaning the aggregate pressure and surrounding being of a relativistic nature. Adrift level or at sea level, Pressure because of air is 14.7psi or 1atm. For each 10m of profundity or depth, pressure increments by around 1atm and consequently, without a doubt the pressure at 10m submerged is 2atm. Albeit straight in nature i.e. Linear, the increment in weight as profundity increments is huge and submerged vehicles must be basically equipped for withstanding a moderately vast sum of weight on the off chance that they are to survive.

4. EXPERIMENTAL FABRICATION

Firstly to start with, a CATIA model of the Under-water robot was made which is facilitating the whole designing and also gave an outline for the project. A P.V.C. (Poly vinyl Chloride) pipe of around 110 mm diameter and appropriate length was used as the main body for the under-water robot.

An Acrylic sheet was cut into 4 square sizes of around 150 mm sides so as to cover the faces of the PVC pipe.

The main purpose of Acrylic sheet was to make the way for camera transparent and to provide adequate strength for closing of pipe for making it water proof.

For fixing of Asbestos sheet, two small cuttings of another PVC pipe of inner diameter 110mm were used and glued to the surface of the PVC pipe on both its ends. After that facing was done to let the faces of the PVC pipes match.

Then for fitting of various components like camera etc. inside the hollow casing of the PVC pipe, it has to be made leak proof.

For achieving this water proof state, so as to not allow water to go inside the PVC pipe as our main working area is inside water, 2 rubber sheets were used. Thickness of rubber sheets is around 7mm and size is same as the square acrylic sheet.

To tighten the rubber sheet nuts, bolts and washers have been used. For this, holes were drilled by using drilling machine in both acrylic sheet and rubber pads. Tightening was done and the

setup was checked for its water-proof ability by drowning it in the swimming pool upto 7ft depth for a considerable time. The setup had no leakage and hence experiment was successful.

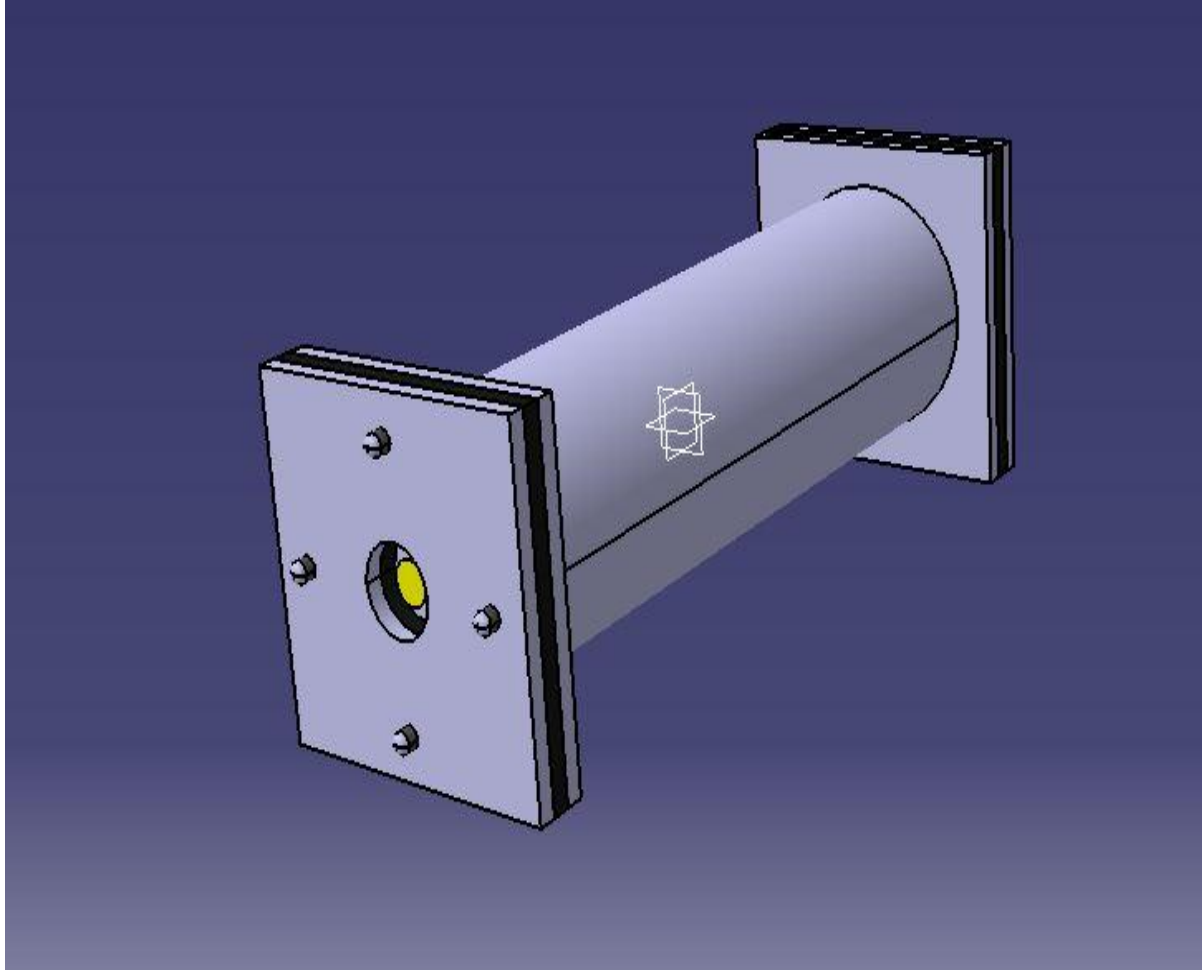


Figure 4.1: The Hull of Underwater robot

After this, a stand was made for the carrying of setup and to attach motor in it. Thin Aluminium hollow square cross section rods were used and step by step they were joined by drilling holes in them using drilling machine and by tightening with bolts and nuts. This structure provided robustness to the structure and also a safety structure to prevent shocks during handling of setup.

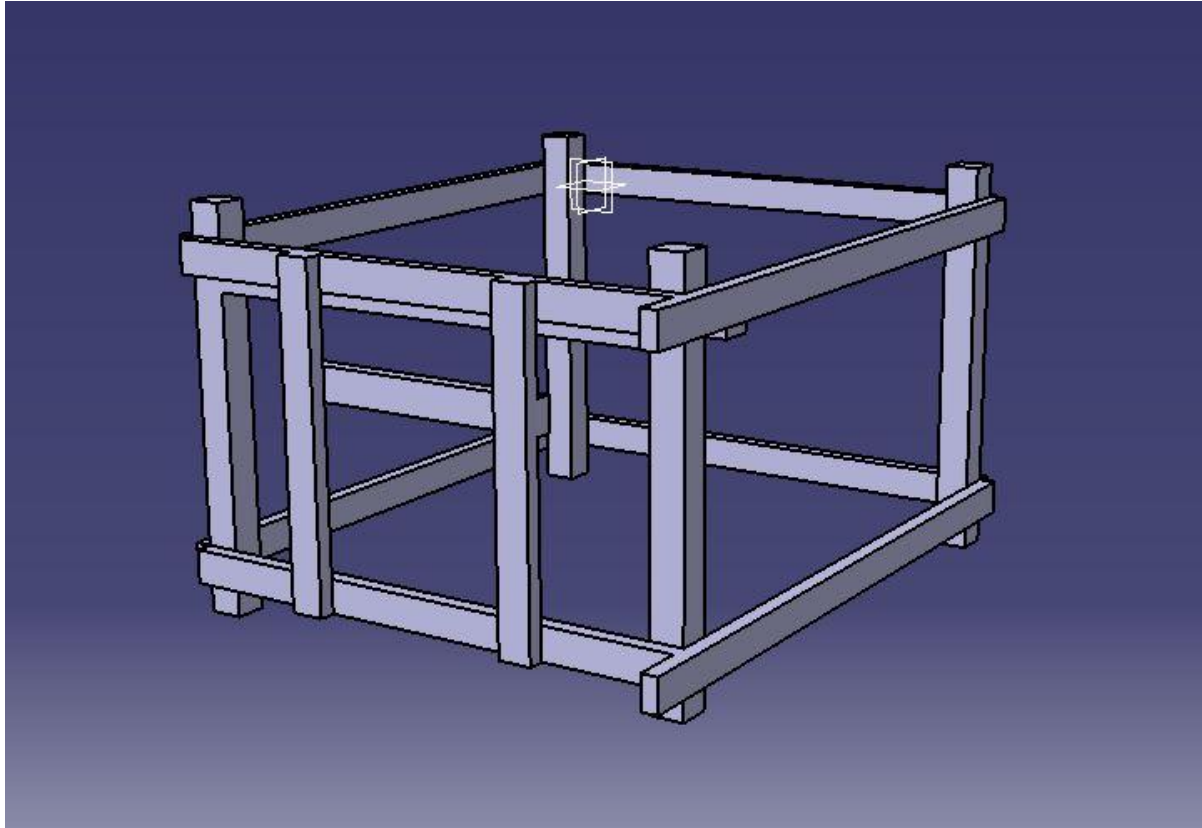


Figure 4.2: The aluminium frame for robustness

A thruster is a must for the navigation of the robot in water. For this purpose, an electric DC motor with 12V rating was used to run a fan attached to its shaft to propel the robot in desired direction. The motor had to be made leak-proof. For this, a plastic covering of suitable size was used for packing the motor. To ensure the leak proof-ness, Silica Gel was used. Caulking gun was used to pour silica Gel on the covering openings. After the Gel became dry, Two wires coming out from the motor were connected to the industrial SMPS for adequate voltage which was checked by micro-meter and the setup was taken to the swimming pool for testing.

The testing was successful and the motor ran successfully without entering of water and the Under-water robot ran successfully in the water. After successful testing, two more motors have been fitted to the robot for the forward, backward and vertical motions respectively.

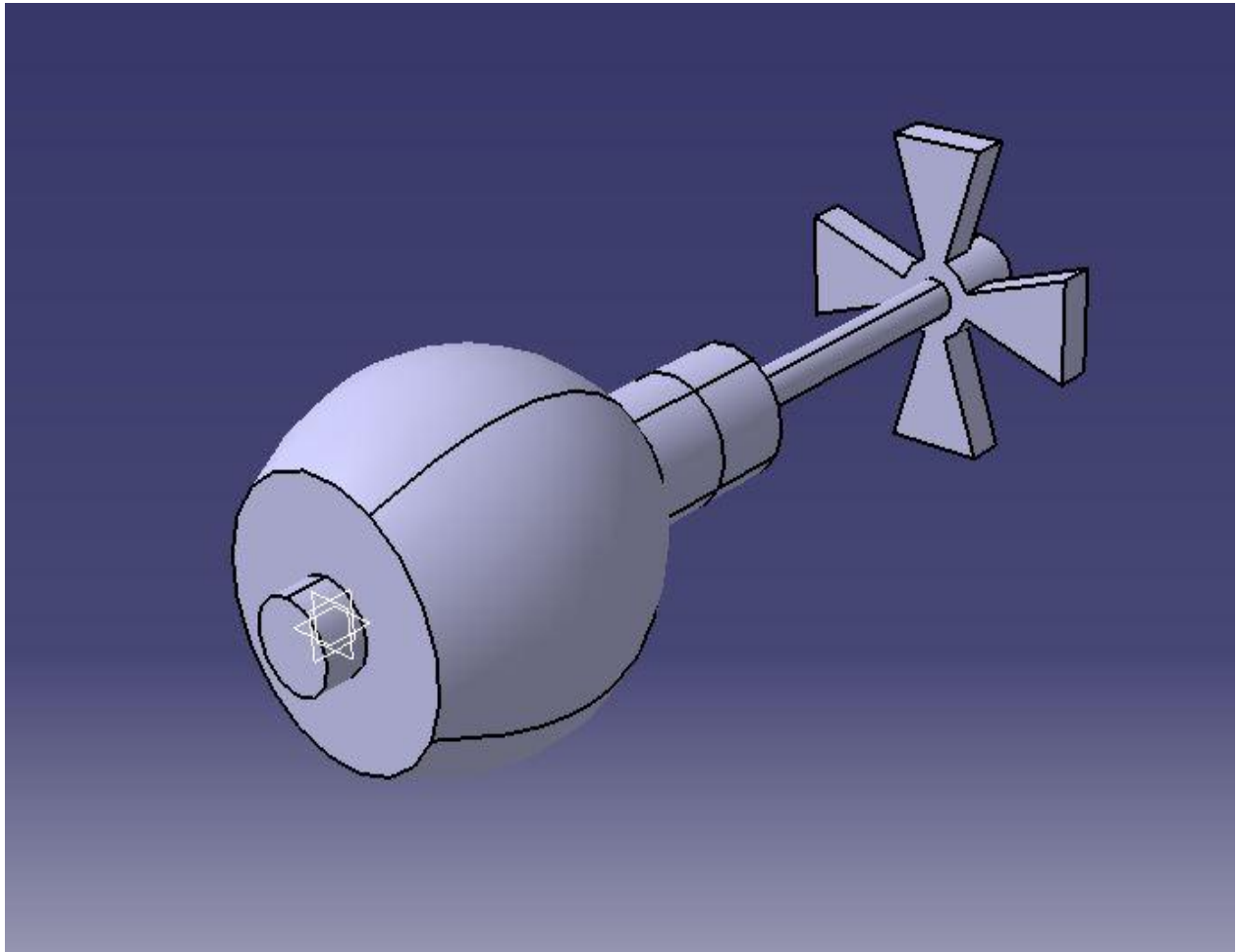


Figure 4.3: CATIA model for Motor

A camera has been installed inside the hollow casing with help of aluminium plates inside the hollow PVC pipe for monitoring of the underwater environment.

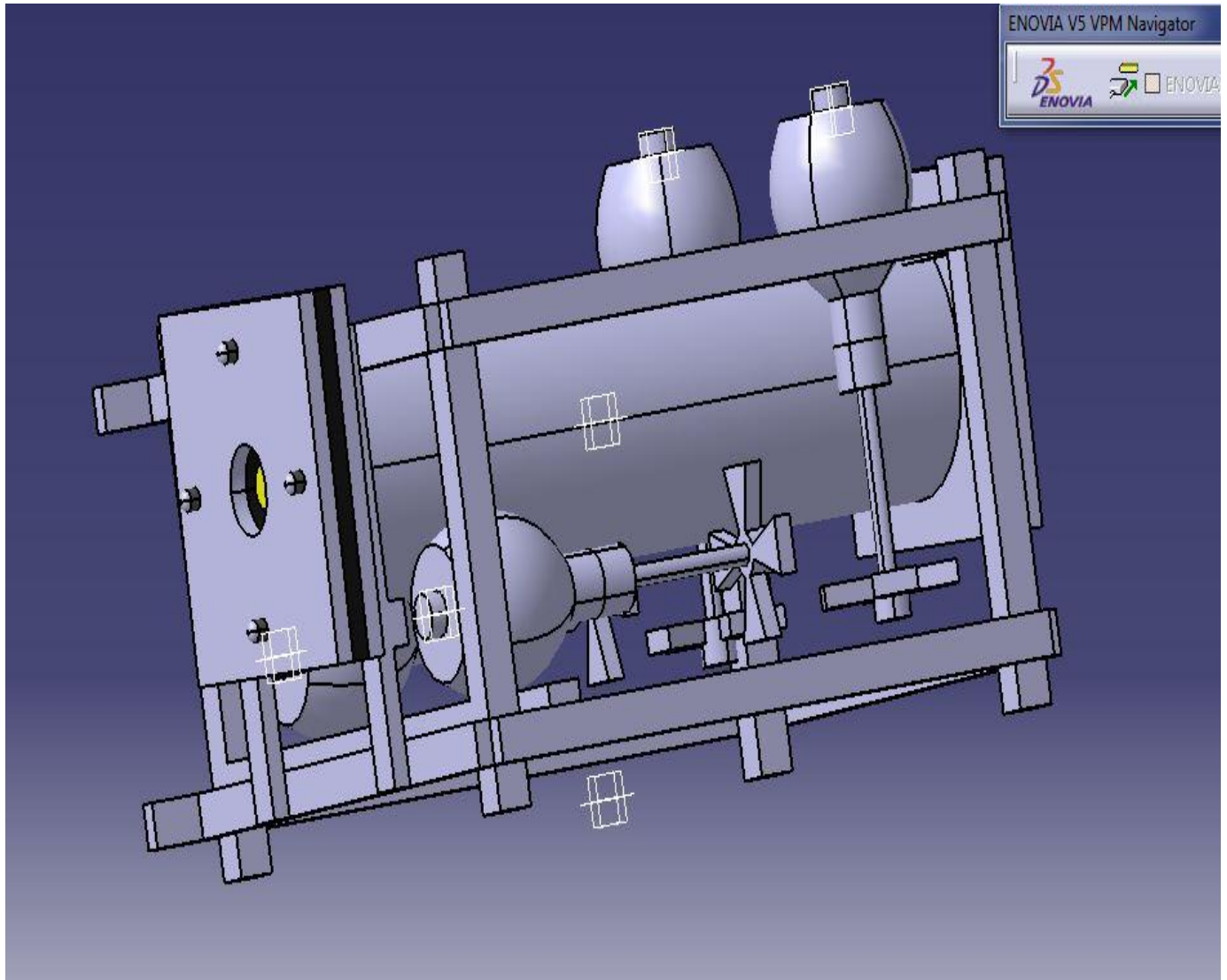


Figure 4.4: CATIA model for the underwater robot

A Sonar sensor has also been fitted with the underwater robot for detecting underwater objects and organisms' distance from the underwater robot while navigating in the underwater environment.

The use of fuzzy logic and fuzzy logic controller for the controlling of motion of the motors of underwater robot is going on this project and is explained with detail in the below section.

5. FUZZY TECHNIQUE FOR NAVIGATION

Instability and uncertainty connected with responsive and reactive routing or navigation for self-governing or autonomous robot or portable systems in obscure or mostly known confused surroundings, particularly, capriciously evolving environment can be disentangled by making coordination and combination of the basic practices or behaviours of portable or mobile robots. The fuzzy method, which is proficient to create acceptable direction and speed or velocity moves of the self-governing robot, is incited here for the robot route or path to achieve its objective securely proceeding onward on obscure static landscapes or terrains. The Fuzzy logic controller, popularly known as FLC, a collective hybrid of distinctive enrolment capacities or membership functions, has been utilized on an exploratory mobile underwater robot which utilizes an arrangement of three multipurpose sensors to see or feel the environment. Activity coordination of the mechanical practices or robotic behaviours, for example, taking after a divider or wall, evading an obstruction and running towards objective or goal, have been achieved utilizing proposed hybridized fuzzy strategy which is found to be capable and part of the way advanced for navigation purpose through many simulations, various experiment and performing various test verifications.

Obstacle Avoidance

The separation between the robots and obstructions go about as appalling strengths for evading the hindrances. At the point when the robot is near to a deterrent, the robot must change its speed and heading angle for staying away from the snag. At the point when the readings from any sensor are not exactly the base edge values, the robot decides an item is close, and after that

obstruction shirking conduct is actuated. Crash evasion has the most elevated need, along these lines, it can override alternate practices.

Wall following behaviour

Without wall following behaviour after conduct in company with snag evasion conduct the robot is incapable of coming to the objective position when it encumbers U moulded or deadlock snags on their way. At the point when the robot is moving to a predetermined focus through a tight channel, or getting away from a U formed obstruction the robot ought to continue heading towards the objective position, however the robot likewise comes closer to the obstructions. At first, robot runs specifically towards focus as snags are detected far from it. Be that as it may, on the off chance that it detects obstructions at the front it will make a left or right swing to evade it.

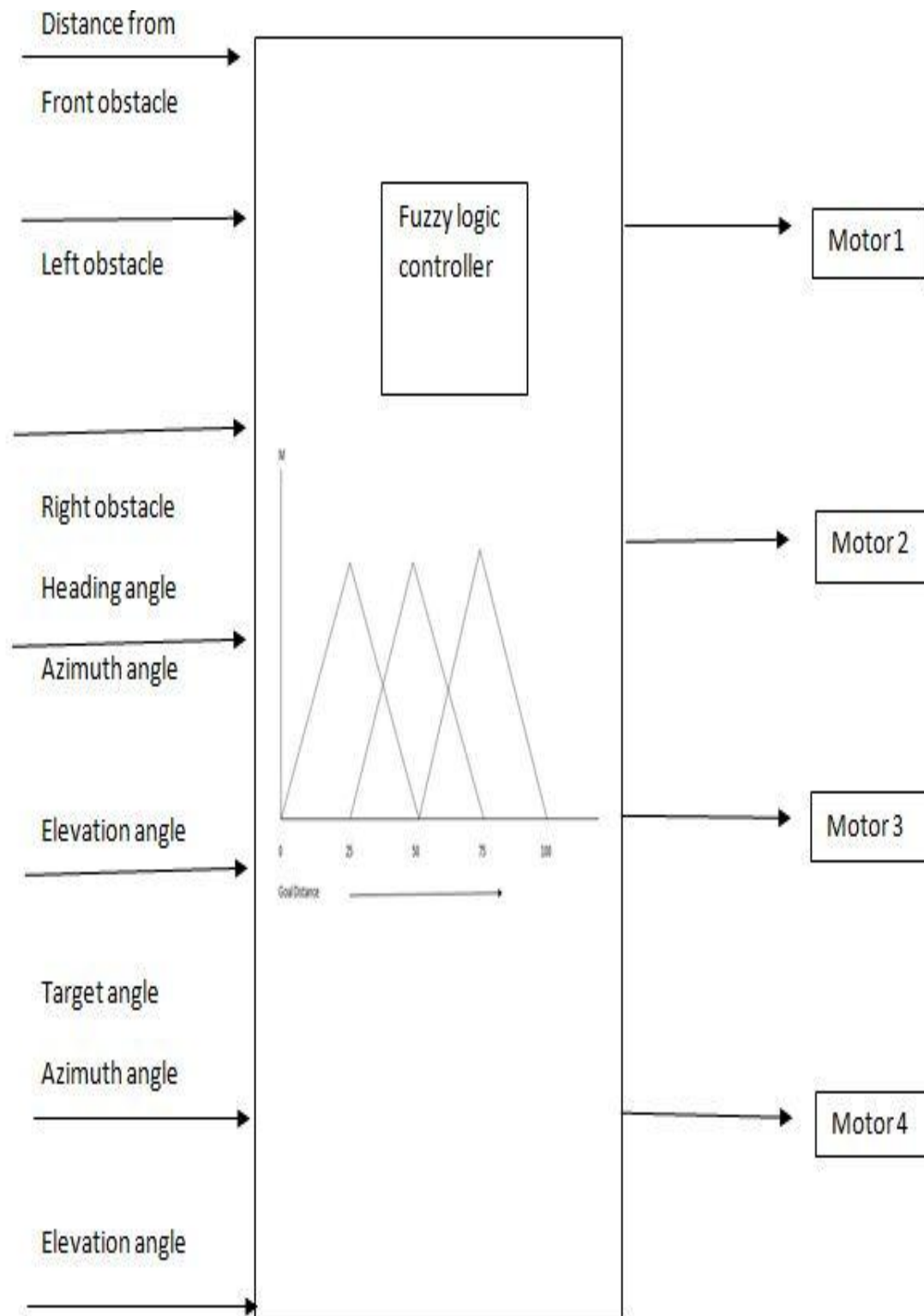


Figure 5.1: Various inputs and outputs have been shown

Various Parameters of fuzzy membership functions:

Table 5.1: Parameters for Obstacle distance

Variables(Membership functions)	Parameters in metres			
Near(Triangular)		0	25	50
Medium(Triangular)		25	50	75
Far(Triangular)		50	75	100

Table 5.2: Parameters for azimuth angle

Variables(Membership functions)	Parameters in degrees		
Negative(Triangular)	-180	-90	0
Zero(Triangular)	-90	0	90
Positive(Triangular)	0	90	180

Table 5.3: Parameters of elevation angle

Variables(Membership functions)	Parameters in degrees		
Negative(Triangular)	-60	-30	0
Zero(Triangular)	-30	0	30
Positive(Triangular)	0	30	60

Table 5.4: Parameters of motors (forward and backward motion)

VARIABLES(MEMBERSHIP FUNCTIONS)	PARAMETERS OF VELOCITY		
SLOW(TRIANGULAR)	0	0.3925	0.785
MEDIUM(TRIANGULAR)	0.3925	0.785	1.1775
FAST(TRIANGULAR)	0.785	1.1775	1.57

Table 5.5: Parameters for motors (for vertical motion)

Variables(membership functions)	Parameters of velocity		
Slow(triangular)	0	0.1425	0.285
Medium(triangular)	0.1425	0.285	0.4275
Fast(triangular)	0.285	0.4275	0.57

Various Graphs for Fuzzy membership functions with the various parameters

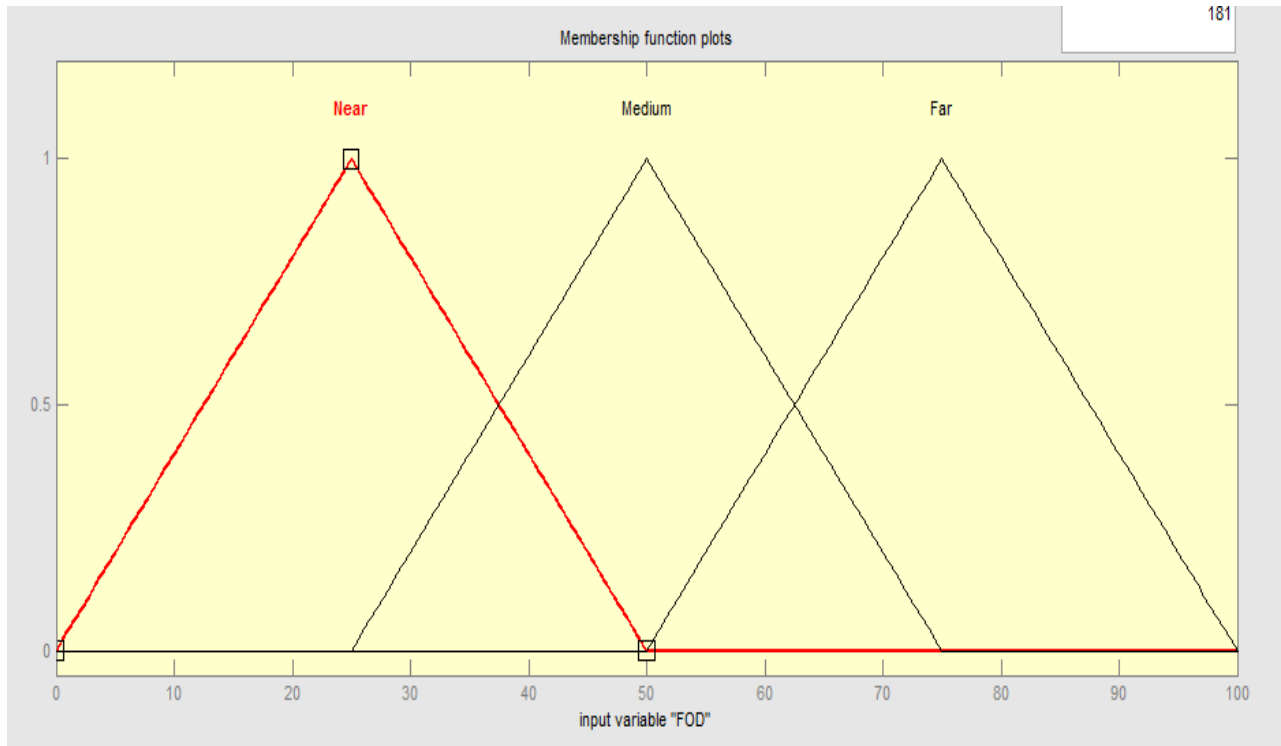


Figure 5.2: Front obstacle distance

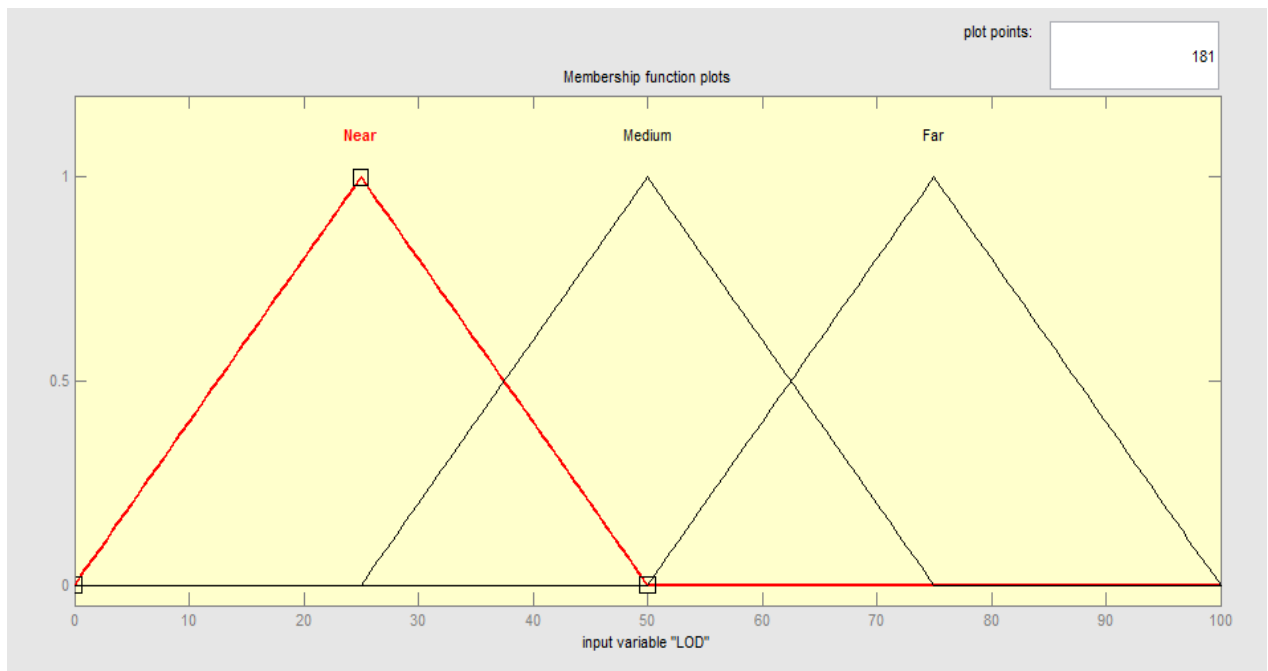


Figure 5.3: Left obstacle distance graph

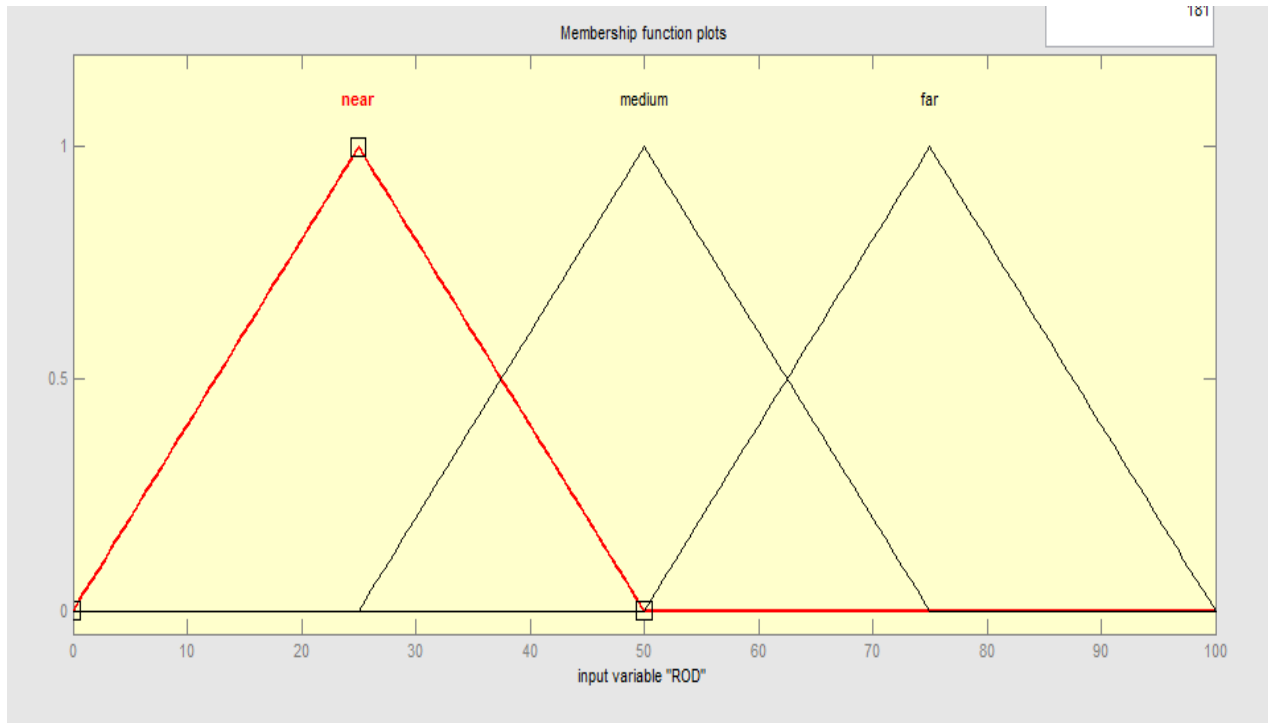


Figure 5.4: Right obstacle distance graph

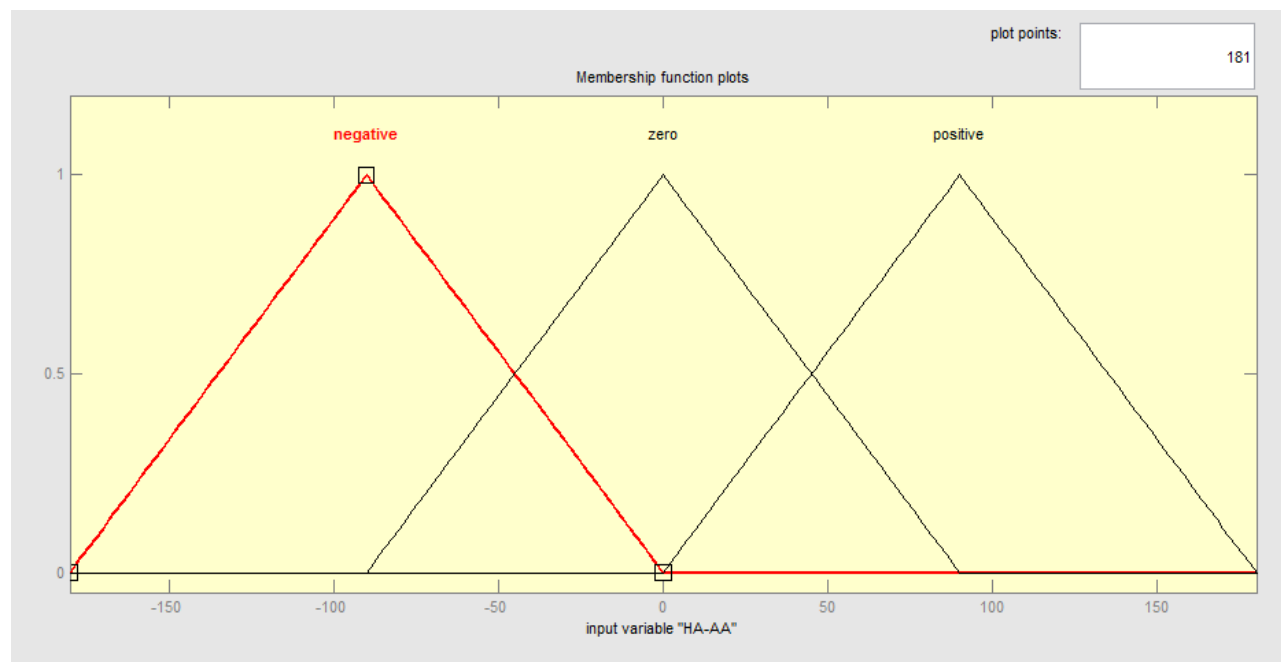


Figure 5.5: Heading Angle-Azimuth angle Graph

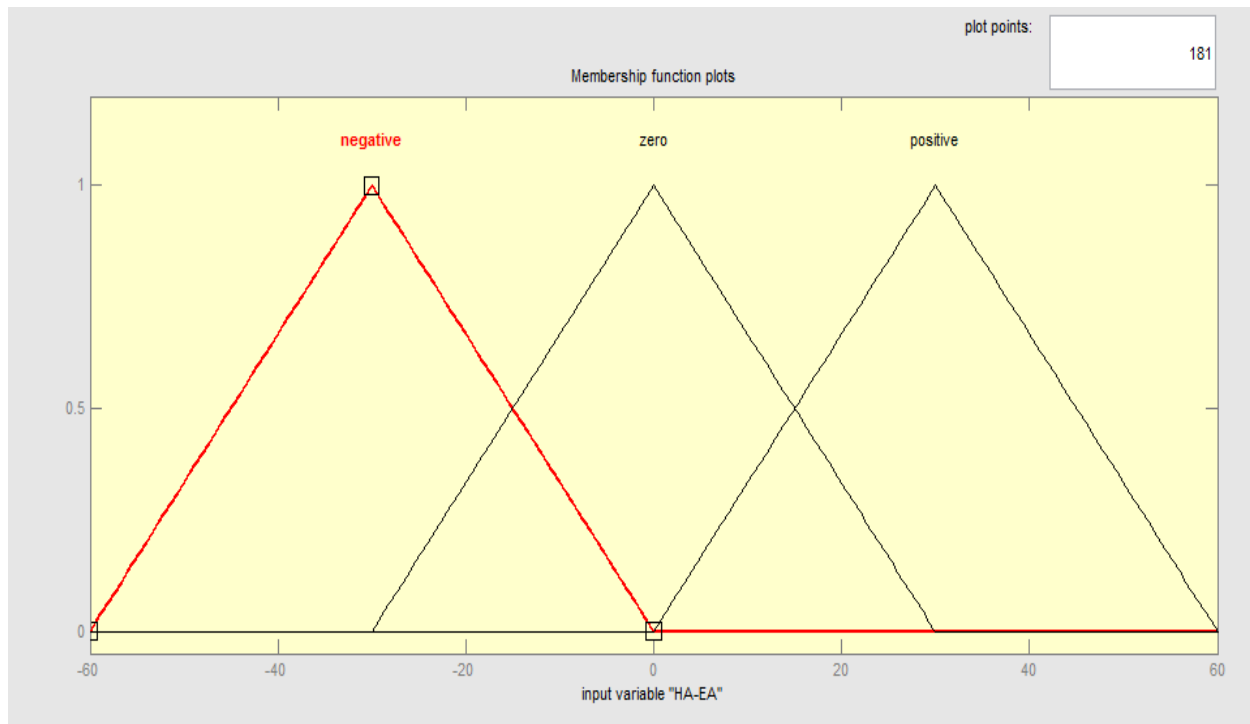


Figure 5.6: Heading angle – Elevation Angle graph

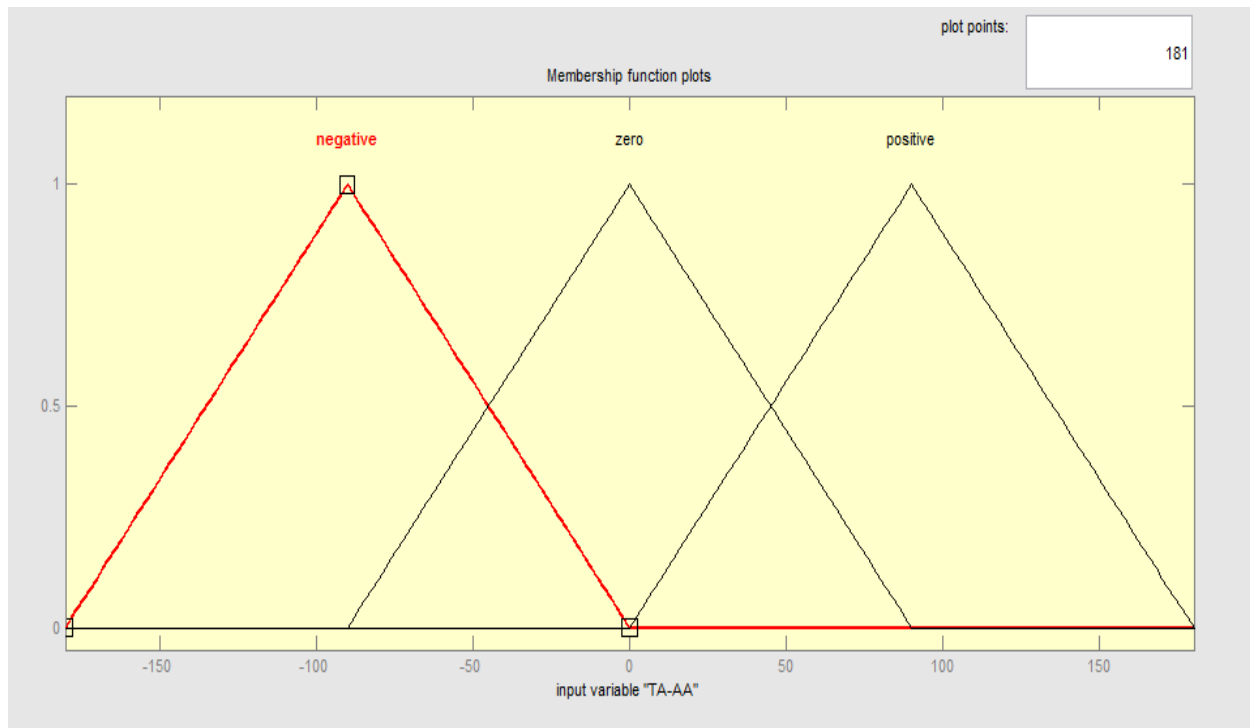


Figure 5.7: Target Angle – Azimuth angle graph

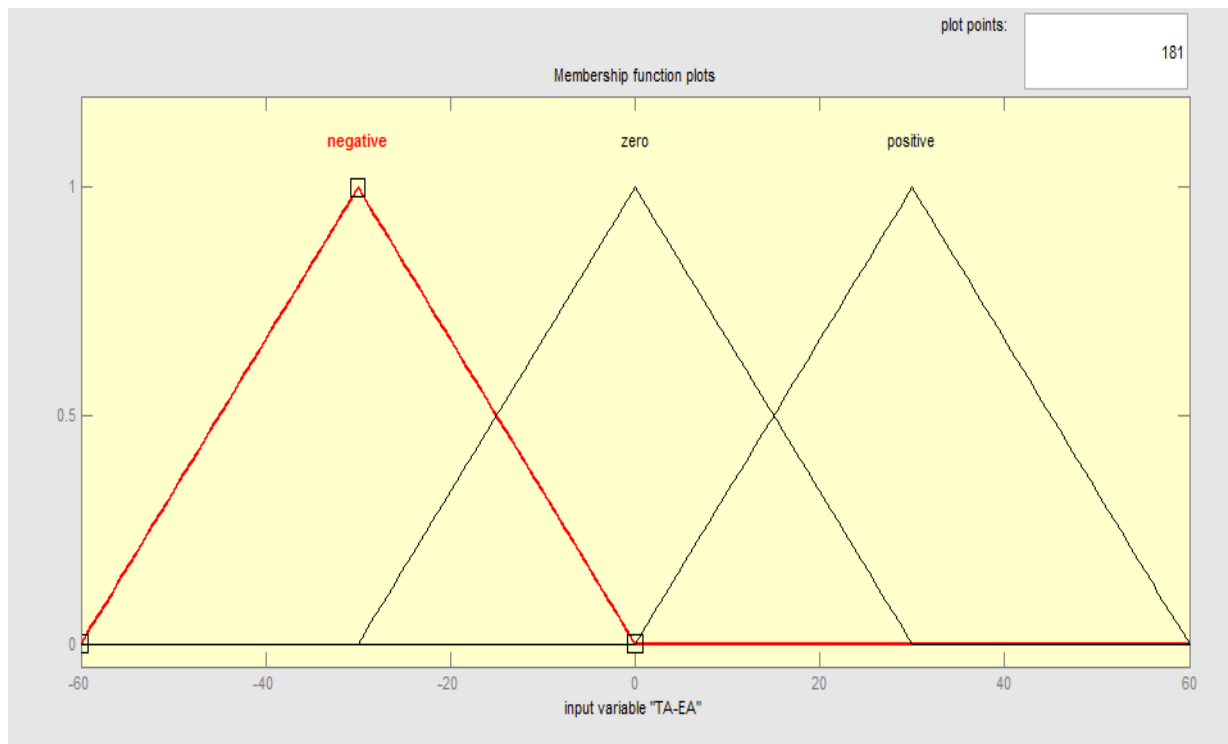


Figure 5.8: Target Angle- Elevation Angle graph

Output Graphs

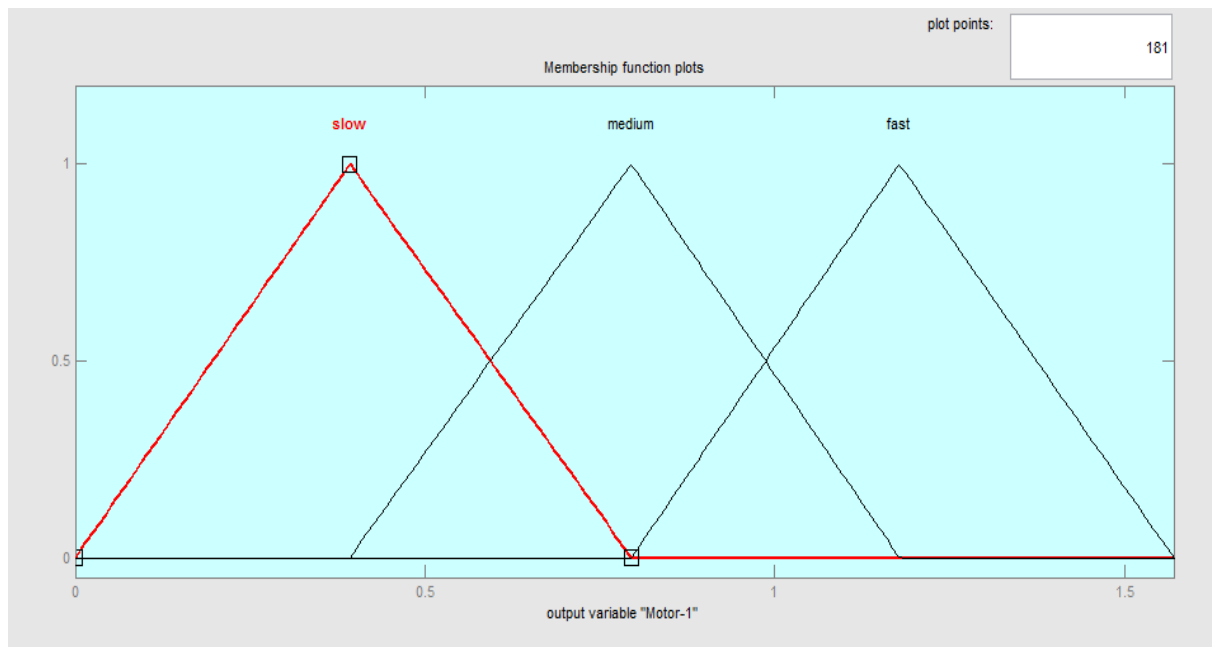


Figure 5.9: Motor 1 Graph

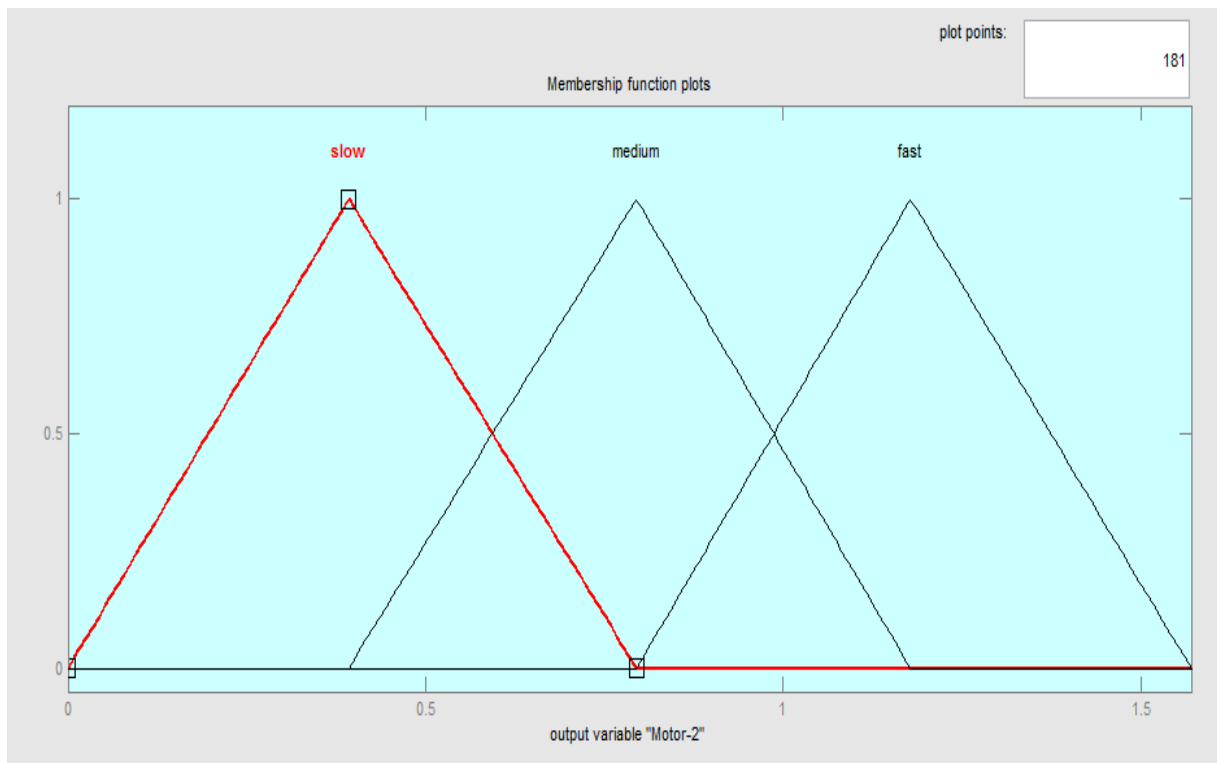


Figure 5.10: Motor 2 Graph

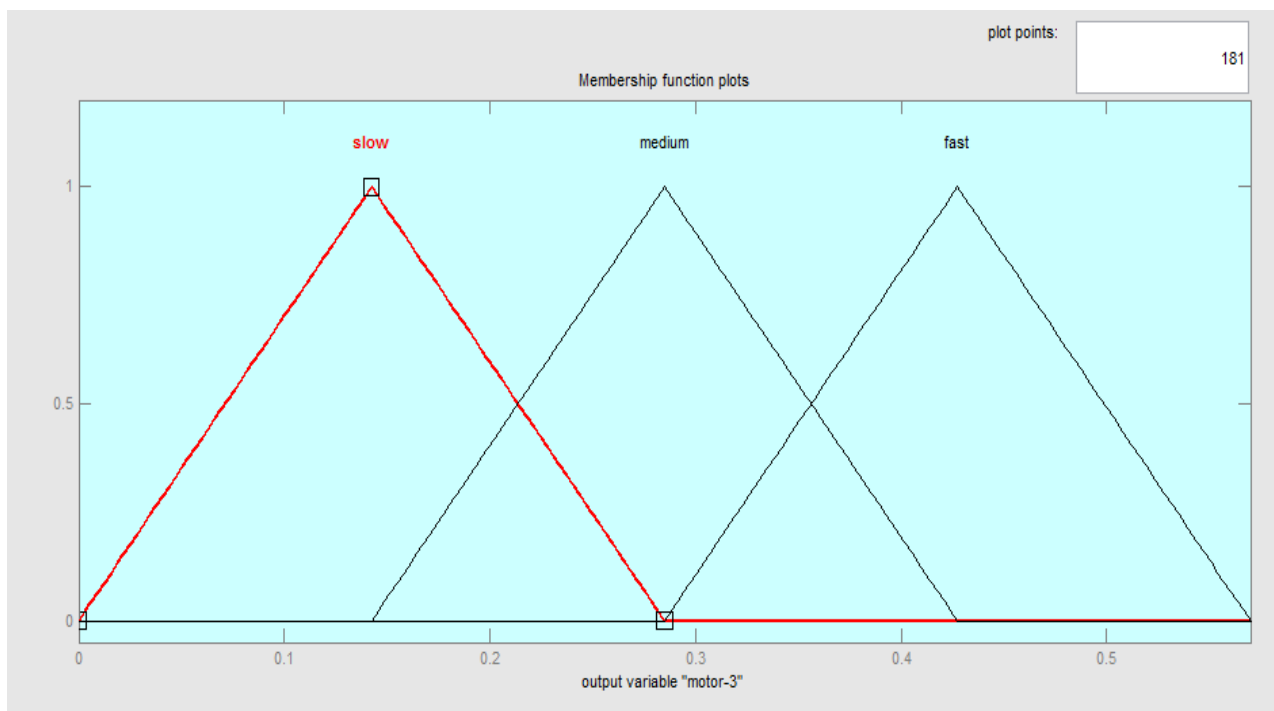


Figure 5.11: Motor 3 Graph

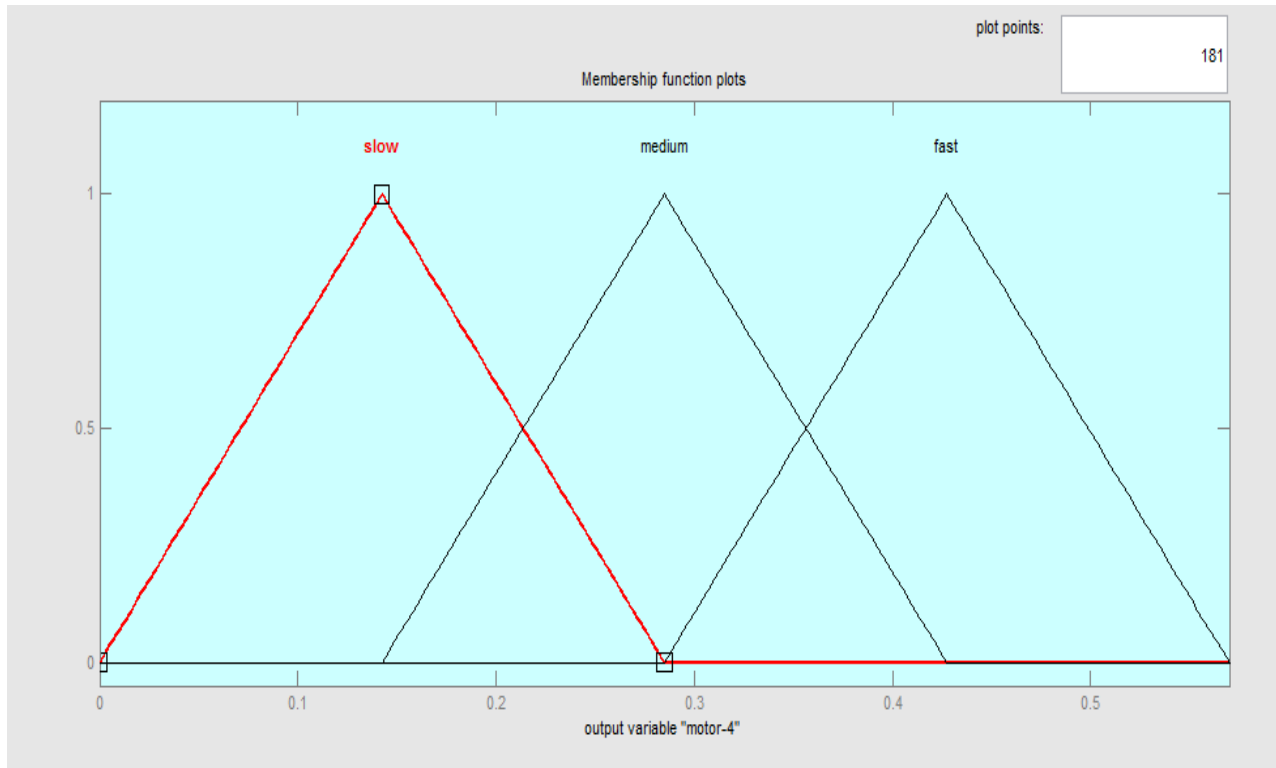


Figure 5.12: Motor 4 Graph

There have been various rules made for fuzzy logic controller:-

1. If FOD is near, LOD is near and ROD is far and HA-AA is positive and HA-EA is zero and TA-AA is zero and TA-EA is zero then Motor 1 is fast and Motor-2 is medium
2. If FOD is near, LOD is medium and ROD is far and HA-AA is positive and HA-EA is zero and TA-AA is zero TA-EA is zero then Motor 1 is fast and Motor-2 is slow
3. If FOD is near, LOD is medium and ROD is far and HA-AA is zero and HA-EA is zero and TA-AA is zero TA-EA is zero then Motor 1 is fast and Motor-2 is slow
4. If FOD is near, LOD is near and ROD is medium and HA-AA is positive and HA-EA is zero and TA-AA is zero TA-EA is zero then Motor 1 is fast and Motor-2 is slow Motor.

5. If FOD is near, LOD is near and ROD is medium and HA-AA is positive and HA-EA is negative and TA-AA is positive TA-EA is zero then Motor 1 is fast and Motor-2 is slow Motor 4 is fast.
6. If FOD is near, LOD is medium and ROD is far and HA-AA is positive and HA-EA is negative and TA-AA is positive TA-EA is zero then Motor 1 is fast and Motor-2 is slow Motor 4 is medium.
7. If FOD is medium, LOD is medium and ROD is far and HA-AA is positive and HA-EA is negative and TA-AA is positive TA-EA is zero then Motor 1 is medium and Motor-2 is slow Motor 4 is medium.
8. If FOD is far, LOD is medium and ROD is far and HA-AA is positive and HA-EA is negative and TA-AA is zero TA-EA is zero then Motor 1 is medium and Motor-2 is slow Motor 4 is fast.
9. If FOD is far, LOD is near and ROD is far and HA-AA is positive and HA-EA is negative and TA-AA is zero TA-EA is zero then Motor 1 is medium and Motor-2 is slow Motor 4 is fast.
10. If FOD is far, LOD is near and ROD is medium and HA-AA is positive and HA-EA is negative and TA-AA is zero TA-EA is zero then Motor 1 is medium and Motor-2 is slow Motor 4 is medium.
11. If FOD is far, LOD is far and ROD is medium and HA-AA is positive and HA-EA is negative and TA-AA is zero TA-EA is zero then Motor 1 is medium and Motor-2 is fast Motor 4 is medium.
12. If FOD is far, LOD is far and ROD is near and HA-AA is positive and HA-EA is negative and TA-AA is zero TA-EA is zero then Motor 1 is slow and Motor-2 is fast Motor 4 is medium.

13. If FOD is near, LOD is medium and ROD is far and HA-AA is positive and HA-EA is negative and TA-AA is positive TA-EA is zero then Motor 1 is fast and Motor-2 is slow Motor 4 is medium.

14. If FOD is medium, LOD is medium and ROD is near and HA-AA is positive and HA-EA is negative and TA-AA is zero TA-EA is zero then Motor 1 is medium and Motor-2 is fast Motor 4 is medium.

15. If FOD is medium, LOD is far and ROD is near and HA-AA is positive and HA-EA is negative and TA-AA is zero TA-EA is zero then Motor 1 is medium and Motor-2 is fast Motor 4 is medium.

16. If FOD is medium, LOD is far and ROD is near and HA-AA is positive and HA-EA is positive and TA-AA is zero TA-EA is zero then Motor 1 is medium and Motor-2 is fast Motor 3 is fast.

6. RESULT AND DISCUSSION

The setup was checked for its water-proof ability by drowning it in the swimming pool upto 7ft depth for a considerable time of around 30 minutes. The setup of hull had no leakage and hence fabrication of hull was successful. The setup was taken to the swimming pool for testing. The testing was successful and the motor ran successfully without entering of water and the Under-water robot ran successfully in the water. After successful testing, two more motors have been fitted to the robot for the forward, backward and vertical motions respectively.

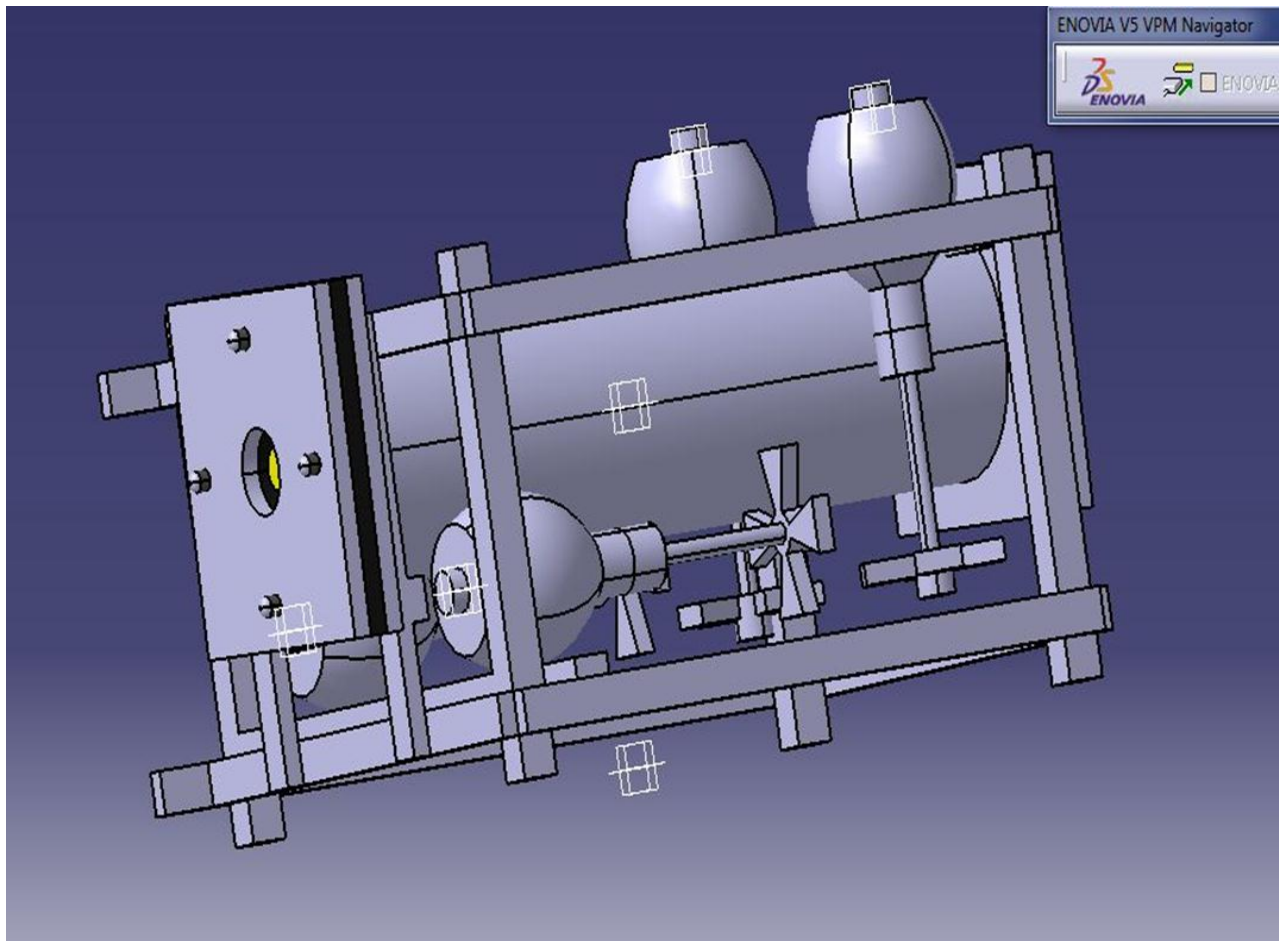


Figure 6.1: The fabricated underwater robot giving the CAD view of the robot made in the laboratory.

The values of the fuzzy have been like- If the front obstacle distance is 39.6 and the left obstacle distance is 34.9 and the ROD is 60.4 and the Heading angle azimuth angle is 44.4 and Heading angle elevation angle is 12.5 and Target angle AA is -29.6 and Target angle EA is 18.1 then the motor 1 has speed 1.18 motor 2 has speed 0.59 motor 3 has speed 0.285 and motor 4 has speed 0.286. The results of the Fuzzy Logic Controller are:-



Figure 6.2: Image of fuzzy Logic Controller results i.e. defuzzification

Table 6.1: Comparison of various Experimental and Simulation results

Scenarios	Simulation path length	Experimental Path length	Error in %	Time taken in Experiment	Time taken for Experiment	Error in %
1	795.2	832	4.4	18.2	19.0	4.5
2	725.4	760	4.6	16.6	17.4	4.6
3	756.6	790	4.3	17.2	18.1	4.25
4	843.4	882	4.8	19.2	20.2	4.85
5	822.2	861	4.5	18.8	19.7	4.5
6	799.1	840	4.9	18.3	19.2	4.8
7	781	820	4.7	17.9	18.8	4.6

Various factors like hydrodynamic damping, stability are still there which are being sorted out with the help of gyro sensors and many other sensors. The fitting of various sensors for example pressure sensors, sonar sensors etc. is the future plan of work on this project in the upcoming months.

7. CONCLUSION

Thus an underwater robot with a new design and new of its kind is made, with multi Degrees of freedom, whose control of motors is being done with the help of fuzzy membership functions and Fuzzy logic and with the help of Fuzzy Logic Controller by keeping motors speed as required.

Table 7.1: The specifications of the developed Underwater Robot

Part	Specifications
Acrylic Sheet	110 mm
Rubber Pads	
Width	7 mm
Side Length	110 mm
Hull length	90 cm
Weight of Robot	8 kg (approx.)
Hull Material	PVC
Supporting Frame	Aluminium
Motor	DC Starting motor With high torque and RPM of 5000 rpm

8. REFERENCES

1. Louis Andrew Gonzalez ,Design, modelling and control of an autonomous underwater vehicle, Bachelor of Engineering Honours Thesis 2004 School of Electrical, Electronic and Computer Engineering, University of Western Australia.
2. T.W. Kim, J. Yuh , Development of a real-time control architecture for a semi-autonomous underwater vehicle for intervention missions Autonomous Systems Laboratory, Control Engineering Practice , Volume 12 , 2004 pp. 1521–153
3. WEI Qing-Ping, Shuo WANG, Xiang DONG, Liu-Ji SHANG, Min TAN , Design and Kinetic Analysis of a Biomimetic Underwater Vehicle with Two Undulating Long-fins, Acta Automatica Sinica, Volume 39 (8), 2013, pp. 1330-1338
4. Khairul Alam, Tapabrata Ray, Sreenatha G. Anavatti , Design and construction of an autonomous underwater vehicle, Neurocomputing, Volume 142, 2012, pp. 16-29
5. Myeong-Jo Son, Tae-wan Kim, Torpedo evasion simulation of underwater vehicle using fuzzy-logic-based tactical decision making in script tactics manager, Expert Systems with Applications, Vol.39 (9) 2012, pp. 7995-8012
6. Nur Afande Ali Hussain, Mohd Rizal Arshad, Rosmiwati Mohd-Mokhtar, Underwater glider modelling and analysis for net buoyancy, depth and pitch angle control Ocean Engineering, Volume 38(16), 2011, pp. 1782-85
7. K. Ishaque, S.S. Abdullah, S.M. Ayob, Z. Salam, A simplified approach to design fuzzy logic controller for an underwater vehicle Ocean Engineering, Volume 38(1), 2011, Pp. 271-284

8. Q. Cai, D.J.L. Brett, D. Browning, N.P. Brandon, A sizing-design methodology for hybrid fuel cell power systems and its application to an unmanned underwater vehicle, *Journal of Power Sources*, Volume 195(19), 2010, pp. 6559-6569
9. Rajesh Kalavalapally, Ravi Penmetsa, Ramana Grandhi, Configuration design of a lightweight torpedo subjected to an underwater explosion, *International Journal of Impact Engineering*, Volume 36(2), 2009, pp. 343-351
10. Wallace M. Bessa, Max S. Dutra, Edwin Kreuzer, Depth control of remotely operated underwater vehicles using an adaptive fuzzy sliding mode controller, *Robotics and Autonomous Systems*, Volume 56 (8), 31, 2008, pp. 670-677
11. Robert D. Christ, Robert L. Wernli Sr Chapter 2 - ROV Design the ROV Manual, 2007, pp. 11-45
12. Carl T.F. Ross, A conceptual design of an underwater vehicle *Ocean Engineering*, Volume 33(16) 2006, pp.. 2087-2104
13. Ian F. Akyildiz, Dario Pompili, Tommaso Melodia

, Underwater acoustic sensor networks: research challenges *Ad Hoc Networks*, Volume 3(3), 2005, pp. 257-279
14. C. A. Woolsey, N. E. Leonard, Stabilizing underwater vehicle motion using internal rotors, *Automatica*, Volume 38(12), 2002, pp. 2053-2062
15. Fernando Lobo Pereira, Control Design for Autonomous Vehicles: A Dynamic Optimization Perspective, *European Journal of Control*, Volume 7 (2–3), 2001, pp. 178-202

16. Masahiko Nakamura, Hiroyuki Kajiwaru, Wataru Koterayama, development of an ROV operated both as towed and self-propulsive vehicle, *Ocean Engineering*, Volume 28(1), 2001, pp. 1-43
17. Ravi Vaidyanathan, Hillel J Chiel, Roger D Quinn A hydrostatic robot for marine applications, *Robotics and Autonomous Systems*, Volume 30(1-2), 2000, pp. 103-113
18. J Amat, A Monferrer, J Batlle, X Cufí, GARBI: a low-cost underwater vehicle, *Microprocessors and Microsystems*, Volume 23(2) 1999, pp. 61-67

9. Publications

1. Published a paper entitled “Autonomous navigation of Underwater Robot using Harmony Search Optimization” in IEEE International Conference at IIT Bombay in December 2014.
2. Corresponded the paper “Design and Analysis of Underwater Robot” to International journal of artificial intelligence and computational Research (IJACR).