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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

DESIGN AND DEVELOPMENT OF SUBMERSIBLE DRONE FOR UNDERWATER IMAGING

A Project Report

Submitted by,

Anubhav Mukherjee	**1RV14EE007**
Dayashankar N P	**1RV16EE019**
Dattatraya kathare	**1RV17EE401**
Yashas B K	**1RV17EE412**

Under the guidance of
Guide
Dr. A. Sreedevi
Associate Professor
Department of EEE
RV College of Engineering ®

In partial fulfilment for the award of degree

of

Bachelor of Engineering

in

Electrical and Electronics Engineering

2019-2020

RV COLLEGE OF ENGINEERING®, BENGALURU-59

(Autonomous Institution Affiliated to VTU, Belagavi)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

CERTIFICATE

Certified that the major project work titled ***'Design and Development of Submersible Drone for Underwater Imaging,*** carried out by **Anubhav Mukherjee (1RV14EE007),Dayashankar N P (1RV16EE019),Dattatraya Kathare (1RV17EE401) and Yashas B K (1RV17EE412)** the bonafide students of RV College of Engineering®, Bengaluru, submitted in partial fulfilment for the award of degree of **Bachelor of Engineering in Electrical and Electronics Engineering** of the Visvesvaraya Technological University, Belagavi, during the year 2019-2020. It is certified that all corrections/suggestions indicated for the Internal Assessment have been incorporated in the major project report deposited in the departmental library. The major project report has been approved as it satisfies the academic requirements in respect of major project work prescribed by the institution for the said degree.

Signature of Guide	Signature of Head of the Department	Signature of Principal
Dr. A. Sreedevi	**Dr. Rudranna Nandihalli**	**Dr. K N Subramanya**

External Viva

Name of Examiners	Signature with Date
1	
2	

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DECLARATION

We, Anubhav Mukherjee (1RV14EE007),Dayashankar N P (1RV16EE019),Dattatraya Kathare (1RV17EE401) and Yashas B K (1RV17EE412) students of eighth semester B.E., Electrical and Electronics Engineering, RV College of Engineering®, Bengaluru, hereby declare that the major project titled **'Design and Development of Submersible Drone for Underwater Imaging'** has been carried out by us and submitted in partial fulfilment for the award of degree of **Bachelor of Engineering** in Electrical and Electronics Engineering during the year 2019-20.

Further, we declare that the content of the dissertation has not been submitted previously by anybody for the award of any degree or diploma to any other university.

We also declare that any Intellectual Property Rights generated out of this major project carried out at RVCE will be the property of RV College of Engineering®, Bengaluru and we will be one of the authors of the same.

Place: Bengaluru

Date:

Name		**Signature**
1. Anubhav Mukherjee	(1RV14EE007)	
2. Dayashankar N P	(1RV16EE019)	
3. Dattatraya Kathare	(1RV17EE401)	
4. Yashas B K	(1RV17EE412)	

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ABSTRACT

Today most of the marine life is in danger. Pollution is on the rise day after day. A good part of our water body is polluted with waste. Most small fishes make use of corals as its habitat. Active monitoring of aquatic life is imperative in tackling this predicament. Corals are dying all over the world because of coral mining, climate change, and other human violent acts. Most of accessible ROV (remote-controlled vehicle) are of a vertical propeller type that uses the second propeller for the sole purpose of retaining distance. Such ROVs are ballast-free and the lack of ballasts significantly restricts the air tight payload capability as buoyancy is a property of continuous power in such systems. However, once the necessary buoyancy is reached, the usage of ballast tanks will adjust and maintain the buoyancy passively without using any further strength. Enabling a greater weight to be transported without compromising any capacity for long term underwater hovering.

Submersible drone was designed and developed to detect and classify different types of corals. A desktop app was developed to display the submersible drone's field of view and to s end thecontrol signal through Tx module to the Submersible drone. The Rx module receives c ontrol signals in the form of RF waves that are sent by the Tx module. Rx module converts RF waves to corresponding signals and transmits them through Raspberry Pi to the Dive controller. To control yaw, pitch, depth and forward movement of the submersible drone, heading control and depth control is enabled upon identification of the specific signal propulsion power. The camera connected to Raspberry pi transmits the live video to a laptop for navigation. Another camera was used to store the video of underwater view, and is then processed in a powerful computer to segment two types of corals. Submersible drone was built by using 3D printing technology incorporating all the control systems in it. Depth control was achieved by using Archimedes principle of buoyancy.

Desktop application was built using Qtcreator to control the drone remotely. Ballast was able to withstand 50 psi pressure. Overall weight of the submersible drone is ~14kg. Deep learning algorithm is implemented by keras segmentation model using unet architecture in google colabs platform. 300 images were used for training the keras segmentation model. Accuracy obtained during detection was 90 percent.

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ACRONYMS

AUSV	Autonomous Unmanned Surface Vessel
BLDC	Brushless Direct Current Motor
CNN	Convolutional Neural Network
CSI	Camera Serial Interface
ESC	Electronic Speed Control
FoV	Field of View
FPV	First Person View
GPS	Global Positioning System
HOG	Histogram of Orientated Gradients
IMU	Inertial Measurement Unit
MC	Main Controller
MIPS	Million Instruction / Second)
ML	Machine Learning
NSL	Neural Structured Learning
OS	Operating System
PCI	Peripheral Component Interconnect
PCB	Printed Circuit Board
PLA	Polylactic acid
PSRR	Power Supply Rejection Ratio
PWM	Pulse Width Modulation
ROI	Region Of Interest
ROV	Remotely Operated Vehicle
RPM	Rotation Per Minute

SBCs	Single Board Computers
SC	Sub Controller
SLA	Stereolithography
SST	Sea Surface Temperature
TC	Thrust Controller
TF	TensorFlow
UART	Universal Asynchronous Receiver-Transmitter
USB	Universal Serial Bus

CHAPTER 1

INTRODUCTION

CHAPTER 1
INTRODUCTION

The corals are biological creatures that setup along the coastal areas and they have evolved millions of years to attain the current state. Corals are important for the marine environment. Thus, upholding the health of the corals is very much needed. Climate variations, pathogen factors, oil pollution and urban wastewater resulted to problems such as black band, white band and yellow band diseases in the corals. Each of these diseases changes the color and tip to the death of corals. Quick detection of these diseases avoids its development and help to reduce the death of corals. For the past ten years coral reef ecosystems of globe has downgraded [1]. The key factor for the extinction of reefs is coral Bleaching. The life of small fishes in marine system is dependent on the corals. To protect the ecosystem of coral reefs a recent study suggests the regular or periodic monitoring of coral reefs [2].

Coral reefs are bleached due to chemical reaction of algae [3]-[4]. The implementation of satellite remote sensing is one of the ways to obtain approximate views of the worldwide oceans in real-time. Thus, to obtain prior alerts on the coral bleaching, the night Sea Surface Temperature (SST) is a important data to measure the thermal condition and level of the bleaching. There are numerous remote sensing satellites going round the globe. These satellites are built to be responsible for SST information for both day and night [5]-[9].

To classify the corals, the Convolutional Neural Network [CNN] is incorporated [10]. A dataset of corals is stored for the study of biological conditions. An algorithm is proposed to classify the corals according to sizes, shape and biological conditions [11]-[12]. The submersible drone is designed and developed to overcome the hindrances of present technology. The novelty of the design is development of Ballast Tank that maintains the submersible drone at one level utilizing the pressure of water. The drone is equipped with all the cameras and sensor to capture the data of coral. The drone is controlled by developed windows application [13].
The loophole of the present existing technology is that they have a propeller equipped with them. The propeller consumes more battery.

1.1 Literature Survey

This research presented a coral classification for initial discovery of unhealthy and dying corals. For classification of the corals, the convolutional neural network was used. A dataset of corals from the Persian Gulf is collected for assessment [1].

The coral reefs are enormous biological set up in the coastal Worldwide coral reef ecosystems is degrading largely that alarms the threat on the vital coral ecosystems. Coral bleaching is significant contributors to the increased Deterioration of reef health. Coral bleaching is activated and persisted during various Environmental stresses. Lengthy part/total bleaching events on coral neighborhoods results coral deaths. There is a strong need for improved understanding, monitoring, and prediction of coral bleaching. The application of satellite remote sensing is the important tools to provide synoptic views of the global oceans in near-real-time and the ability to monitor global reef areas. Therefore, to provide early warnings on the coral bleaching, the nocturnal Sea Surface Temperature (SST) is an important parameter to assess the thermal conditions and intensity of the bleaching [2].

Traditionally the Corals are monitored through the image processing technique. Underwater images still suffer from many drawbacks and the study on this topic is going on. The effort is achieved on segmentation. The original canny edge detector is modified. To extract the features blob extraction process is used. The results are promising with efficiency and reliability of 96% and 88% respectively [3].

Battery is needed for all the underwater vehicles. The main problem of battery in underwater vehicle is that they operate at high pressure and the temperature i.e. $<5\ ^0$C at that point chemical reactions won't take place leading to power outage. Battery rating decides the size and the range of the drone. The authors have presented a high-density battery pack and its enclosures. Batteries are enclosed with oil to handle the sea pressure. It is called oil compensated method and is incorporated in all the packs. They have pointed and worked only on battery packs for submersible or underwater vehicles [4].

Camera is one of the important sensors, there are many problems attached to available sensor. A light characteristic in water and biological movement makes the image scatter or noisy many times. This paper aims to review the state-of-the-art techniques in underwater image processing by highlighting the contributions and challenges presented in over 40 papers [5].

This research discusses about developing unmanned small scaled underwater drone. The drone is tested for twin-rotor on aerial based with all yaws and pitch control. The drone is built for underwater capabilities. The design is achieved on windows platform SolidWorks. The propulsion is based on a single BLDC motor. The mechanism is controlled by joystick. The mechanism is tested for thrust movement for different pressure [6].

This research explains Archimedes principle for submersible drones. A submarine is an underground platform of watercraft for self-governing operation under water. In order to exceed under water it is designed to overcome ground laws specially Archimedes principle considering its flexible and economic structure and propulsion systems design. The focal determination of this investigation is to design and fabricate a prototype submarine The proposed model is an economic innovative design to ensure canny structure, propulsion, diving system and efficient power system has focused in the implemented prototype. To submerge hydrostatically this research on designing basically implies Archimedes principle and buoyancy force shows that negative buoyancy is exerted either by increasing its own weight or decreasing its displacement of water [7].

The available UUV's are not economical and have limited abilities. This research provided an idea for designing small UUV for environment investigation, navigation and control. This is also used to target tracking under water of small lakes and rivers. The designed electrical and mechanical systems are modular. Small size and light weight have provided the drone perfect mobility. The buoyancy and gravity of the SUUV is calculated to keep the drone stable. Simulation results based on ProE platform showed that the SUUV meets the target design and meets the standard [8].

The study of submarine control design under the frame work of Individual Channel Design is presented. The drone is adhered to 80 meters British standard. The assumption of authors is that the drone is designed to operate at low peptic conditions The ICD outline multivariable control design of submarines is solved, in an effective and clear manner, by utilising conventional methods such as Nyquist and Bode plots. The outline of this work is testing of diagonal controllers. The features of the clarification to the control problem are dogged by the multivariable structure function rose from the definition of the input-output channels. Earlier designs based on diagonal controllers deliberated the input-output channel defined by paring the bow hydroplanes with depth and stern hydroplanes with pitch angle [9].

This research discusses about Bathymetric data. These data are fundamental for navigational chart and 3D sea models. It is collected from different techniques and sensors on various platforms such as satellite, aircraft, and drone. The Micro VEGA drone is an Open Prototype of Autonomous Unmanned Surface Vessel (AUSV) is designed for coastal regions with depth of 20meters. It is equipped with a series of sensors to acquire the morpho-bathymetric high precision data. This survey is a distinctive submission case of this technology; the Open Prototype Micro Vega has an interdisciplinary breath and it is going to be applied to various research fields. In future, it will expect to do new knowledge, new survey strategies and an industrial prototype in fiberglass [10].

This research discusses the design overview and usage of Autonomous underwater vehicle. The earth is 70% of water and 30% of land. To discover the 70% of underwater an unmanned vehicle is necessary. The design overview for Autonomous Unmanned vehicle along with the drawbacks of the vehicle is presented [11].

This research provides the need and development of Autonomous Unmanned vehicles. The research on this field is popular now a days. In this paper the authors have developed a model design for propulsion system and summarized the developments and improvements in this particular field of interest [12].

This study explains the impact of Propulsion Drivers used for the Drones. The propulsion system affects directly the stability of AUV at depth of ocean. The design is presented based on the three-dimensional flow around the vehicle and the lifting line theory of propeller action. Deviation of the axial distance between the propeller and stator and the number of the stator blades on the propulsor characteristics are studied. The main key factors that are considered in this work is torque balance and efficiency [13].

1.2 Motivation

Most RoV (Remotely operated Vehicle) are of vertical propeller type. As the submersible drones that are available in the market are provided with a separate propeller for maintaining the altitude. These RoV’s consume more power, hence leading to the problems like less operating time, noise, and threat to small underwater species.

1.3 Problem Statement

To overcome all the problems stated above, this project was aimed to design, fabricate, and test a wirelessly controlled submersible vehicle for real time underwater imaging of aquatic life. The use of ballast tanks changes and hold the buoyancy passively. The ballast tanks are designed to use power only to achieve the required buoyancy. Therefore, allowing for a larger payload to be carried without losing any power for underwater hovering for long duration

1.4 Objectives

The objectives of the project are as follows

- Development of submersible drone.
- Design and implementation of controller for propulsion.
- Design and implementation of heading and depth controller.
- Design and integration of drive system for motor.
- Development and implementation of image processing system.

1.5 Methodology

The Methodology of the project is shown in Figure 1.1.

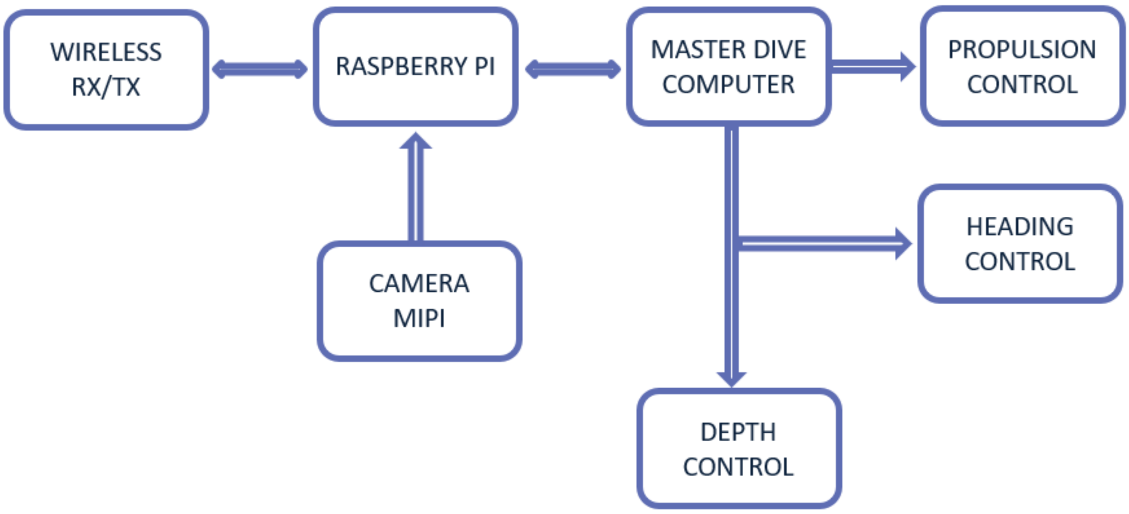

Figure 1.1. Methodology

Submersible drone is controlled by the control signals in the form of RF waves received by the Rx module. Rx module converts RF waves to corresponding signals and send them to the Dive controller through Raspberry Pi. Upon detecting the particular signal propulsion control, heading control and depth control is activated to control yaw, pitch, depth and forward movement of the submersible drone. Camera connected to the Raspberry pi transmits the live video to the laptop for navigation. Another camera stores the video and is processed later to segment two types of corals in a powerful computing machine.

1.6 Organization of Report

The major project report has been organized as follows:

Chapter 1: Consists of introduction, literature survey, objectives of the project, layout of the project and methodology.

Chapter 2: Discusses the fundamentals and theory behind the modelling of the Submersible drone, it also explains the properties of submersible drone.

Chapter 3: Provides the detailed explanation of the design and various components of the Submersible drone.

Chapter 4: Explores into the implementation of the design in the Solidworks and proteus software. The detailed explanation of the components is provided as well.

Chapter 5: Provides the results of the project and the explanation of the results and inferences.

Chapter 6: Deals with the conclusion and future scope of the work.

CHAPTER 2

OVERVIEW OF SUBMERSIBLE DRONE AND UNDERWATER IMAGING

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This chapter defines the basic terminologies and image processing basics required for understanding this project. Terminologies like Submersible drone, Propulsion, Heading, Rudder, Elevator, ballast and buoyancy are explained in a easy manner. Support softwares such as Solidworks, Qt and Python libraries such as OpenCV, TensorFlow, Keras are introduced in this chapter.

2.1 Submersible Drone

Submersible drone is an unmanned radio-controlled vehicle used for several purposes including underwater imaging, photography, defense, sensing the underwater parameters etc. [7].

2.2 NavLink FPV control system

FPV system is basically video piloting, a simple way to pilot a radio-controlled vehicle with vision capability. The remote-controlled vehicle’s video footage is transmitted to the controller’s screen wirelessly so that the controller can pilot the vehicle with ease.

2.3 Propulsion and Heading

The movement and control of the submersible drone mainly depends on two factors, they are propulsion and heading.

Propulsion

Propulsion is the action of pushing to drive a mass forward. In this effort propulsion actually refers to the forward movement.

Heading

Heading basically refers to the direction control. Rudder control and Elevator control are together called heading.

Rudder

Rudder is a primary control surface used to steer the submersible drone. Rudder is used to control the yaw of the entire submersible drone.

Elevator

Elevator in this effort refers to the pitch movement of the submersible drone. The entire submersible drone changes its altitude by using elevator wings.

2.4 Buoyancy Control

Buoyancy is the force exerted on an object that is wholly or partly immersed in a fluid. Submersible drone works based on the principle of buoyancy. Buoyancy is achieved by the use of ballast tank.

2.5 Ballast

Ballast is structure that is used to provide stability to a underwater vehicle. **Ballast**, other than cargo, may be placed in a vehicle, often a ship or the gondola of a balloon or airship, to provide stability.

2.6 Digital Image Processing

An image is described as a 2D function, f(u,v), where u and v are spatial co- ordinates and the magnitude of the function f at any set of coordinates (u,v) is labelled as the intensity or gray level of the image at that position. If u,v and the intensity levels of f are all fixed and distinct, the image obtained is called a digital image [2]. The domain of digital image processing involves processing of digital images with the help of digital computers. The main advantages of Digital Image Processing techniques are - versatility, repeatable characteristics and also the preservative ability of actual data precision.

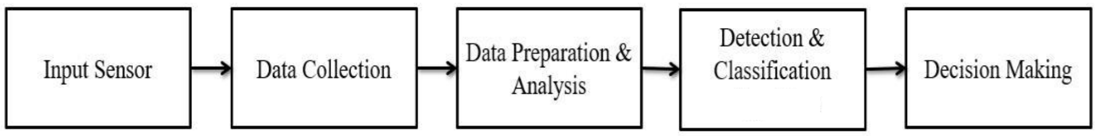

Figure 2.1. Block diagram of image processing

The block diagram of the methodology of the image processing is shown in Figure 2.1
It consists of an input sensor, a data collection stage, a data preparation and analysis stage, a detection and classification stage and finally a decision making stage.

Input sensor: Input data is collected from a camera fixed to the front end of the submarine.

Data collection: The data is acquired from the source of google images. The two types of corals brain coral and acropora coral images are each of 150 nos.

Data preparation and analysis: Collected data is processed. The images were then cropped, resized, annotated and augmented for further analysis.

Detection and classification: In machine learning approach, the UNet deep learning model is used in the classification of two different types of the coral.

Decision making: The segmentation of the two types of coral is done based on the color that was assigned to the particular coral during the process of annotation.

Neural networks

A neural network is a popular machine learning algorithm that is being used in the present. This algorithm is based on the neural architecture of a human or animal brain. Just like the human brain, a basic building block here is called a neuron [1]. The neuron functionality is to find an output from a set of inputs by applying certain functions;

that is similar in functionality to the human neuron . The functionality of a neuron is as shown in the Figure 2.2.

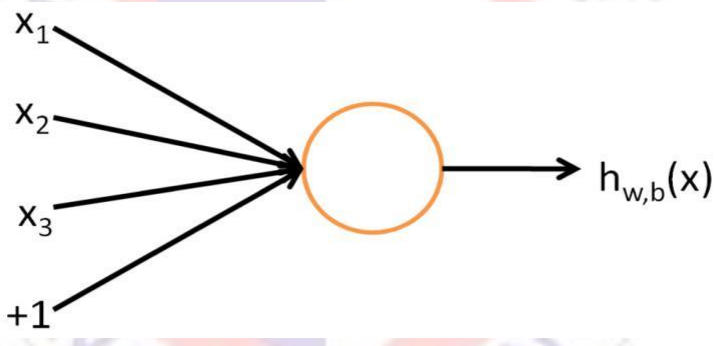

Figure 2.2. Neuron Functionality

The function used by the neuron to get the output from a set of inputs is termed as an activation function. There are five major activation functions step, sigmoid, tanh, ReLU and Leaky ReLU. Each of these activation functions is described in detail below.

Step function

A step function is defined as shown in Figure 2.3.

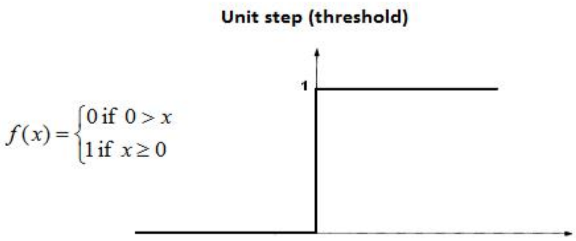

Figure 2.3. Step Function

For all x greater than or equal to zero, the step function returns an output of 1. For all x less than zero, the output is zero. From the graph it is seen that the function is differentiable throughout except at zero.

Sigmoid Function

A sigmoid function is defined mathematically as shown in Figure 2.4

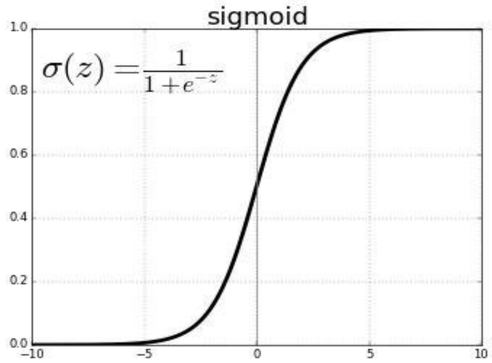

Figure 2.4. Sigmoid Function

The sigmoid function outputs a 1 when the value of z tends to infinity and outputs a zero when the value of z tends to minus infinity. Here z is an independent variable. This function is an approximate function of the dependent variable. The sigmoid function is used as an approximation function for the following reasons:

- It identifies non-linearity in the data that is a must for modeling accurately.
- It is used with gradient descent and back propagation approaches for calculating weights of different layers as it is differentiable throughout the entire range.

Tanh Function

The tanh(z) function is a rescaled version of the sigmoid, and its output range is $[-1,1]$ instead of [0,1]. The Figure 2.5 shows the graphical representation of the tanh function.

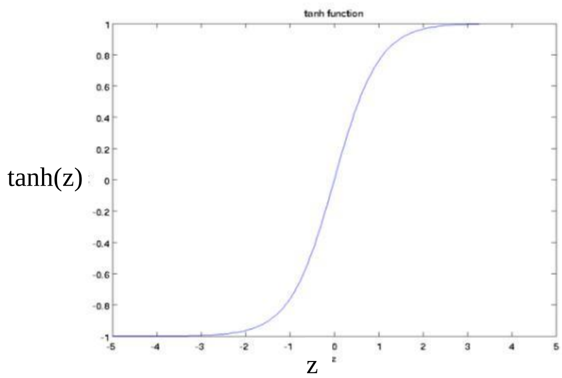

Figure 2.5. Tanh Function

The general reason for using a tanh function in some places instead of the sigmoid function is because since data is centered on 0, the derivatives are higher. As the gradient increases, the learning rate improves.

2.7 Convolutional Neural Networks

Convolution Neural Networks (CNN) is one of the variants of neural networks. It is used widely in the field of Computer Vision. It consists of hidden layers and derives its name from that. The hidden layers [30] of a CNN typically consist of convolution layers, pooling layers, fully connected layers, and normalization layers. Convolution and pooling functions are used as activation functions instead of using the usual activation functions explained earlier like ReLU, sigmoid, Tanh, etc. The Figure 2.6. shows a typical convolution network [1].

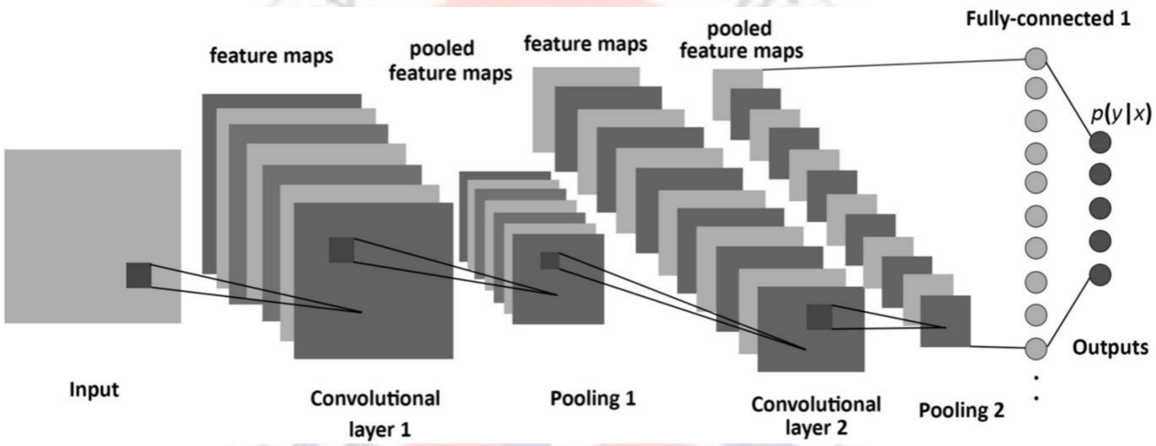

Figure 2.6. Convolution network

Convolution: Convolution operates on two signals (in 1D) or two images (in 2D). One signal is an input signal (or an image) the other signal acts as a kernel or filter on the input image and produces an output. Thus in simple terms, it takes an input signal applies a filter over it, to produce a modified signal.

In terms of image processing, the kernel slides over an entire image and changes the value of each pixel in this process. The Figure 2.7. illustrates the convolution process.

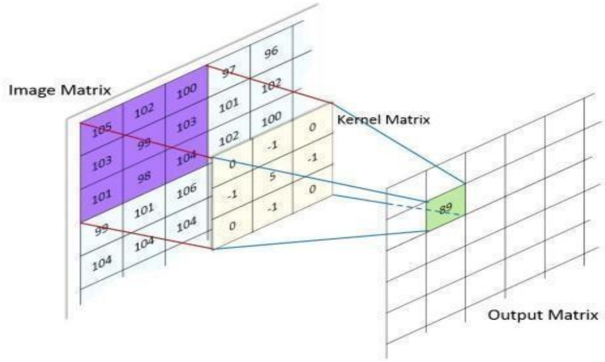

Figure 2.7. Convolution of Image Matrix and Kernel Matrix

Pooling: It is a sample-based discretization process. It is achieved in order to down-sample an input representation (image, hidden-layer output matrix, etc.), reducing its dimensionality and allowing for assumptions to be made about features contained in the sub-regions binned. There are 2 main types of pooling: max pooling and min pooling. Max pooling is based on picking up the maximum value from the selected region while min pooling is based on picking up the minimum value from the selected region. The Figure 2.8. illustrates an example of max pooling.

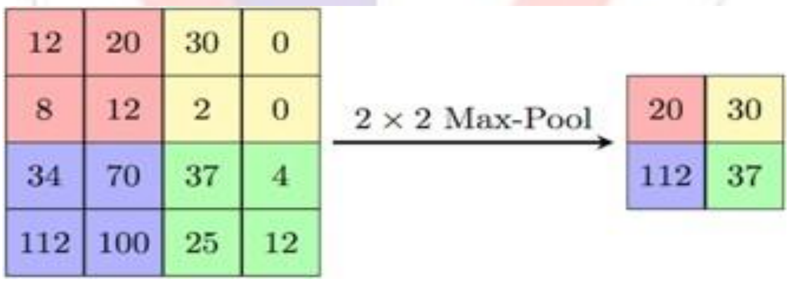

Figure 2.8. Max Pooling

The various layers of a convolution neural network are as follows:

Convolution Layer

Convolution is the first layer to extract features from an input image. Convolution preserves the relationship between pixels by learning image features using matrix of input data. It is a mathematical operation that takes two inputs: an image matrix and a filter (or a kernel). By application of filters, convolution of an image with different filters performs operations such as edge detection, blur and sharpen.

Strides

Stride is the number of pixels shifts over the input matrix. If the stride is 1 the filters are moved to 1 pixel at a time. Similarly, if the stride is 2 then the filters are moved to 2 pixels at a time and so on. The Figure 2.9. shows the working of convolution with a stride of 2.

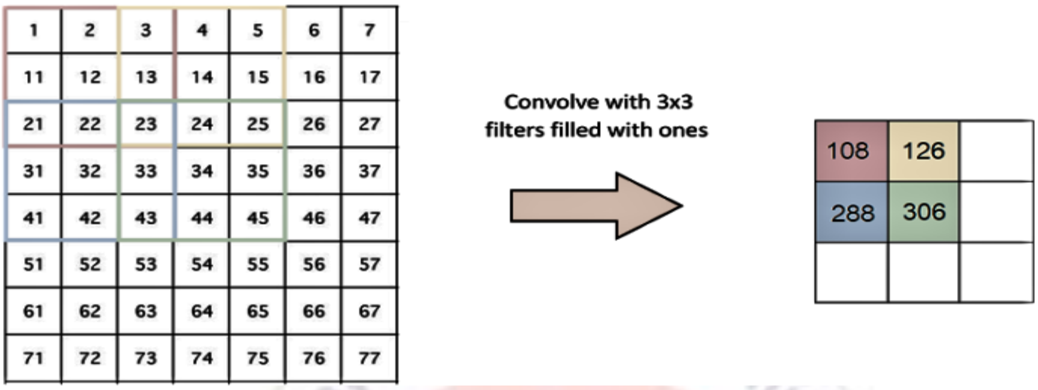

Figure 2.9. Convolution with stride of 2

Padding

Padding is a term relevant to convolutional neural networks as it refers to the amount of pixels added to an image when it is being processed by the kernel of a CNN. For example, if the padding in a CNN is set to zero, then every pixel value that is added will be of value zero. If, however, the zero padding is set to one, there will be a one pixel border added to the image with a pixel value of zero.

Pooling Layer

Pooling layers reduce the size of images if the size of images are too large. Spatial pooling also called as sub sampling or down-sampling that reduces the dimensionality of each map but retains the important information. Spatial pooling is of the following types:

- Max Pooling: It takes the largest element from the rectified feature map
- Average Pooling: It divides the input into rectangular pooling regions and computes the average value of each region
- Sum Pooling: It takes the sum of all elements in the feature map cell

Fully connected Layer

The matrix is flattened into a network and fed into a fully connected layer like network. The Figure 2.10 shows a fully connected layer after the pooling layer.

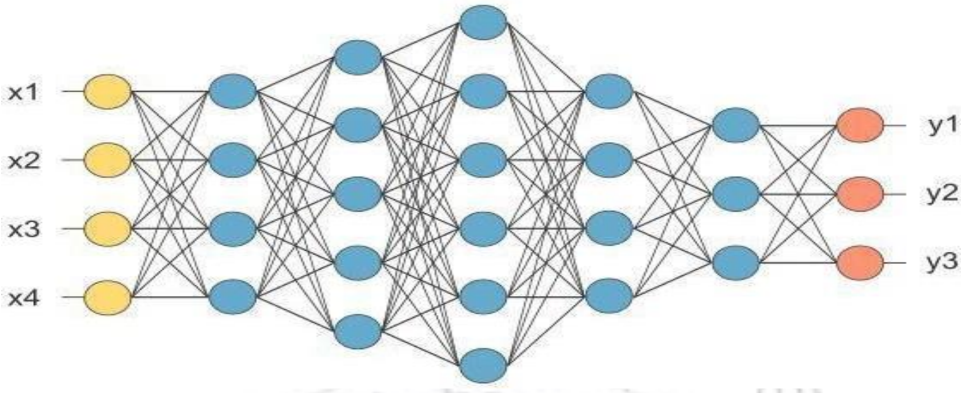

Figure 2.10. Fully Connected Layer

From the diagram shown, feature map matrix is converted as vector (x1, x2, x3….). With the fully connected layers, the features are combined to create a model. Finally, activation functions like sigmoid, ReLU as discussed previously are used to classify the outputs into car, truck, etc.

2.8 CNN Architecture for UNET

UNet, evolved from the traditional convolutional neural network, was first designed and applied in 2015 to process biomedical images. As a general convolutional neural network focuses its task on image classification. Input is an image and output is one label, but in case of corals, it requires not only to distinguish between the coral and the gravels, but also to localise the area of corals.

UNet is dedicated to solving this problem. The reason it is able to localise and distinguish borders is by doing classification on every pixel, so the input and output share the same size.

The basic foundation of the network is shown in Figure 2.11

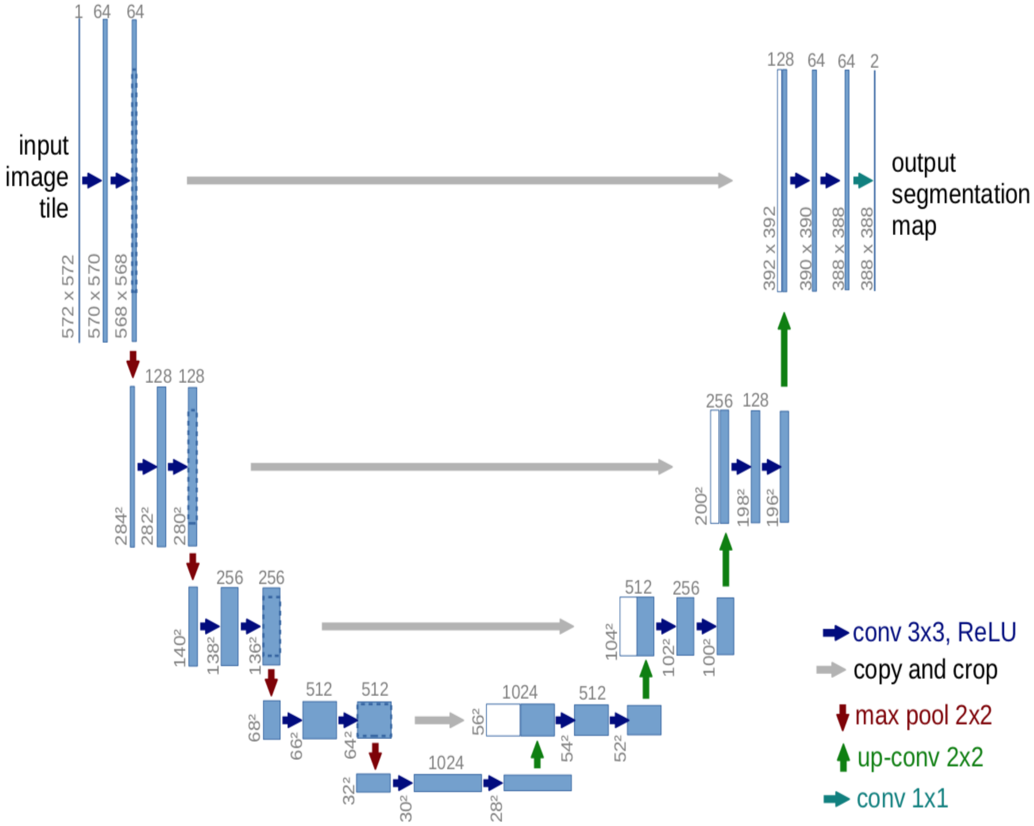

Figure 2.11. UNet Network

The architecture is symmetric and consists of two major parts — the left part is called contracting path, that is constituted by the general convolutional process; the right part is expansive path, that is constituted by transposed 2d convolutional layers(can think it as an up sampling technic)

Contraction Path

The contracting path follows the formula:

Conv_layer1->conv_layer2->max_pooling->dropout(optional)

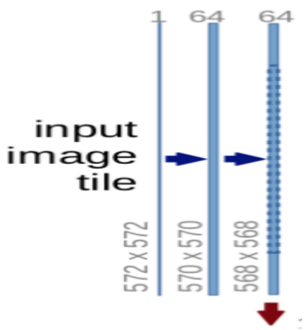

Figure 2.12. Input Image tile

Each process constitutes two convolutional layers, and the number of channel changes from 1 → 64, as convolution process will increase the depth of the image. The red arrow pointing down is the max pooling process that halves down size of image(the size reduced from 572x572 → 568x568 is due to padding issues, but the implementation here uses padding= “same”). The process is repeated 3 more times. Figure 2.12 shows the input image tile.When the network reaches at the bottommost, still 2 convolutional layers are built, but with no max pooling**:**

The image at this moment has been resized to 28x28x1024.Let’s get to the expansive path.

Expansion Path

In the expansive path, the image is going to be upsized to its original size. The formula follows:

conv_2d_transpose -> concatenate -> conv_layer1 -> conv_layer2

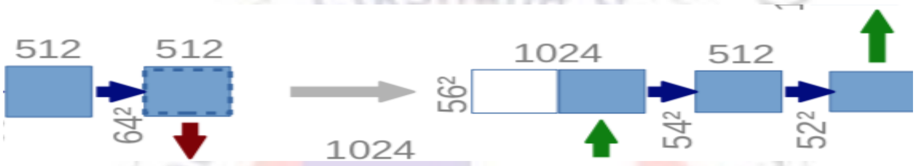

Figure 2.13. Expansion path

Figure 2.13 shows the expansion path.

Transposed convolution is an upsampling technic that expands the size of images. Basically, it does some padding on the original image followed by a convolution operation. After the transposed convolution, the image is upsized from 28x28x1024 → 56x56x512, and then, this image is concatenated with the corresponding image from the contracting path and together makes an image of size 56x56x1024. The reason here is to combine the information from the previous layers in order to get a more precise prediction. In line 4 and line 5, 2 other convolution layers are added. Same as before, this process is repeated 3 more times. Figure 2.14 shows the output segmentation map.

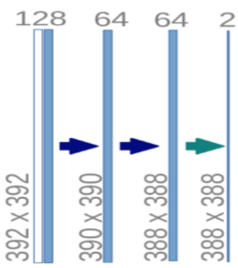

Figure 2.14 Output segmentation map

Now reached the uppermost of the architecture, the last step is to reshape the image to satisfy prediction requirements. The last layer is a convolution layer with 1 filter of size 1x1. And the rest left is the same for neural network training.

2.9 Support Software

OpenCV

OpenCV is a library mainly focusing on real-time applications. OpenCV provides common platforms for users to create computer vision applications and develop products on machine learning techniques. OpenCV supports C, C++, Java, Python interfaces and runs on Windows, Linux, Android, and Mac OS. It has nearly 500 algorithms and 5000 functions supporting those algorithms.

Applications of OpenCV are

- Facial recognition
- Gesture recognition
- Object tracking
- Stereopsis stereo vision (increasing depth of the image obtained from 2 cameras)

OpenCV contains statistical machine learning library that contains

- Boosting
- Decision tree learning
- K-nearest neighbor algorithm
- Artificial neural network
- Random forest

Python

Python is an interpreted, high-level, general-purpose programming language. It helps the users express the concepts in fewer lines compared to other programming languages. Python supports multiple paradigms like imperative, object-oriented, and functional programming. For memory management, Python uses dynamic typing, reference counting, cycle detecting garbage collector. The main feature of Python is dynamic name resolution that binds variable name and method during program execution. The greatest strength of Python is its huge collecting of libraries for various tasks. HTTP and MIME protocols and many standard formats for internet-facing applications. The Python package Index contains over 92000 packages offering various functionalities. Few of them are mentioned in the following:

- Graphical user interfaces
- Image processing
- Automation and web scraping
- Networking and communications
- Scientific computing

TensorFlow

It is an open source artificial intelligence library, employing data of graphs to assemble models. It permits engineers to make enormous scope neural systems with numerous layers. TensorFlow is basically used for: Classification, Perception, Understanding, Discovering, Prediction and Creation.

TensorFlow 2 spotlights on effortlessness and convenience, with refreshes like anxious execution, intuitive elevated level APIs, and adaptable model structure on any stage.

Libraries and augmentations practiced in TensorFlow:

i. Tensor Board gives the perception and tooling required for AI experimentation:

- Tracking and imagining measurements, for example, loss and precision.
- Visualizing the model diagram.
- Viewing histograms of loads, inclinations, or different tensors as they change after some time.
- Displaying pictures, content, and sound information.

ii. TensorFlow Datasets is an assortment of datasets prepared to use, with Tensor-Flow or other Python ML systems, for example, Jax. All datasets are uncovered as TensorFlow data datasets, empowering simple to-utilize and high-performance input pipelines.

iii. TensorFlow Probability (TFP) is a Python library based on Tensor-Flow that makes it simple to consolidate probabilistic models and deep learning on present day equipment (TPU, GPU).

iv. Neural Structured Learning (NSL) is another learning worldview to train neural systems by employing organized signals along with feature inputs. The NSL system in TensorFlow gives easy to apply APIs and instruments for designers to prepare models with arranged signals like

Keras APIs to empower training with graphs and inhospitable disturbances, TF operations and capacities to allow training with structure while wielding lower-level TensorFlow APIs, Tools to fabricate charts and build chart contributions for training.

Keras

Keras is TensorFlow's high level API for building and training profound learning models. It is maneuvered for quick prototyping, best in class research, and creation.

Following points explain the advantages of Keras:

- Accommodating: has a straightforward, reliable interface and gives clear and activity capable criticism for client mistakes.
- Easy to broaden: Writing custom structure squares, make new layers, measurements, loss functions and create cutting edge models.
- Modular and composable: Keras models are made by associating configurable structure squares together, with scarcely any limitations.

Google Colab

Colaboratory, or "Colab" for short, permits you to compose write and execute Python in your browser, with

- Zero configuration required
- Free access to GPUs
- Easy sharing

Qt C++

Qt Creator provides a cross-platform, complete integrated development environment (IDE) for application developers to create applications for desktop and mobile device platforms, such as Linux, Windows and Android. The GUI application in this effort is built using qt creator.

Solidworks 2018

Solidworks is a 3D Modelling software produced by Dessault Systems. Solidworks 2018 provides with lot of features including 2d sketching, Assembling, Extruding, Grooving, 3D Modelling etc. The part files designed using Solidworks 2018 is 3D printed after slicing through the slicing software.

CHAPTER 3

HARDWARE AND SOFTWARE DESIGN OF SUBMERSIBLE DRONE

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HARDWARE AND SOFTWARE DESIGN OF SUBMERSIBLE DRONE

Project design is a phase of the project that includes planning of various processes involved in the project. This chapter includes the basic block diagram followed by the detailed explanation of electronic and mechanical parts of the submersible drone.

3.1 Block Diagram

The Figure 3.1 shows the block diagram of the project showing all the systems present in the submersible drone

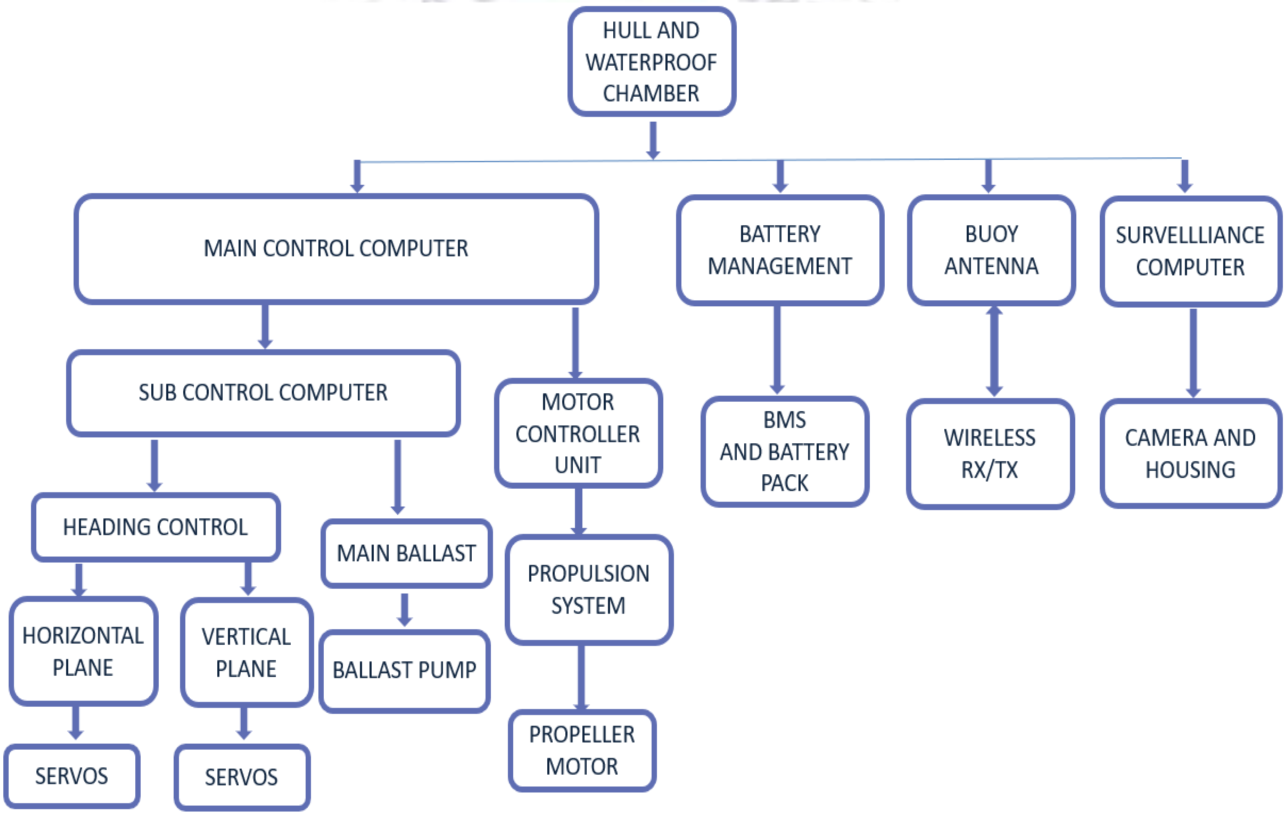

Figure 3.1. Block diagram of Submersible drone

3.2 Specifications

- Depth – 20m
- Weight – <15kg
- Operating time – 15 minutes

3.3 Hull Design

Hull is the outer structure of submersible drone that contains all the components required for the operation of submersible drone [6][8][11]. Submersible drone hull is made by 3d printing. The structure size is designed as 920mm length and 150mm diameter based on the dimensions of each component that is going to be placed inside the submarine. The material chosen for this purpose is PLA because of the following reasons.

- **PLA** is made from renewable raw materials.
- It has little carbon footprint compared to fossil-based plastics.
- It is easier to print because it takes temperature of 180 degree for extruder and 50 degree for heated bed.

Figure 3.2 shows the designed 3D model isometric view. The 3D model is designed by using Solidworks 2018 software.

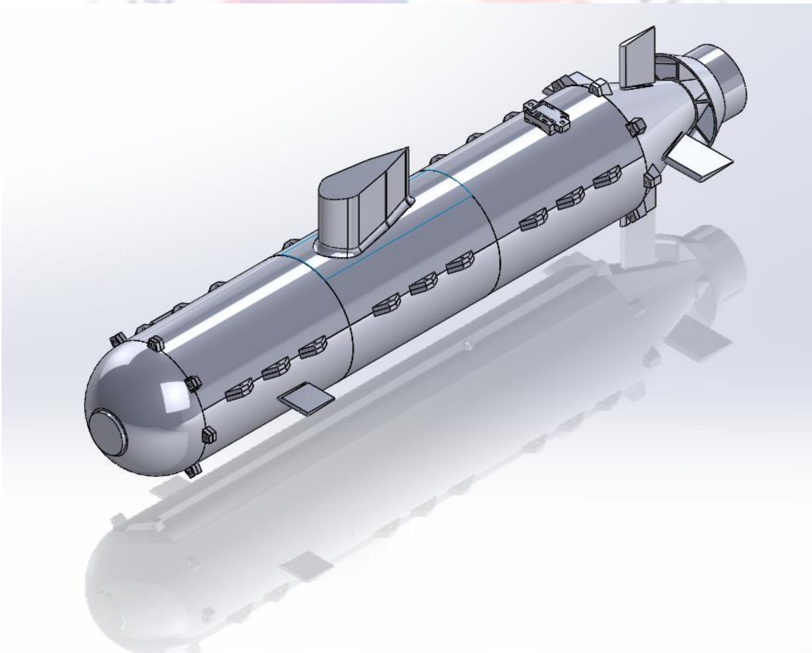

Figure 3.2. Designed Submersible Drone Isometric view

Hull is divided into 4 parts

- Main body
- Front dome
- Conning Tower
- Tail

Main body

Main body consists of six parts. Two of six parts in the Main body is shown in Figure 3.3. The reason behind making the main body into six parts is because of the limitation of 3d printer. Each part is a semi cylindrical with dimension of 150mm diameter and length of 220mm.Hull houses all the components required for the submersible drone to operate. It includes Raspberry pi, Main ballast, PCB, Fixed ballast, pumps, solenoid and battery pack.

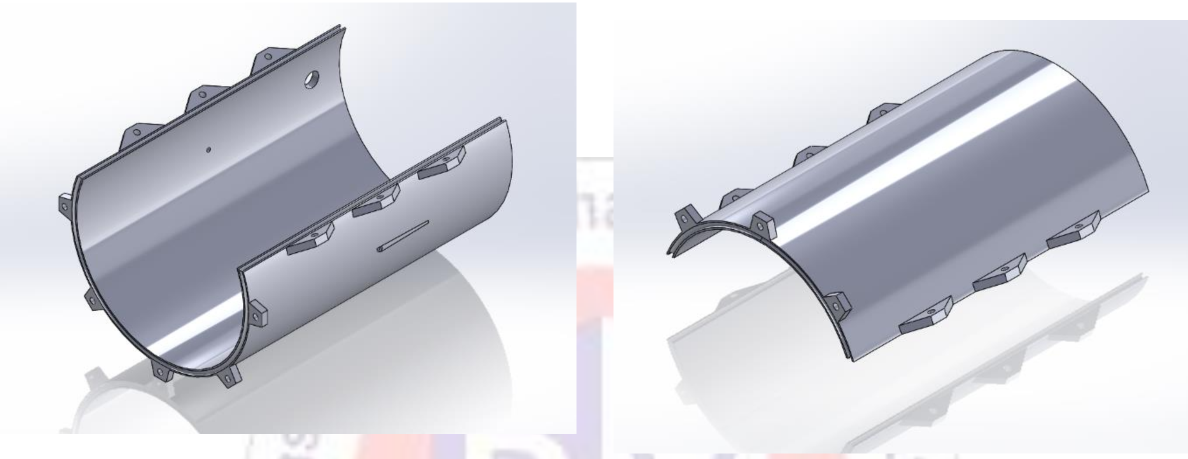

Figure 3.3. Bottom and top part of hull

Front dome

Front dome is semi spherical structure adopted to hold the camera and to provide aerodynamics for the submersible drone. Figure 3.4 shows the designed front dome.

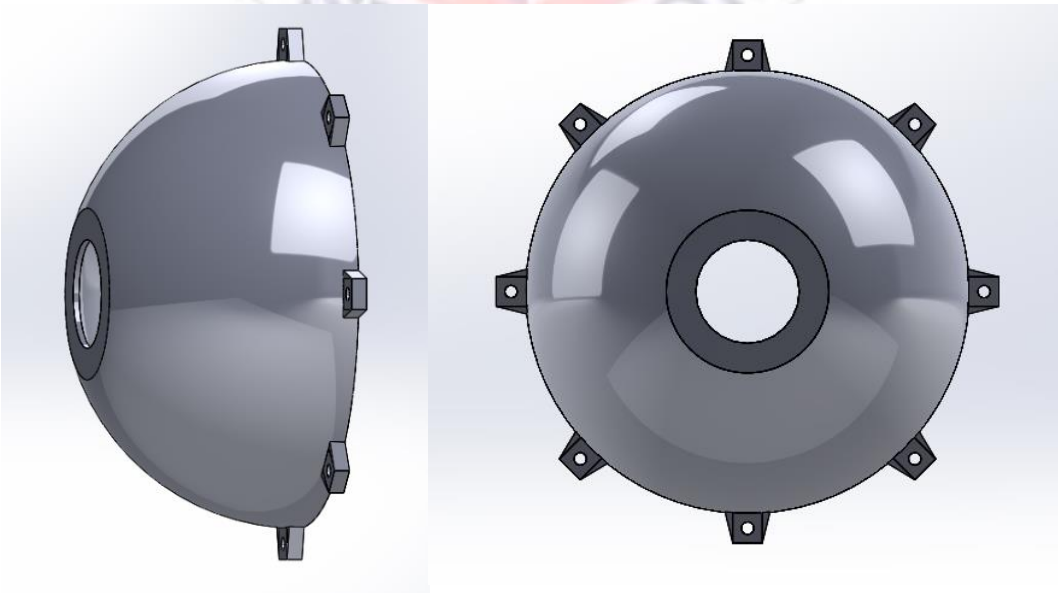

Figure 3.4. Designed front dome

Conning Tower

Conning Tower is a name called to a platform in submersible drone shown in Figure 3.5. It incorporates transmitter and receiver antenna inside it. Conning Tower also serves the purpose of maintaining the roll of the submersible drone.

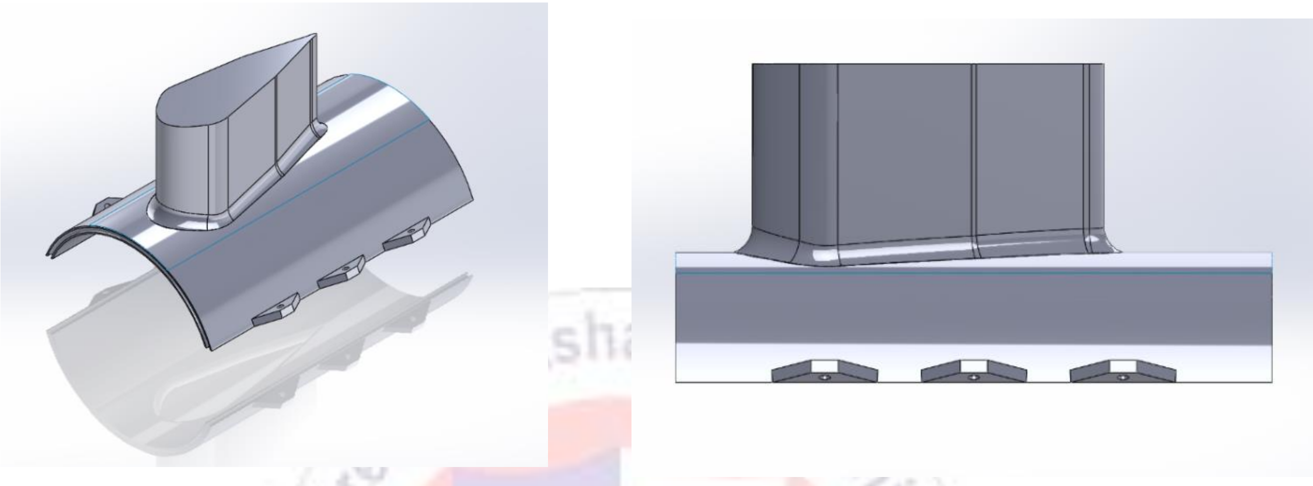

Figure 3.5. Conning Tower isometric view and side view

Tail

Tail is one of the mechanically complex structure. It houses the rudder and elevator mechanism. The propulsion motor is housed inside the tail. Guide planes takes the support of tail to sit in position. Figure 3.6 shows the 3D model of tail designed using Solidworks 2018.

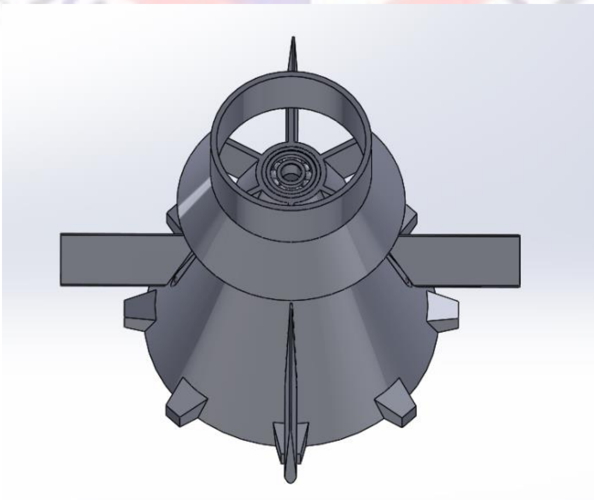

Figure 3.6. Designed tail

3.4 Heading control design

Heading control mainly consists of two parameters.

- Rudder control
- Elevator control

Rudder control

The mechanism for rudder control is achieved by using DC servo 9g motor and multiple connecting rods with joints. Servo motor is responsible for moving two rudder planes up to a angle of 90 degree. Figure 3.7 shows the designed rudder and elevator plane mechanism.

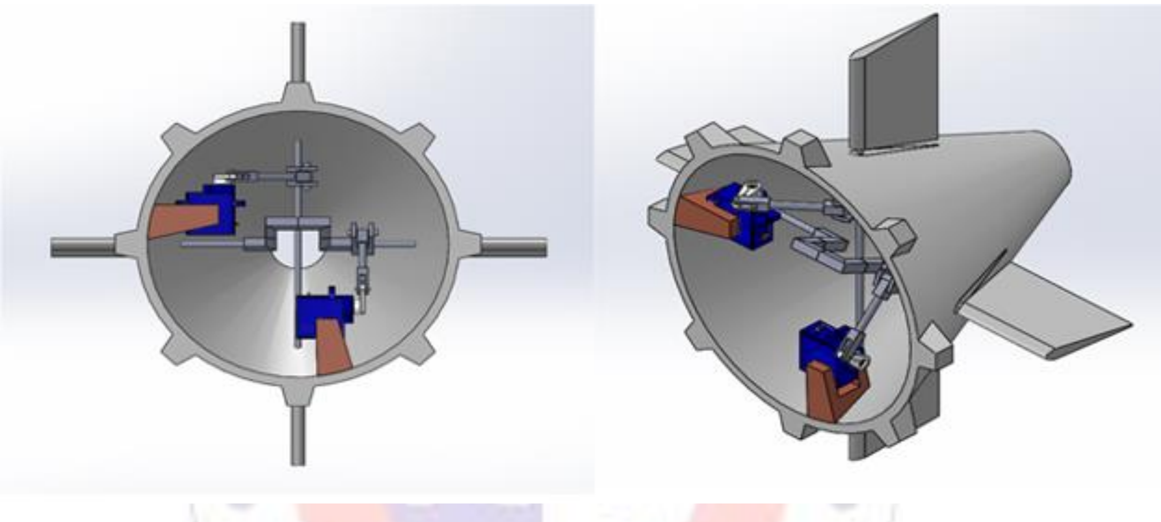

Figure 3.7. Tail elevator and rudder mechanism

Elevator control

Elevator control is achieved by the use of one axis joints and DC servo motors. There are four elevator wings, two are placed at the front of the submersible drone and other two are placed

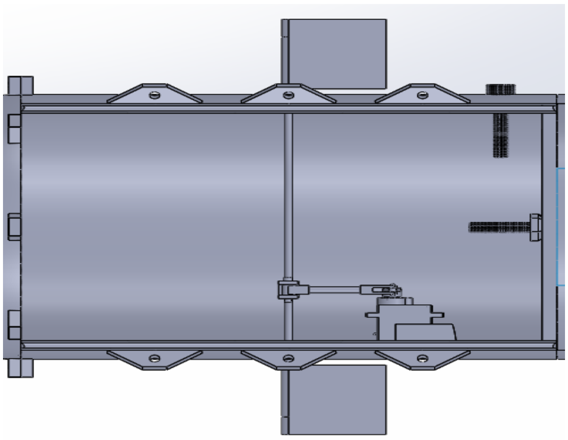

Figure 3.8. Designed front elevator mechanism

at the tail of submersible drone. The degree of freedom supported for the four elevator wings is 90 degrees. Figure 3.8. shows the designed front elevator mechanism.

3.5 Main ballast design

The volume of ballast tank is chosen to be approximately one third of the volume of submersible drone. This makes submersible drone to have proper depth stability. Main ballast tank is a pressure withstand able vessel that is responsible for making the submersible drone maintain the altitude inside the water body. By increasing the water volume inside the ballast tank, submersible drone moves to certain depth. It is controlled by the diaphragm pump. By emptying the ballast tank, the submersible drone surfaces by the use of centrifugal pump. After determining the space required for all the components inside the submersible drone, the space that is remaining is acquired to design the ballast. If the ballast becomes bigger then pump is turned on for more time that is energy consuming. In order to reduce the effort of the pump concept of fixed ballast is introduced. The buoyancy of the submersible drone is maintained in such a way that if a low volume of water is added to the ballast tank, the submersible drone is going to sink thereby reducing the operation time of the diaphragm pump. The same method is followed for surfacing as well. The fixed ballast is achieved by adding metal pieces into the submersible drone. Figure 3.9 shows the top view and isometric view of designed ballast respectively.

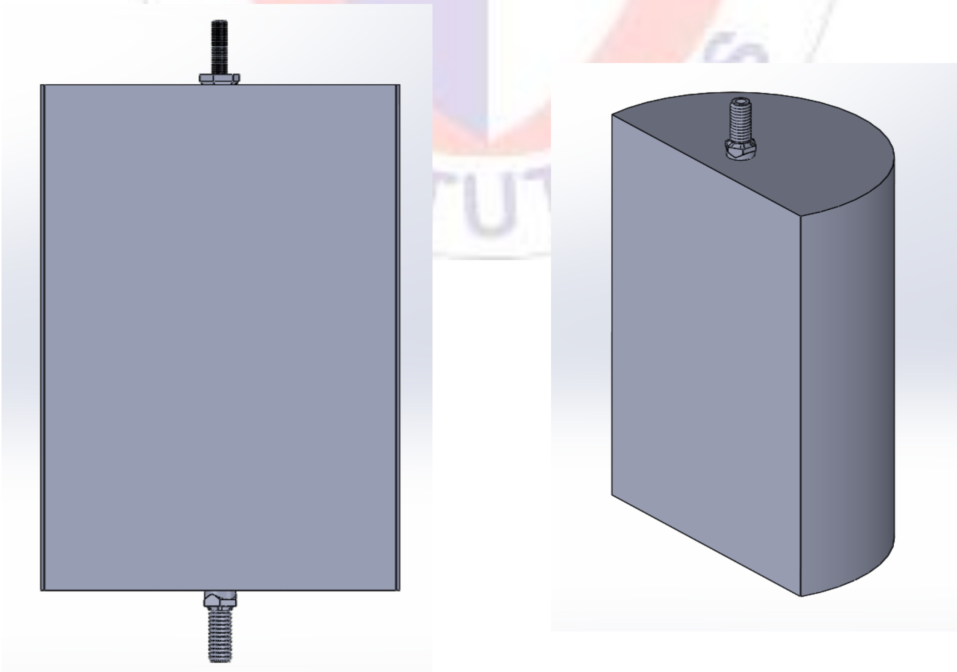

Figure 3.9. Top and Isometric view of ballast

3.6 Main Controller (MC)

A Main Controller is a hardware that is responsible for the governing and task scheduling of the sub controller.

Figure 3.10. Atmega 328p chip

The MC interfaces with various sensors such as the current sensor, the digital compass, a temperature sensor, and a hall encoder input from the propulsion motor. Studying the required array of sensors, the most economical and well-suited device that is used for the purpose was selected as Atmel/Microchip Atmega328P. The microcontroller has a 20 MIPS (Million Instruction / Second) CPU speed at 20 MHz and 32 KB of flash memory. The device is set to operate at 16 MHz to save power and deliver apt speeds. It also has 2 KB of primary memory (SRAM) with 1 UART, 2 SPI and 1 I2C communication ports. Since the Main Controller is responsible for communications with both Capture Process computer and Sub Controllers, it is imperative to have at least 3 means of communication. The device is connected to the Main Controller using a TTL-UART to USB converter housing a FTDI FT232 chip. The sub controllers are connected over SPI ports for information exchange. Figure 3.10 shows the ATmega328 chip.

The board houses an ACS712 30A current sensor that monitors the incoming current into the battery voltage bus circuitry. The sensor outputs a linear voltage on it's sense pins and the output fluctuations are suppressed by an internal RC filter. The devices uses an external 100 nF(recommended) ceramic capacitor for this job. The device has a sensitivity of 66mV/A and minimal PSRR and slew rate.

The digital compass is a magnetometer device that can detect and provide the absolute heading of the vessel under water. In the absence of the GPS device the compass becomes the most major navigational director. The device is a MEMS chip that is I2C capable and data transmissions happen via the Main Controller's Atmega328P chip. This data is then sent to MC for navigation.

The temperature in the compartment of the vessel will increase due to heat dissipated by motor, battery and pumps. Hence it is important to monitor the temperature as a parameter of operational capability. The sensor used for this job is a TI LM35 solid state temperature sensor. It outputs linear voltage as a reference for the temperature and has a sensitivity of 10mV/degC.

A hall sensor is a device that measures the magnetic field and reports the changes in the magnetic fields around it. An encoder is a device that reports the position or state of another device or part. In regard to rotary devices, an encoder is a device that measures and reports the angular displacement from a set reference. Hence a Hall encoder employs a set number of magnets, sometimes only one to report the position of the shaft of a rotary device. Since three-phase permanent magnet motor is used, accurately procuring the location of the shaft using the rotor magnets on the motor is easier. The encoder in this case is used to calculate the angular speed or the RPM of the machine used for propulsion of the vessel.

3.7 Sub Controller

A sub controller is a hardware that is responsible for the controlling and signaling of the rest of the electronic devices in the circuitry in the system. The Sub Controller (SC) interfaces with devices such as the inverter used for motor control, the pump controllers and other devices like the servo motors used for the navigational systems. Similar to the MC the SC was chosen as Atmega328P since they would have same peripheral devices and better compatibility. In the designed system there are two SCs that are responsible for two main dynamics of the propulsion and navigation system. One being Thrust Controller and another is the Dive Controller. They are all set up to communicate with the master over SPI and I2C interfaces while the UART is reserved for communication with the Capture Process Computer.

Heading Controller and Sensors

A Dive Controller is responsible for control of the dynamic ballast tank and the guide planes used for submerging and steering the vessel. A ballast tank is a buoyancy control device used to dynamically change the weight and hence, buoyancy of the vessel by intaking and ejecting water into it. To operate the tank there are two pumps and a solenoid value required at the bare minimum.

The intake pump is a one-way pump that draws in water from the bottom surface of the vessel shown in Figure 3.11 and hold the water inside the ballast tank as an high pressure water-air mixture. If the vessel is required to surface the solenoid valve at the exit line is released, and a ejection pump is used to pump out the water from the ballast tank. To control these pumps and solenoids at least three independent PWMs are required that is provided by the Dive Controller. The PWMs are generated by Atmega328P's internal clock oscillator and timers. These PWMs are then fed into a single quadrant chopper type power converter.

Figure 3.11. Diaphragm Pump

The Dive Controller also has an IMU connected over its I2C lane. The purpose of this sensor is to read the two axis Gyroscopic reading and the three axis acceleration from an MPU6050 MEMS device shown in Figure 3.12. The data is further forwarded to the Capture Process Computer and is internally used as well to readjust the parameters as a feedback system.

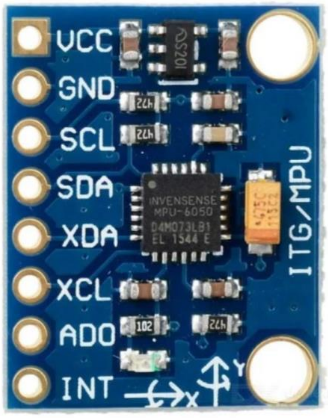

Figure 3.12. Gyroscope with acceleration sensor

Motor Controller

A Thrust Controller (TC) is responsible for the control of the propulsion of the vessel. The propulsion system consists of a BLDC motor and an Electronic Speed Controller (ESC). The ESC is directly connected to the TC and receives throttle value in form of PWM, the ESC is also connected to the main battery voltage rail and draws current from there. Thrust Controller gates the inverter to the rails using a single MOSFET in an single quadrant chopper scheme that can turn the system off in case of an exception or an emergency.

The Thrust controller is further connected over UART to the CPC and is capable of receiving auxiliary commands from the system to slow down and various other actions as override to aid the capture process of the CPC. The TC also has access to the MC and can access the required sensor values for safety and maintenance.

3.8 Propulsion Motor selection

Several classes, makes and models of motors are available on the market. Usually you can broadly classify them as AC Motors as shown in Figure 3.13. and DC Motors depending on the type of feed that powers the system. They can also be classified into Brushed and Brushless machines. The input feed classification is based on the nature of current/voltage fed to machine. These types of machines also produce an alternating back emf. For a machine to rotate it is imperative for it to switch current directions in the coils to magnetize in the required orientation. While the AC machines use the AC input feed to achieve that, a DC Machine uses an assembly of brushes often made of carbon or copper and a commutator assembly shown in Figure 3.14. A commutator assembly is a part of the machine's rotor that rotates with same speed as the shaft since it's mounted on it. This rotating ring of split conductors are connected to the appropriate coils for producing the necessary magnetization with respect to the position of the rotor on the 'theta' plane. However, even though Brushed DC Motors are the simplest to

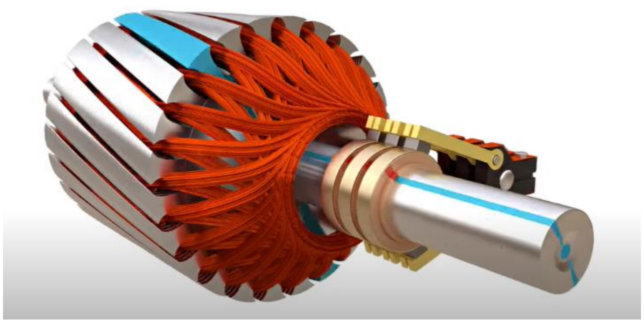

Figure 3.13. AC Induction Slip Ring rotor

control, they have rather poor power density and have extremely high rate of wear and tear for high acceleration applications.

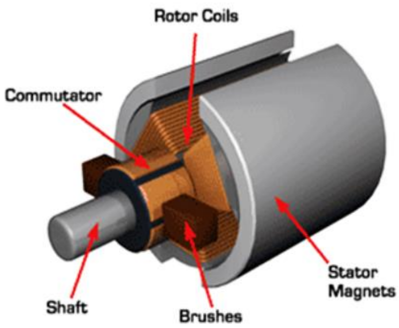

Figure 3.14. Brushed DC motor rotor with commutator

As per the conclusion Brushed motor cannot be used, that is the most appropriate machine to bear on a DC System, other options need to be considered. AC Field wound machines are not an option because of its poor power density and huge volumetric ratios. Also, it would need a separate pure sine wave inverter and SVM/DTC to control it, hence this option is eliminated for complexity and poor size match. Next considered is the PMSM or PMAC machines.

These however have a high-power density, still require a Pure sine inverter (VFD) to operate since they are wave wound. But however, one configuration of PMSM is a Brushless DC or BLDC machine, that is essentially a PMSM but with lap wound stator, hence having significantly larger inductance than a generic PMSM. This allows the BLDC motor for Quazi sine or switched DC Voltages to be fed into the machine without a problem. The BLDCs like PMSMs have very high-power density and its volumetric parameters are further superior. Additionally, they also house Neodymium Magnets with excellent field strengths and very tight hysteresis curves.

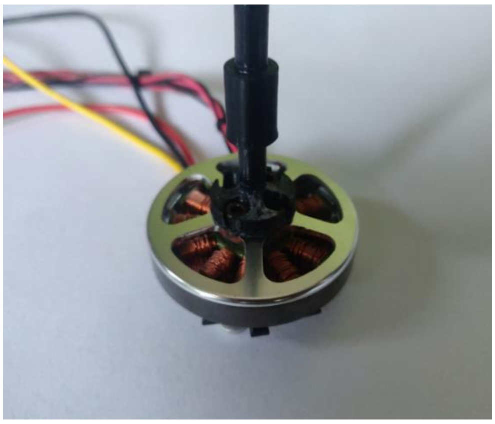

Figure 3.15. BLDC Motor

Considering all the pros and cons, the BLDC was selected as the type of the motor. Figure 3.15 and Figure 3.16 shows the BLDC motor and its Back emf waveform respectively.

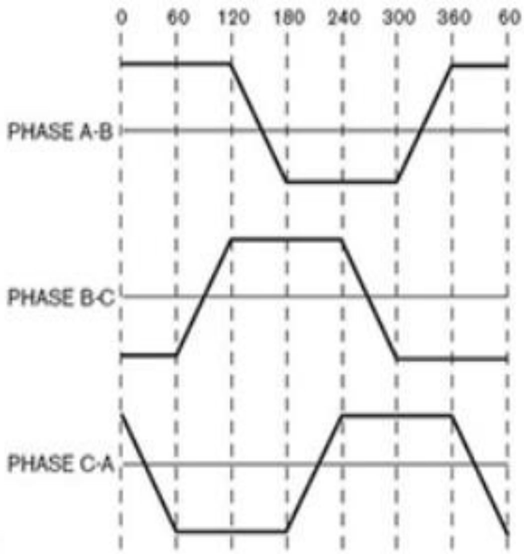

Figure 3.16. Back EMF waveform

The required angular velocity for the vessel's propeller shaft was decided as up to 3000 RPM and a minimum RPM of 1100 for continuous thrust. Hence a 180 kv BLDC motor was selected with appropriate voltage ratings and torque. . The Motor is rated at 750W at upto 22.2V - 24V max. Operating voltage is 11.1V and hence can only draw upto 20A of the maximum rated 40A of the motor. The power is cut into a quarter due to both voltage and current being halfed at the same time. So system specific power rating of the machine would be a maximum of 11.1V multiplied by 20A of maximum current drawn = 222W or around ~250W of power. Hence, all crucial parameters of the propulsion motor are now selected and decided for implementation into the system.

3.9 Battery Pack Design

Battery pack is the power source of the submersible drone. Six 18650 cells are used to obtain the configuration of 3S2P. A charging port is built on the outer structure of submersible drone to ensure easy charging without taking battery out of the submersible drone. Figure 3.17 shows the battery pack with BMS attached to it. The nominal voltage of the BLDC motor is 11.1 V so the battery is designed based on the same [3].

Nominal voltage taken : 11.1V

Current required : ~70A

Battery Capacity : 8509 mAh ~ 8.5 Ah

Discharge Co-efficient (C-rating) : Max.current(Imax)/Capacity = 8.23C ~ 10C

Const. Power = (2 πNT)/60 = 377.8W

Operating time : 15 minutes

$E_{cont.} = P_{cont} \times T_{op} = 94.45$ Wh

Figure 3.17. 3S2P Battery Pack

3.10 Transmitter-Receiver Module Selection

The communication system of a remotely operated vehicle is the most critical part of the operation process. To make sure a smooth operation capability at medium ranges, two types of full duplex communication topologies were selected. There are broadly two types of antennas available for communications, unidirectional and omnidirectional. The unidirectional antennas have high directivity and by sacrificing the lobes on the other sides radiates power in only one direction creating an elongated lobe that is more focused and has significantly longer range.

The omnidirectional antennas do the exact opposite. They have smaller overlapping lobes spread out in all directions, hence called omni-directional.

It is obvious that directional antennas on moving vessels cannot be mounted stationary. Hence there is a needed of two types of communicative links. One of high frequency low power and high range, that will have high bandwidth and is mounted with an omni directional antenna.

Figure 3.18. NRF Tx/Rx Module

The purpose of doing this is to send the critical commands and location information back to base station. The other communicative link is of high frequency, high power and high bandwidth. Since this mode has high frequency, it will have reduced range. Here, high gain directional antennas are used to boost the gain of the system. The purpose of this mode would be to transmit heavy data like video streams and other video processing results and commands. Figure 3.18 shows the full duplex module used for controlling the submersible drone.

The high frequency band was selected as 2.4 GHz RF connected to a 4dBi gain omnidirectional antenna and the high frequency device used is deploying on the 2400 Mhz band by IEEE802.11n protocol. This is the same band used by WiFi and can host speeds upto 300 Mbps that is sufficient for streaming high resolution videos from the submersible drone back to the base wirelessly. Both the devices have a transmit power of 20 dBm, that is around 100 milliwatts and ranges upto 1 km in straight line of sight.

Figure 3.19 show the transmitter circuit that consists of NRF module connected to Arduino nano. Two joystick modules are used for the purpose of controlling throttle, direction and depth of the submersible drone. The whole circuit is powered by a lipo battery. Figure 3.20 shows the receiver circuit consisting of a NRF module with as Arduino. The data received from the NRF module is sent to the sub controller. Sub controllers act according to the data received.

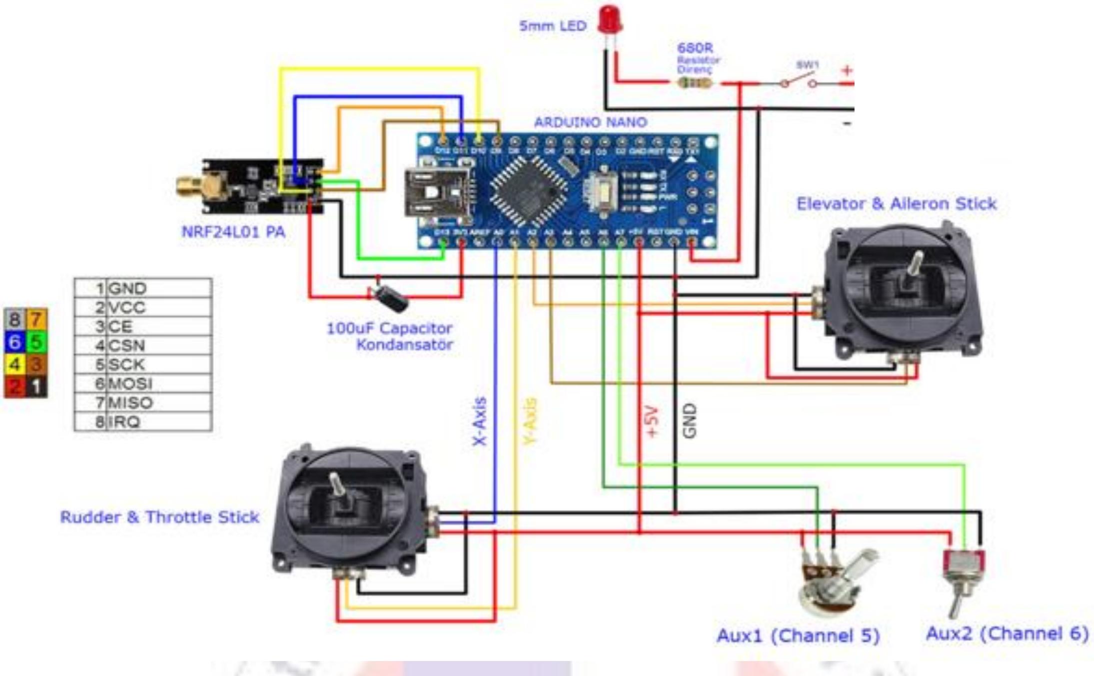

Figure 3.19. Transmitter circuit

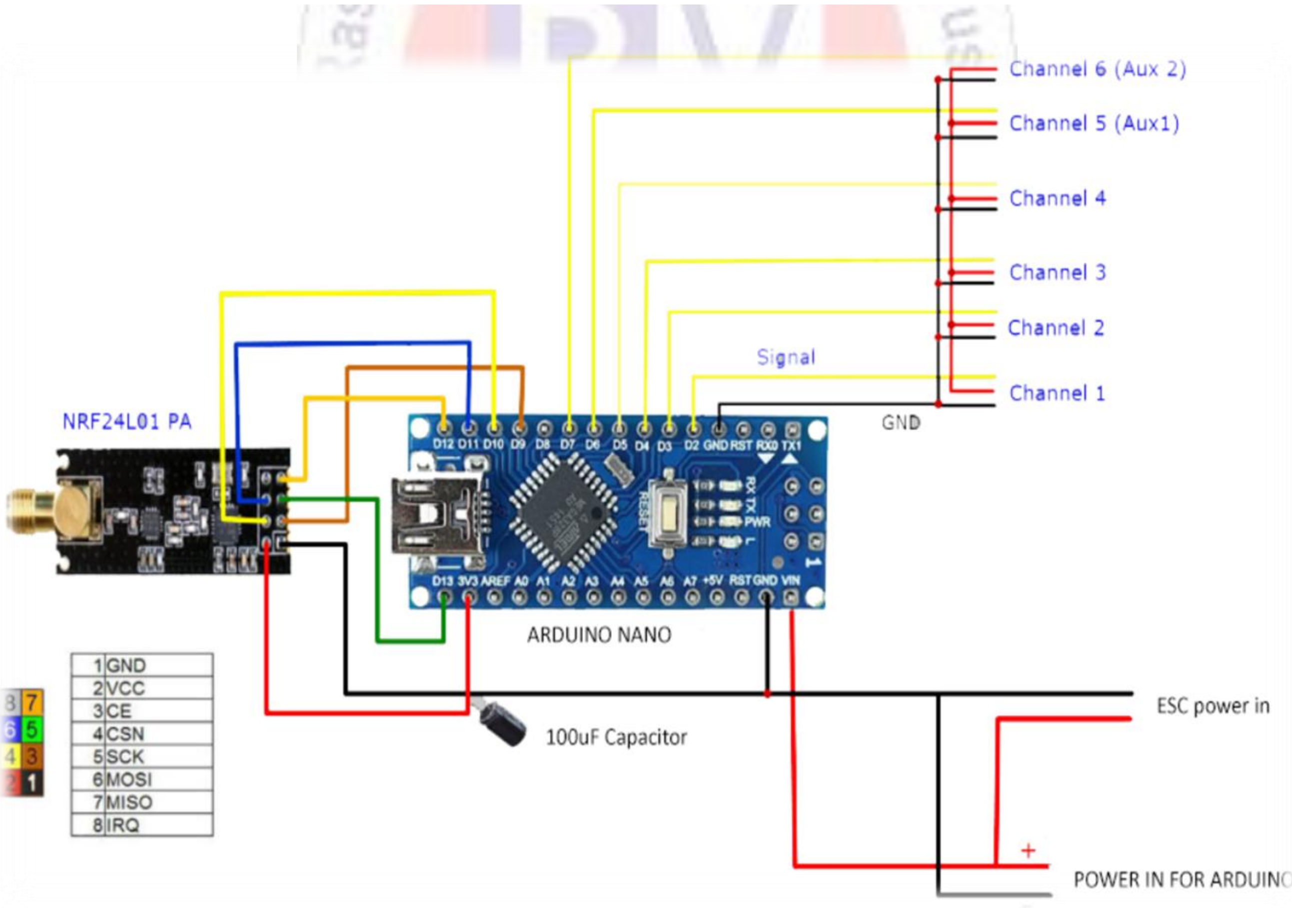

Figure 3.20. Receiver circuit

3.11 Capture Process Computer

A capture process computer is a computing device that takes up the role of capturing frames from a motion camera and filters frames from the video coming from the camera sensor module. This process is imperative to remove frames that are not usable due to motion blur and various other reasons. The capture process computer also serves are an intermediate buffer between the main image processor, that is a larger, faster and more power consuming computer and cannot be placed inside of the vehicle, hence taking off some load from the image processing computer. Raspberry Pi 4 is shown in Figure 3.21 and camera sensor is shown in Figure 3.22.

Figure 3.21. Raspberry Pi 4

A Raspberry Pi 4B was selected for the task as it has 4 x ARM Cortex A72 cores running at 1.5 GHz base speed and is boosted upto 2 GHz if required. Contrary to other economic SBCs(Single Board Computers) the Raspberry Pi also has a large amount of primary memory amounting up to 4 gigabytes or 8 gigabytes. The 4 GB version was selected as the most suitable candidate for the work. The Raspberry Pi houses two SuperSpeed USB 3 ports and two High Speed USB 2 ports capable of at least 480 Mbps of transfer speeds. The board also supports direct PCI based camera interface known as CSI, that allows for a smooth video capture and power delivery process. The secondary storage on the SBC is a MicroSD card, and is used to process, store and transmit frames required for the task.

Figure 3.22. Pi Camera

The camera sensor connected to the Capture Process Computer is also used for navigational reference of the vehicle. The OV5647 sensor is rated at 5 Million Pixels and is FullHD capable. The device also hosts a wide-angle lens with a FoV of 130 degrees. The device connects to the CSI port mentioned earlier and is fully compatible with most popular SBCs including the Raspberry Pi 4B. The device is configured to broadcast over an IEEE 802.11ac network. The wireless network functions at 5GHz and has a wide bandwidth but low range. The low range is compensated with the help of a directional antenna. Interfacing Raspberry Pi with the camera is shown in Figure 3.23.

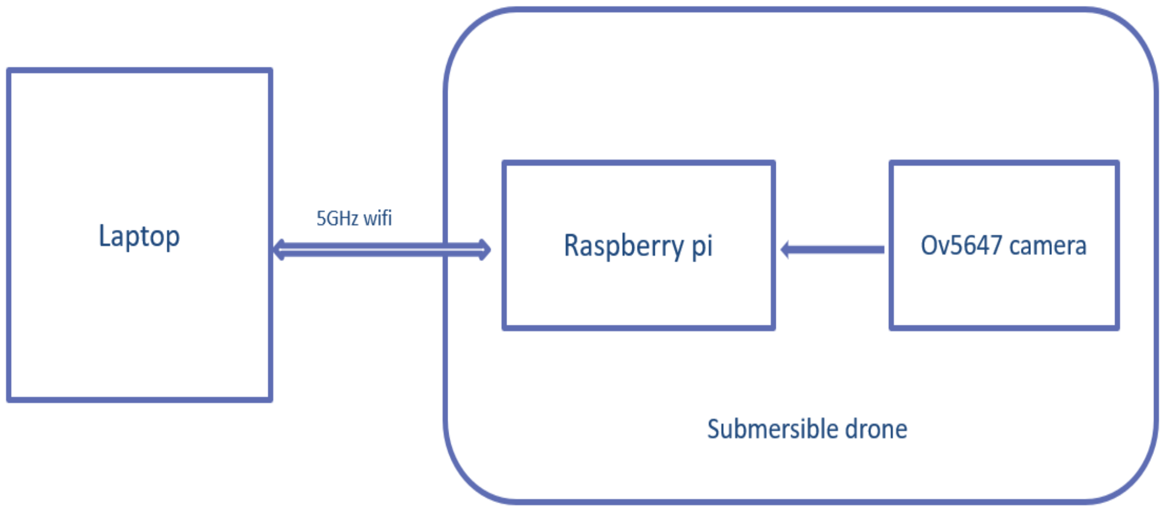

Figure 3.23. Camera, Raspberry pi and Laptop interfacing

The entire Capture Process computer including the camera consumes a total maximum of 15W at 5V, hence drawing a maximum current of 3A. The power delivery is achieved over an USB type C cable connected to the LM2596S High Speed switching converters. The power dissipation is achieved using heat sinks only at low load times, but the mode is switched to active cooling or forced cooling using a fan once the load increases. This increases the consumption rate of the Capture Process Computer up to 20W. Active cooling is rarely used as the device is self-limiting and only gets heavy loads at burst rather than continuous.

Camera selection

In this project two cameras are employed. One is to record high quality video. Another medium resolution camera is incorporated for the purpose of navigation. Figure 3.24 shows the GoPro camera. The video feed recorded from the GoPro camera is taken and processed later for the coral detection.

Figure 3.24. Go Pro Camera

3.12 PCB design

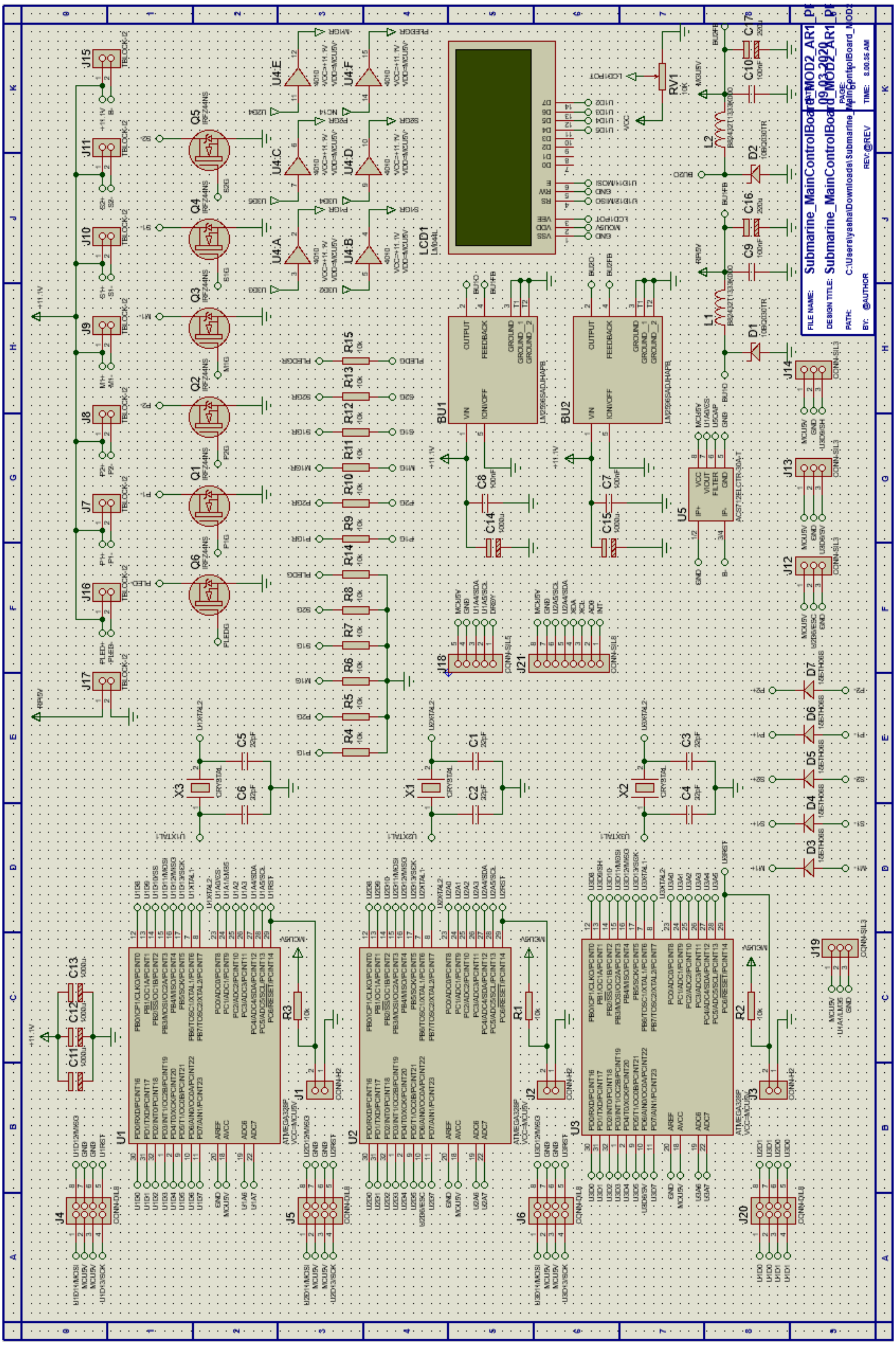

Figure 3.25. PCB Schematic

There are many components like power converters, sensors and computing devices in the circuitry. To integrate them into a compact solution and to reduce the clutter of wires Printed Circuit Boards are necessary. The PCB designed and fabricated for this project measures 100mm x 100mm in dimension. The power circuit of the board carries a lot of current and has thick copper traces. It also has the power switches like Mosfets and converters like the LM2596S switchers along with other passive power components such as inductors and capacitors. The power circuit is connected to the motors and pumps and operates them. The logic part is the low power or low current part and has more number of connections connecting various sensors, daughter boards and microcontrollers to various other integrated circuits.

Figure 3.25 shows the schematic of the PCB.

Figure 3.26 shows the Single quadrant chopper circuit used for switching different components like diaphragm pump, solenoid, centrifugal pump and electronic speed control. It consists of 11.1V power rail, terminal blocks, Mosfets, freewheeling diodes and level shifters. Switching ON and OFF is controlled by the signals received from the sub controllers.

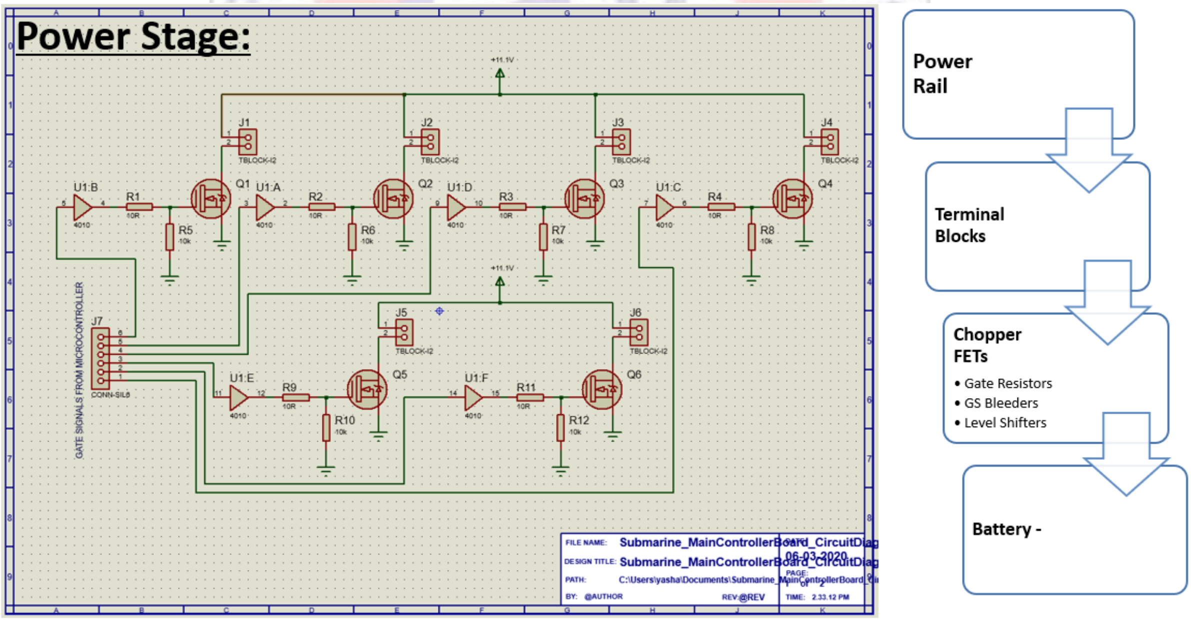

Figure 3.26. Single quadrant chopper circuit

The standard circuit from the data sheet is printed in the PCB to obtain the required voltage i.e. 5V. Buck converter circuit is used to convert 12V to 5V that is required for the operation of main controller, sub controller , raspberry pi and the sensors such as accelerometer, gyroscope. Figure 3.27 shows the buck converter circuit diagram.

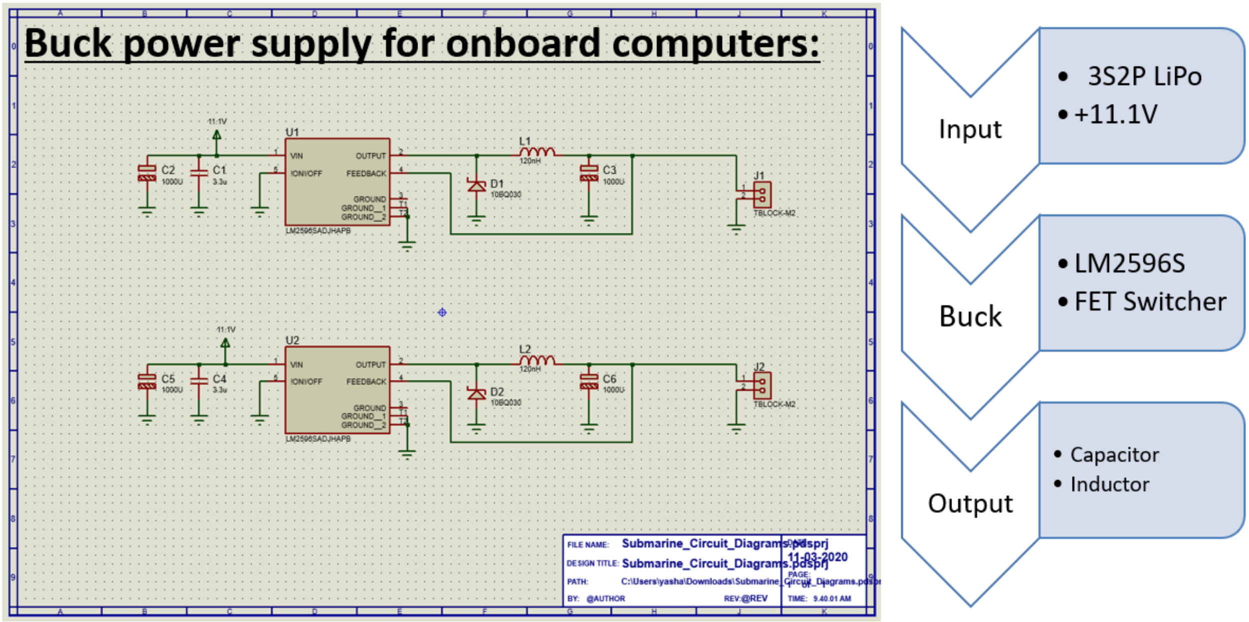

Figure 3.27. Buck converter circuit

The PCB used is a two-layer Eurocard board type. The PCB is designed using Proteus Suite software. Figure 3.28 shows the layout of the PCB.

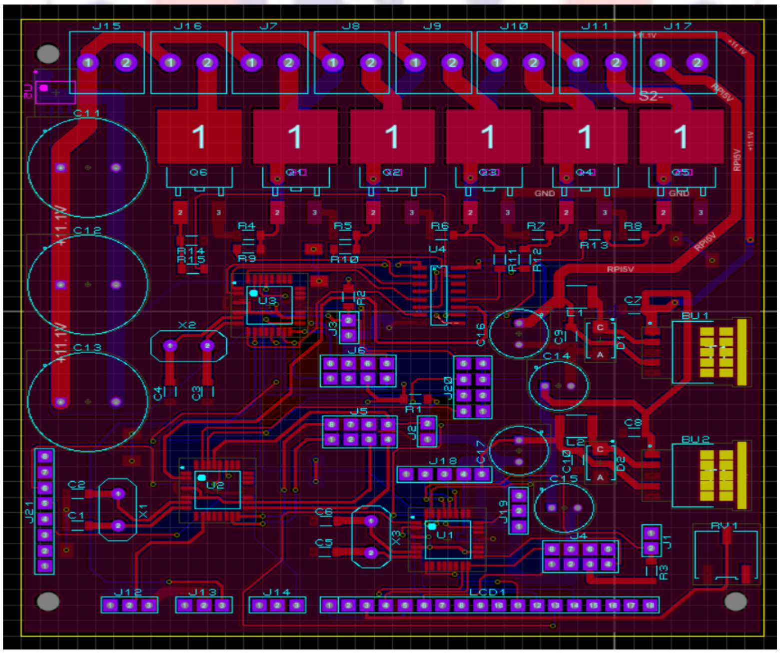

Figure 3.28. PCB layout

Figure 3.29 shows the rendered 3D PCB view with all the components placed using the Proteus Design Suite software.

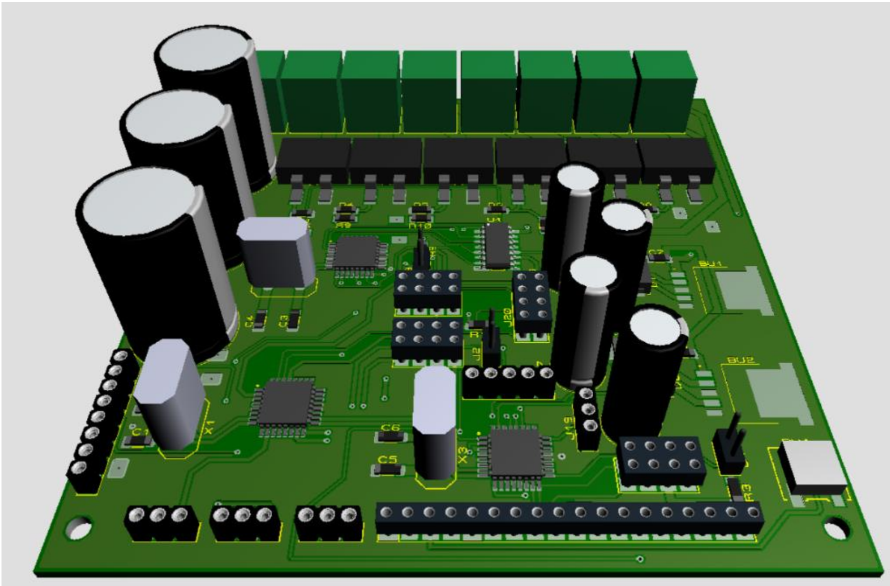

Figure 3.29. PCB 3D view

3.13 Machine Learning Approach

This approach is broadly divided into the processes of detection, extraction and classification. Figure 3.30 shows the block diagram of Machine Learning Approach.

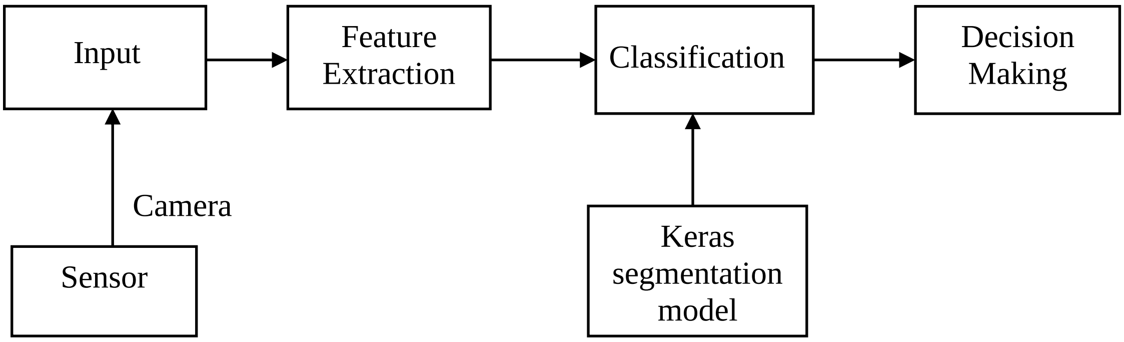

Figure 3.30. Block diagram of Machine learning approach

Input

Input data is collected with the use of camera. It captures data and is retrieved in the form of video at the rate of 30 frames per second. Then images are extracted from the captured data, that is further used for pre-processing like annotation and data augmentation.

Feature Extraction

For extracting useful information and omitting extraneous information, a feature extraction method is needed. In this project Histogram of Orientated Gradients (HOG) feature descriptor is used for feature extraction information, like the shape of the object, its color, the edges, background, etc. The HOG descriptor technique counts for the occurrences of gradient orientation in localized portions of an image-detection window and region of interest (ROI).

Classification

The image features generated by HOG is given as the input for classification algorithm. Both positive and negative features of region of interest are been given for classification. Binary classification algorithm called support vector machine is been used for classification task to remove false positives and correctly predict true positives.

CHAPTER 4

HARDWARE AND SOFTWARE IMPLEMENTATION

CHAPTER 4

HARDWARE AND SOFTWARE IMPLEMENTATION

This chapter deals with the implementation of hardware comprising of mechanical components and electrical components to make the submersible drone. Development of algorithm for software part includes detection of corals. Mechanical part includes the hull, vertical and horizontal plane mechanism, ballast, motor mounts, valves, bearing and sealing. Electrical part includes the BLDC motor, servo motor, PCB, pumps, solenoids, camera and motor controller. Software part contains keras segmentation model.

4.1 Submersible Drone-Control System

Submersible drone mainly consists of three parts in its control system for its functionality. They are:

- Main Ballast Pump control for controlling the depth of the submersible drone.
- Propulsion motor control for achieving the forward movement of the submersible drone.
- Rudder and Elevator control for the pitch and yaw control of the submersible drone.

Main Ballast Pump Control using single quadrant choppers

Main ballast pump serves the purpose of pumping the water into the ballast tank from the water body to adjust buoyancy. The control of diaphragm pump is achieved by using single quadrant choppers placed in a printed circuit board. The diaphragm pump is capable of building 100 psi pressure. Figure 4.1 shows the PCB containing freewheeling diodes.

Figure 4.1. Freewheeling diodes

Propulsion Motor Control signals

The propulsion motor is responsible for the forward movement of the submersible drone. The propulsion motor adopted is 300Kv BLDC motor. Propulsion motor receives signals from the 30A ESC. The speed of the propulsion motor is controlled by the SC incorporated in the PCB. Figure 4.2 shows the picture of 30A esc used in this project.

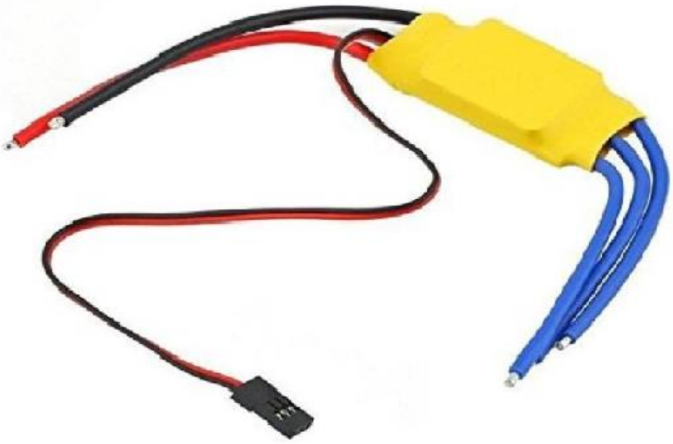

Figure 4.2. Electronic Speed Controller

Servo Motors for Rudder and Elevators

9g DC servo motor is adopted to control the rudders and elevators. Rudders are responsible for controlling the yaw of submarine. Elevator basically controls the pitch of the submarine There are two elevator servos. One at the tail of the submarine and another at the hull of the submarine. Three servos are used for the rudders, tail elevators and hull elevators respectively. Figure 4.3 shows the implemented rudder and elevator mechanism.

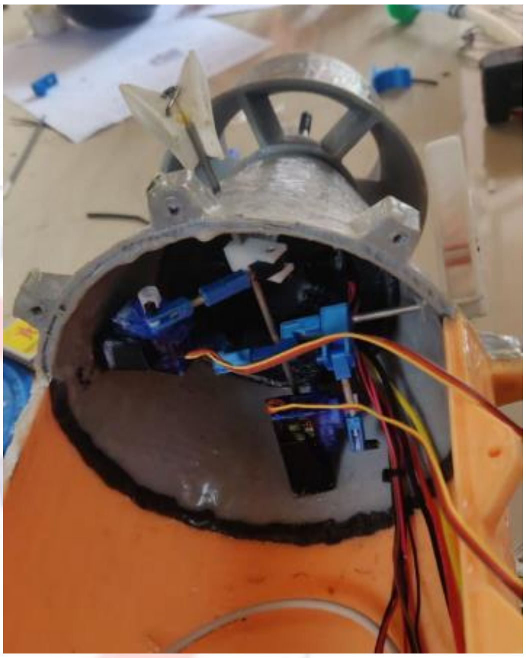

Figure 4.3. Rudder and Elevator mechanism with servos connected

Solenoid Control signals

Solenoid acts as a electronic water valve between the main ballast outlet and the output pump inlet. The purpose of using the solenoid is to hold the pressure built up in the main ballast. The solenoid gets it's power from the single quadrant chopper that is in turn controlled by a onboard computer. The position of solenoid and diaphragm pump is shown in the Figure 4.4.

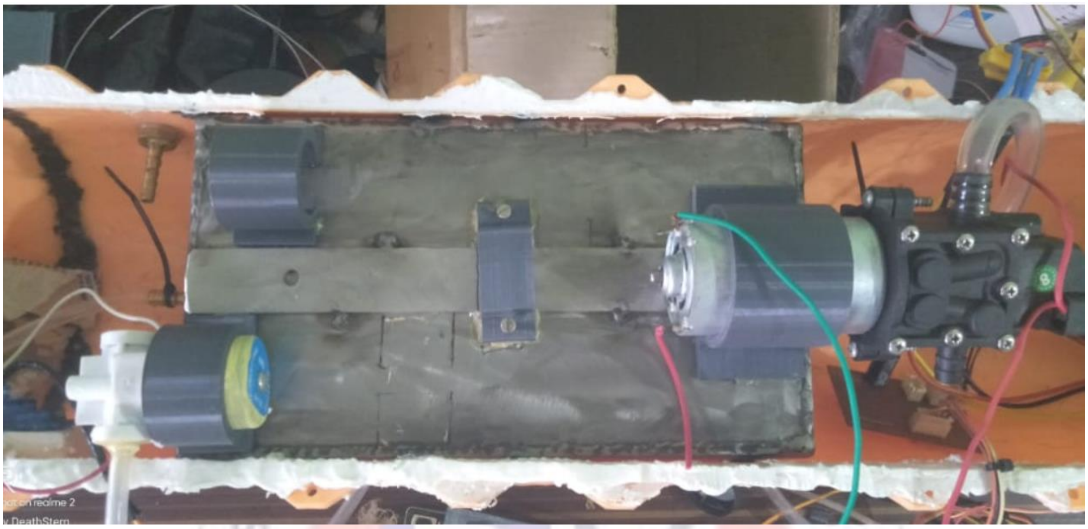

Figure 4.4. Solenoid and diaphragm pump fixed on ballast

PCB soldering

The PCB layout designed using proteus software is printed and the components are soldered to the board manually using soldering iron. Figure 4.5 shows the final PCB.

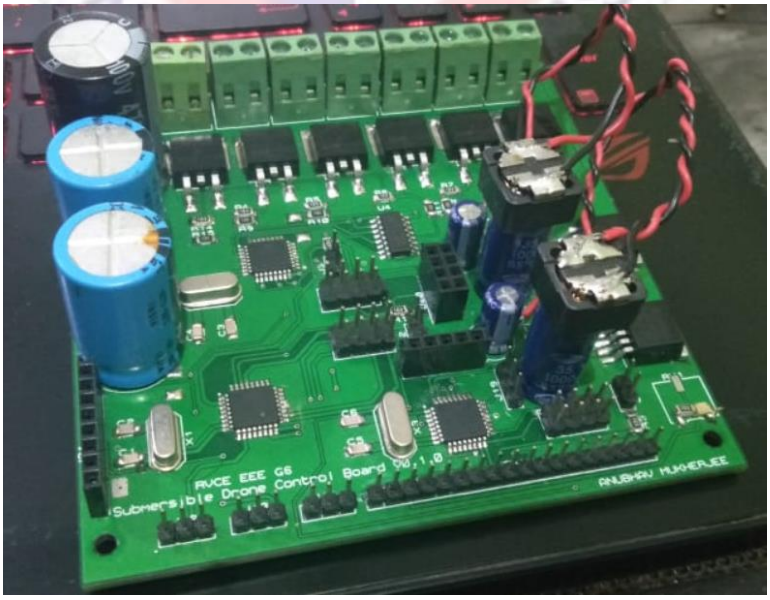

Figure 4.5 Final PCB with components

4.2 Submersible Drone-Mechanical Implementation

Submersible drone is a mechanically complex vehicle. It includes several components like main ballast, fixed ballast, different pump holders, charging port, Camera holder, Electronics holder box, propulsion motor holder etc. Some of the complex parts are explain under this topic. Figure 4.6 shows the different view of the 3D printed submersible drone.

Figure 4.6. Different views of 3D printed Submersible drone

Main Ballast Tank

Main ballast is the heart of submarine i.e. it makes the submersible drone submersible. To be elaborate, the buoyancy of the whole submarine is controlled by filling the water into the main ballast pump and vice versa. The input to the main ballast tank is supplied by diaphragm pump and the output is managed by centrifugal pump. The main ballast tank is constructed using 3mm stainless steel sheets. Figure 4.7 shows the ballast built using 3mm thick stainless-steel sheet. Brass nozzles are used for both inlet and outlet valve. Stainless steel metal is chosen to make sure the ballast tank is rust free.

Figure 4.7. Top and Isometric view of stainless-steel ballast

Propeller

A **propeller** is a device with a rotating hub and radiating blades that are set at a pitch to form a helical spiral, that, once rotated, performs an action that is similar to Archimedes' screw. It converts rotational power into linear push by acting upon a water. Figure 4.8 shows the propellers printed through FDM and SLA process.

Figure 4.8. Propeller modelled using FDM process and SLA process

Guide Planes

Guide planes basically directs the fluid into the propeller for easier propulsion. They also protect the propeller from mechanical damage due to collision with other particles in the water body such as twigs, aquatic life, underwater plants etc. Figure 4.9 shows the 3d printed propeller shroud.

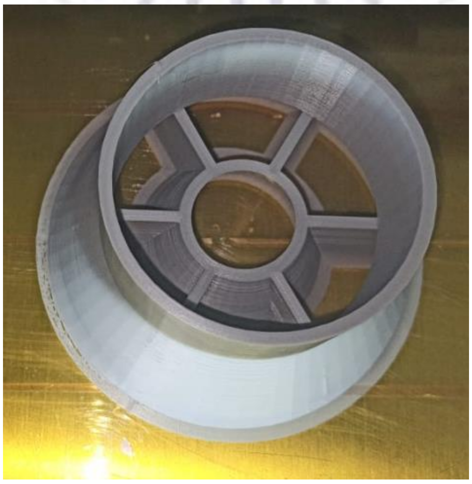

Figure 4.9. Propeller shroud

Sealing and Plumbing

Sealing of underwater devices is a complicated task so choosing the correct materials for sealing is a necessity. Hull of the submersible drone is coated with a resin at the ratio of 10:1 resin and hardener respectively.

4.3 Submersible drone control GUI

The control system of the drone is build up according to required outputs and means of providing the output. But for the control system of actively decide what outputs has to be made, it is necessary to have a way of providing input to it. To bridge the gap between the user and the control system, a front-end GUI based application was made that provides a human machine interface to convey instructions to the device underwater and both display the camera feed so that the submersible drone is navigated easily.

The GUI is created in C++ with various python wrapped embedded code. The IDE used for the backend and frontend of the software is Qt as they provide a rich library of implementable functions and extensive graphic library that is available for free. The final software is compiled as a semi-standalone executable file that works with the support of the framework dlls (dynamic link libraries) from the system's OS and Qt's libraries.

4.3 Deep Learning Approach

The design of this approach has been divided into two sections namely training and testing phases. Both of them follows particular flow of processes to ultimately obtain a model that helps in the segmentation of the corals.

4.3.1 Training Phase

During training phase, main processes involved are data preparation for training deep learning architecture like darknet architecture by tuning hyper parameters such as learning rate, number of epochs, batch size. The trained model is later used in testing phase for detection and classification of object of interest.

The Figure 4.10 shows the block diagram of training phase of the deep learning approach.

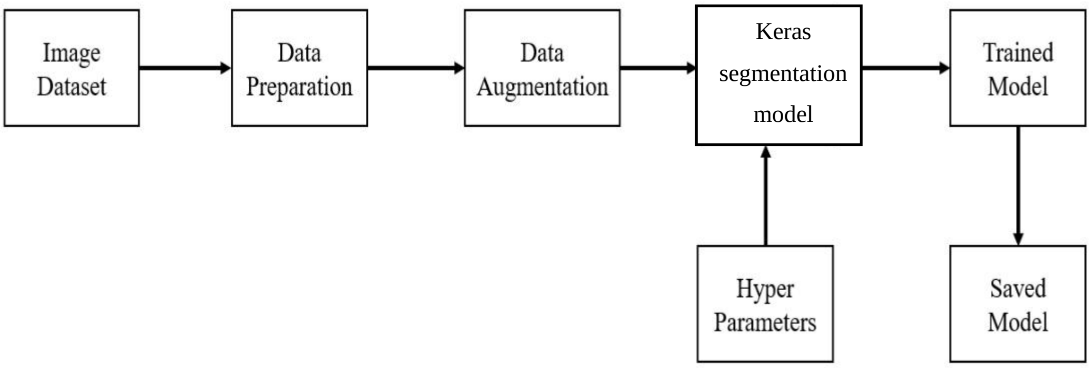

Figure 4.10. Block diagram of training phase of deep learning approach

The flow of the whole phase is described in the following:

Image Dataset

The first step is to obtain the dataset of different types of corals. The dataset two types of corals brain coral and the acropora coral are obtained from the google images of 150 nos each.

Data Preparation

In data preparation process image dataset obtained is cleaned and scrutinized. Ground truth for two different types of coral brain coral and acropora coral need to be prepared for training deep learning model. Ground truth is the part of the image were the coral present in image dataset. This will also be helpful in performance evaluation of the deep learning model results. Ground truth preparation carried out using annotation tool called Adobe Photoshop.

Selection and filtering the dataset

During the process of selection of the images, some of the images that were over focused shown in Figure 4.12. Normal image is shown in Figure 4.11. Due to present of such images the model will unable to learn the features of the background that will in turn lead false positive and thus reducing the overall efficiency of the model.

Figure 4.11. Normal image

Figure 4.12. Over focused image

Once the sufficient dataset is ready for the image processing the images are equalized and the annotation is carried out for further segmentation of the various classes of corals. The

Annotation is the process of manually defining regions in an image and it is done using the Adobe Photoshop as shown in Figure 4.13 and Figure 4.14 respectively.

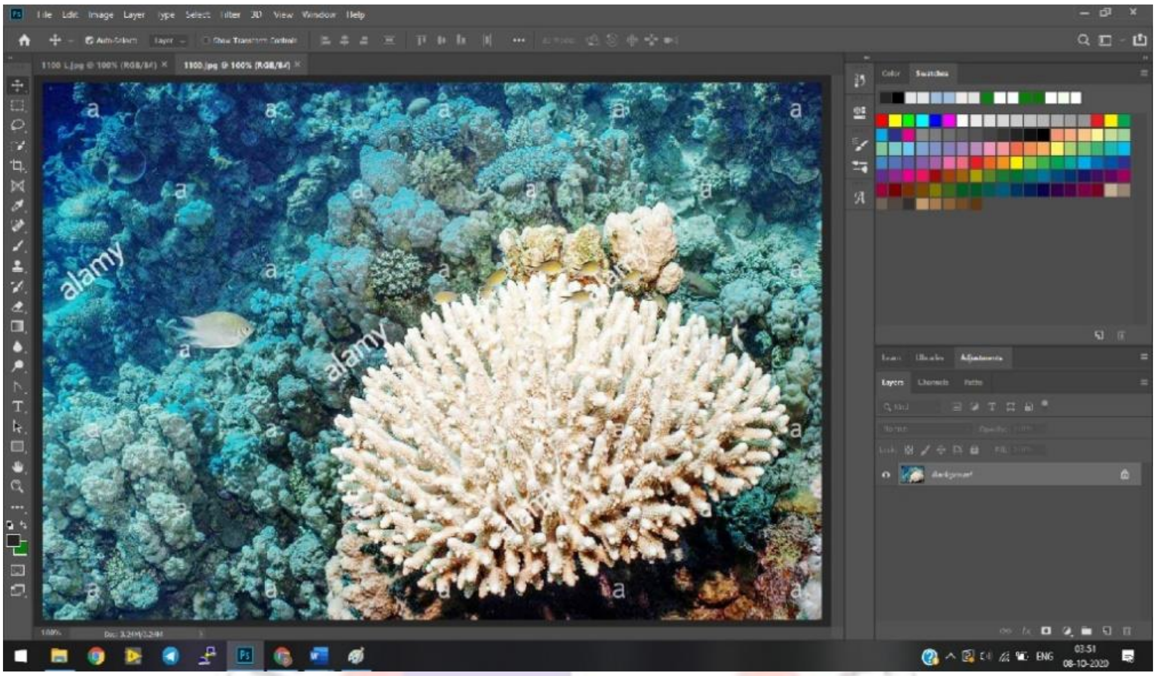

Figure 4.13. Coral before Annotation

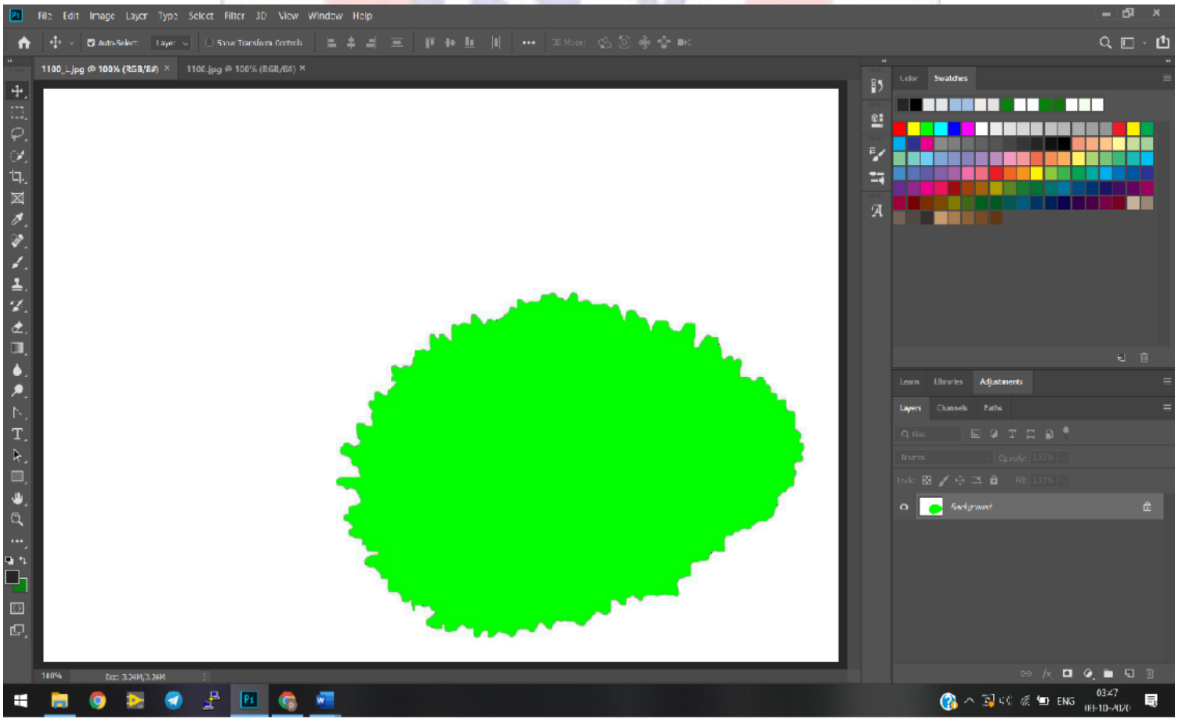

Figure 4.14. Coral after Annotation

During this process the black color(256,256,256) is set for brain coral as shown in the Figure 4.15 and green color (0,256,0) is set for the acropora coral as shown in the Figure 4.16. In the annotated images the background is set to white color (0,0,0).

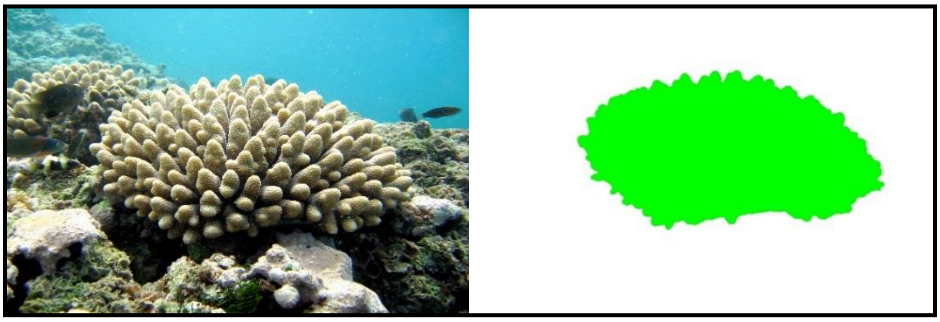

Figure 4.16. Original and annotated acropora coral

Figure 4.15. Original and annotated brain coral

Data Augmentation

Deep learning model requires more data; Data set might not have some scenarios that might occur during testing phase. To overcome this drawback and also increase data for training, data augmentation like flipping, rotation, translation, cropping, shear effect is carried out.

4.4 Detection using Keras Segmentation model

The function takes an image as input and outputs a matrix, or mask. Each element tells the class or instance that pixel belongs to. Some high-level features of images are useful for segmenting images. Color, for example, is a common one. White screens ensure the background of an image is a single color that is programmatically detected and replaced in post-processing. Heuristics like these form the basis for traditional segmentation algorithms based on image histograms, edges, and other clustering techniques. While these techniques are simple, fast, and memory efficient, they typically require lots of use-case specific tuning and have limited accuracy on complex scenes. More recently, machine and deep learning has emerged as a powerful new tool providing flexibility and high levels of accuracy. Machine learning approaches to image segmentation train models to identify that features of an image are important, rather than designing bespoke heuristics by hand. Deep neural networks have proven particularly adept at performing segmentation tasks. Figure 4.17 shows the UNet Segmentation process.

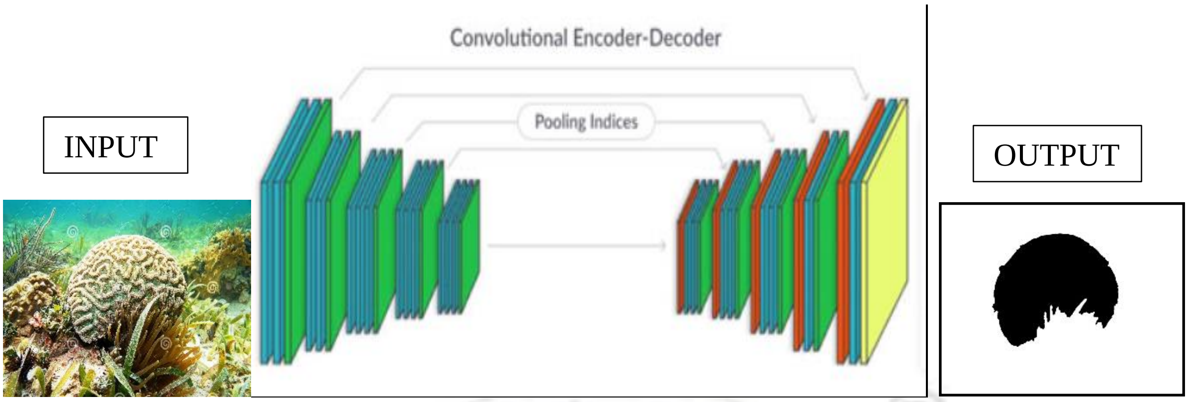

Figure 4.17. Keras Segmentation model

CHAPTER 5

RESULTS AND DISCUSSION

CHAPTER 5

RESULTS AND DISCUSSION

This chapter deals with results obtained from this project. Results include PCB testing, Guide plane testing, BLDC motor testing and Ballast pressure testing. Result obtained i.e. detection of coral is shown in this chapter.

5.1 HARDWARE RESULTS:

Testing is defined as a capability of a component or structure to withstand and operate in a required condition.

PCB Testing

Programming the ATmega328 microcontroller is done by the use of Arduino through ICSP pins. The MOSFET's were tested for its switching operation. The output of the gyroscope and accelerometer is tested for its outputs at different angles and motion. DC-DC converter were tested to get the required voltage.

Rudder and Elevator Testing

Control signal is applied to the rudder and elevator servo mechanism to check its operation and performance. Figure 5.1. Rudder and Elevator position 1 and position 2 shows different position of rudder and elevator wings. During this process several mechanical modifications

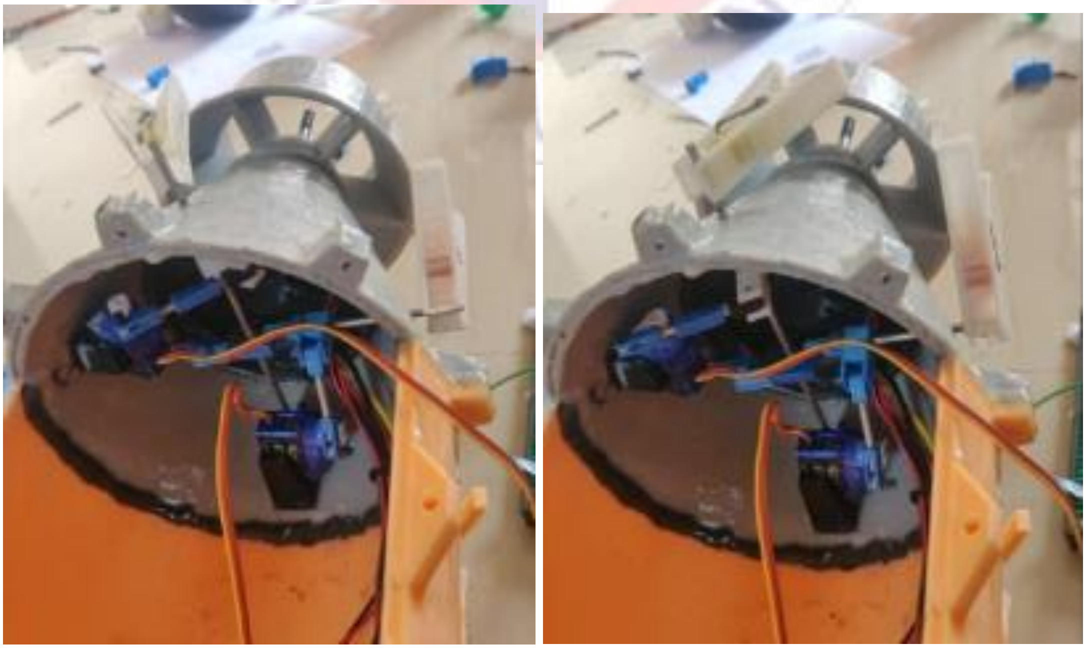

Figure 5.1. Rudder and Elevator position 1 and position 2

were done do get the desired operation. Servo is controlled by supplying pwm signals as shown in Figure 5.2.

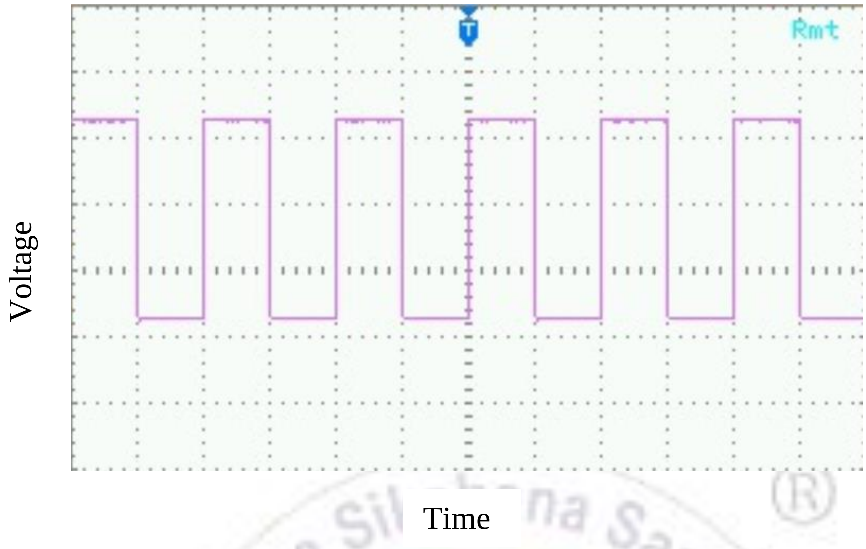

Figure 5.2 Servo motor signal waveform

Propulsion Motor Testing

Propulsion motor is tested with propeller connected to detect the amount of thrust exerted by it into the water. Figure 5.3. Propulsion motor at zero throttle and full throttle shows the Propulsion motor at zero and full throttle. For the purpose of testing, the PWM signal is

Figure 5.3. Propulsion motor at zero throttle and full throttle

generated by Arduino nano as shown in Figure 5.4. The speed from zero throttle to maximum throttle is applied to test the mechanical withstand ability of the propeller. Figure 5.5 shows the voltage across the two terminals of BLDC motor.

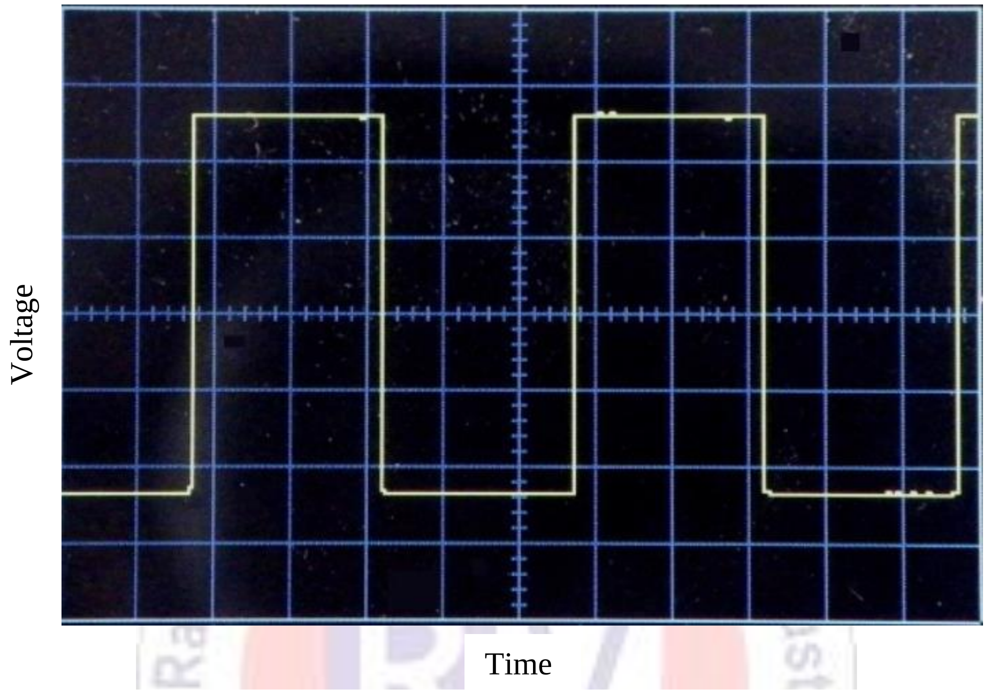

Figure 5.4 PWM signal for ESC

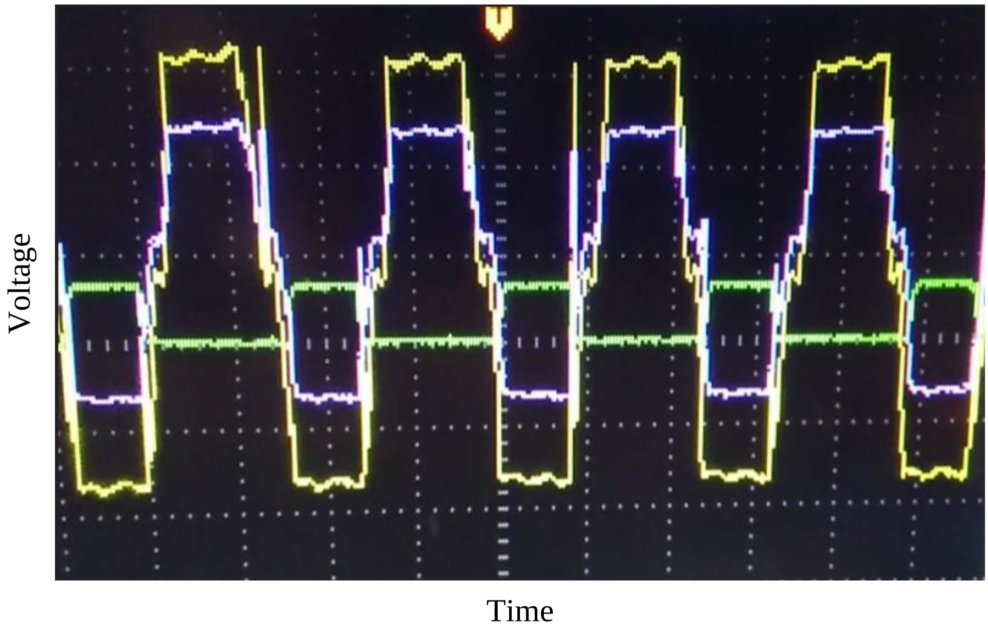

Figure 5.5 Voltage across two teminals of BLDC motor

Ballast Pressure Testing

There are four cases in this topic that describes about all the issues faced. It covers different designs designed for the sole purpose of withstanding the pressure required to fill certain volume of water.

Case 1: The structure shown in Figure 5.6 is designed and 3D printed, treated with acetone to make it completely water tight. For the sole purpose of testing the pressure holding capability

Figure 5.6. Pressure testing vessel

of the PLA material this effort is made. The test piece is able to withstand 50 psi pressure without leakage. The diaphragm pump turned off automatically after reaching 50 psi pressure due to pressure limit switch.

Case 2: The desired volume ballast is designed and 3D printed, sealed with araldite, two coats of resin in the ratio of 10:1 resin and hardener respectively is applied inside and outside of the ballast. Left to cure for 5 days. During the pressure testing of the ballast there were several

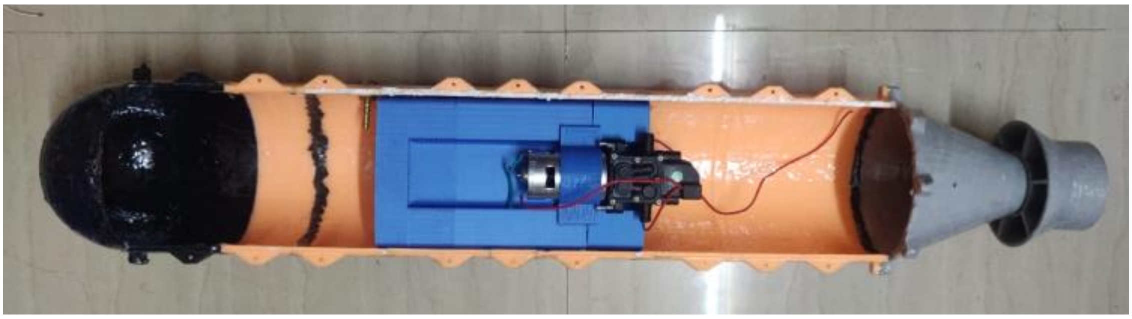

Figure 5.7. Ballast 1

leakages that were not good for the submersible drone so this ballast design failed. Figure 5.7 shows the ballast inside the submersible drone.

Case 3: New model with better interlocking mechanism for ballast is designed and 3D printed, coated with resin two times in the ratio of 10:1 resin and hardener respectively. Araldited at borders. During the pressure test it leaked at edges so this ballast also failed. Figure 5.8 shows the second failed ballast.

Figure 5.8. Ballast 2

Case 4: Considering all the failed ballasts, it is proved that 3D printed ballast cannot hold the pressure. In order to withstand the pressure, the only option left is to use stainless steel ballast

Figure 5.9. Ballast 3

because stainless steel is rust proof. Proper sheet metal design is made using Solidworks. Cutting and welding of sheet metal is done in the workshop. Newly designed stainless-steel ballast held the 50-psi pressure and the result came as success. Figure 5.9 shows the final ballast approved for implementation in submersible drone.

GUI APPLICATION

The GUI application consists of various gauges, a control input stream that works with both keyboards and joysticks and a central video feed that streams the submersible drone's on board computer. This all in all concludes for a seamless control process and makes the submersible drone easy and engaging to use. Figure 5.10 shows the GUI application with live video feed .

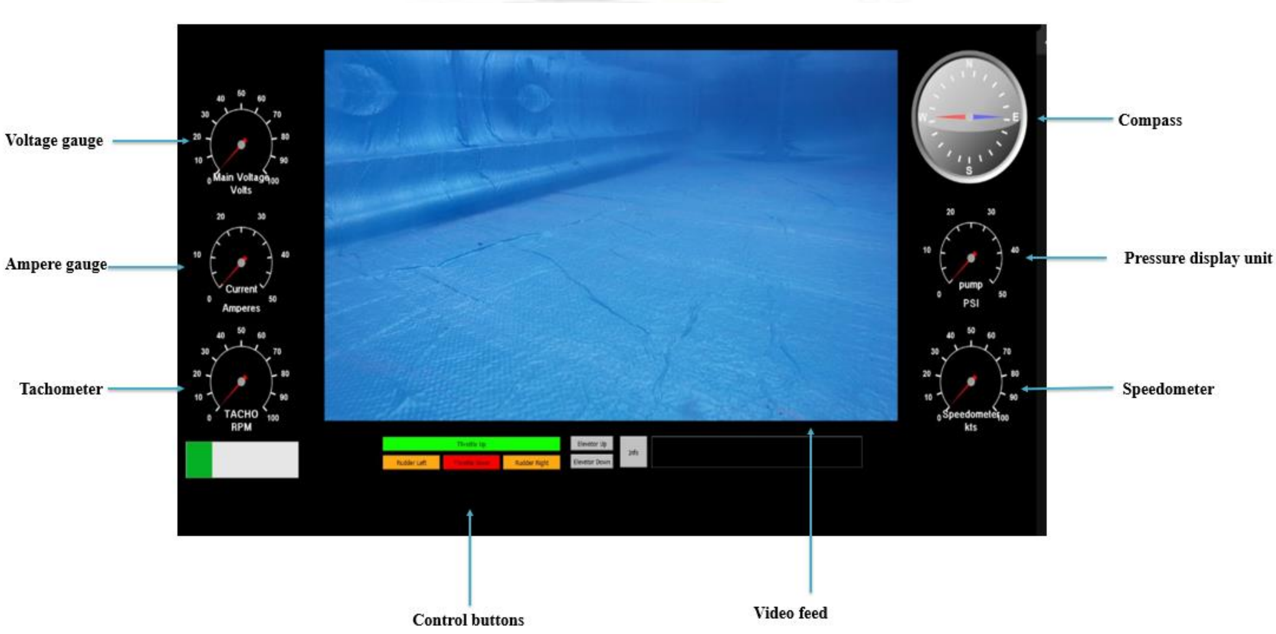

Figure 5.10. Submersible Drone control software

5.2 SOFTWARE RESULTS

The coral reef plays very important role in the marine ecosystem. The corals provide the habitation and shelter to many marine organisms. The coral detection is achieved in order to track the concentration of different types of corals at different location. With the help of video that is capture on the camera the health of the coral can also be tracked periodically. Coral detection is used to classify the different types of coral that are found deep under water.

Detection Types

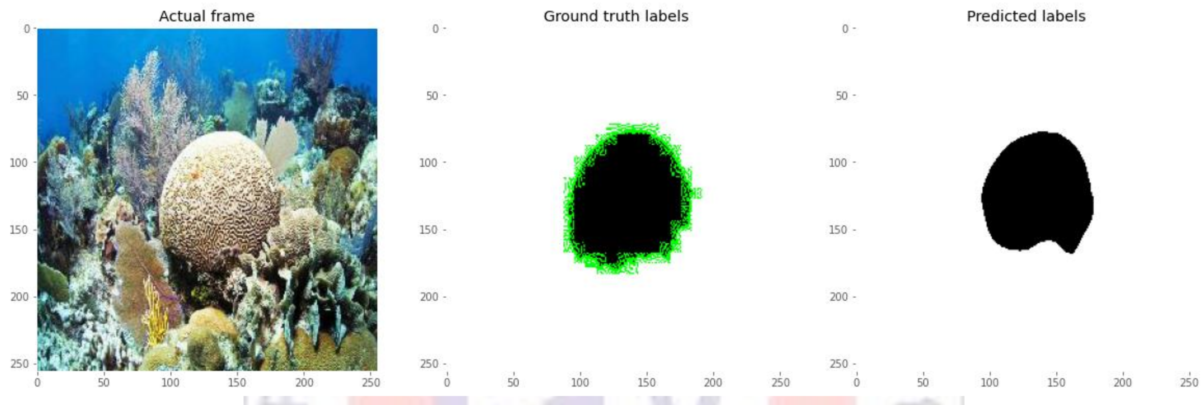

Figure 5.11. Brain coral prediction

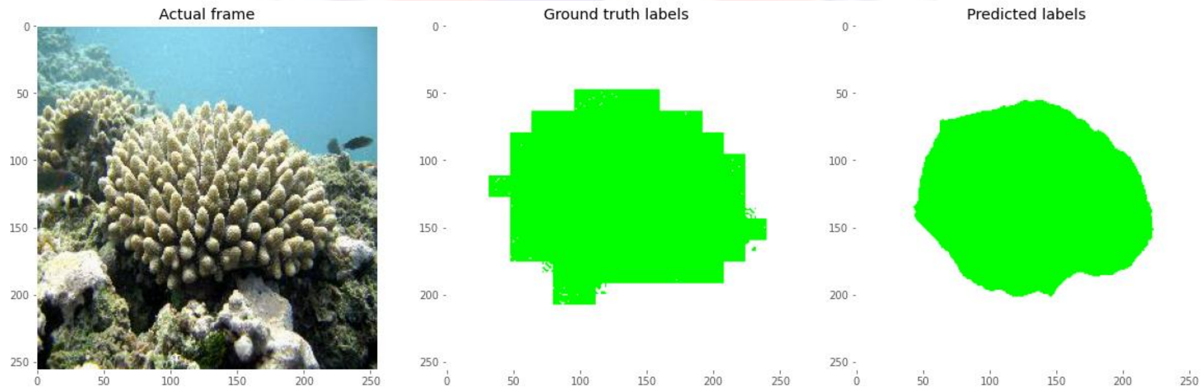

Figure 5.12. Acropora coral prediction

In this project two most commonly found corals are considered that are brain coral and acropora coral. The segmentation is achieved by assigning the corals with respective color in order to differentiate the two types of corals. In this process the brain coral is set to black cooler(0,0,0) as shown in Figure 5.11. Brain coral prediction and the acropora coral is set to green color(0,256,0) as shown in Figure 5.12.

The detection consists of the actual frame that is to be detected and the ground truth label shows the actual coral that has to be detection and the predicted label shows coral detected by the model that is build and trained in this project. The level of detection varies depending upon the complexity of the image that is to be detected. The Figure 5.11. Brain coral prediction shows the level of detection of the brain coral even though the complexity of detection was high because at the background there were many other aquatic organisms but it could precisely detect only the coral and classify the type of the coral. Figure 5.12 gives the detection and classification of acropora coral.

Figure 5.13. shows the detection of coral from a video feed.

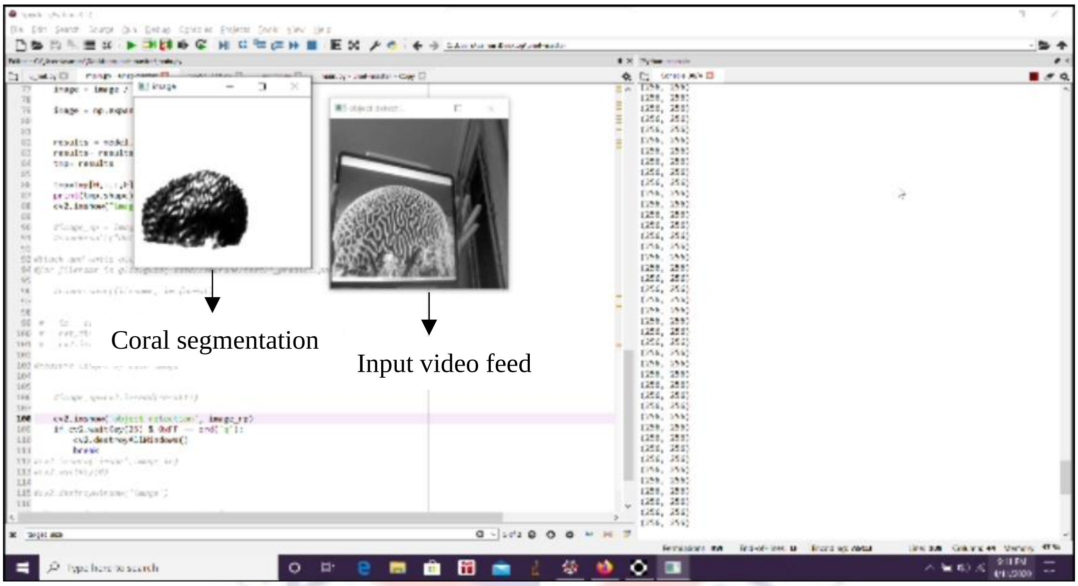

Figure 5.13. Video feed detection

Model Accuracy and Graphs

CNN arrcitecture along with UNet model was used to obtain the real time detection of coral. It was implemented using OpenCV and Python. Along with Python programming language, Numpy, Tensorflow, Keras libraries were used. The dataset was downloaded from various sources from the Google images were used to train and test the model. The dataset consists of two types of corals namely brain coral and acropora coral. The training set consists of about 300 sample images while the test/validation set consisted of 35 sample images, that is 90% of dataset was used for training and 10% of dataset was used for testing. Validation set was used to validate the training process. About 15 epoch cycle were run to obtain an accurate results.

In every epoch the accuracy, loss are noted. The accuracy models obtained for the project are as shown in Figure 5.14.

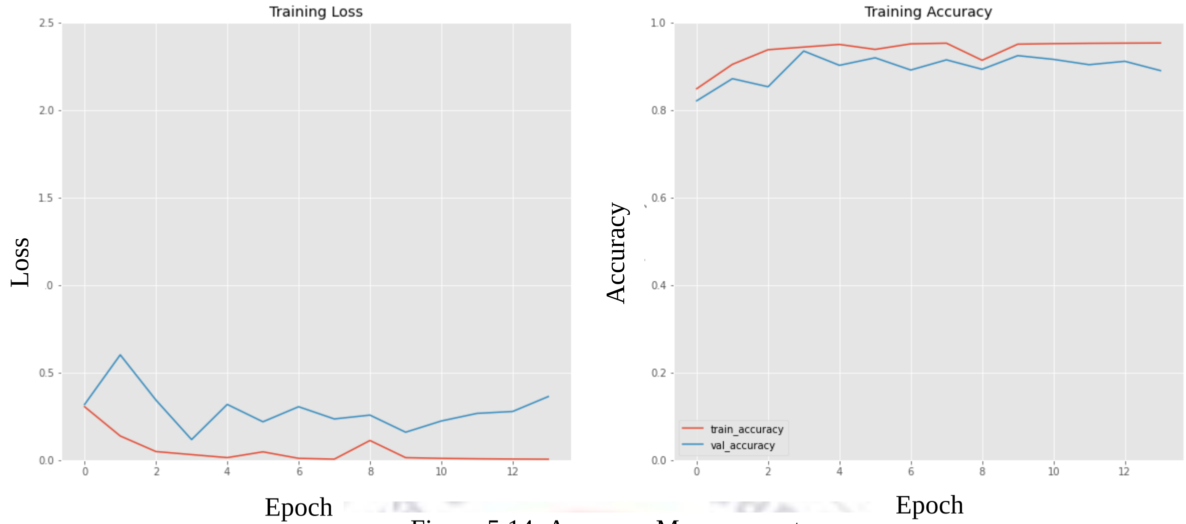

Figure 5.14. Accuracy Measurements

Accuracy here is a metric for evaluating classification models. It is a measure of accuracy of the model predicted compared to the true data. As seen from the graph, accuracy during testing is more than that during training of the dataset.

Loss function is used to optimize a machine learning algorithm. The loss is computed on the training and the testing dataset and is analyzed based on what degree the model is working in these 2 datasets. As seen from the graph, loss during testing is about 3.6% and loss during the training is about 0.46%. The accuracy of the model is about 95% during the training and about 92% during validation.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

Most of the marine life is dying today. The pollution is increasing day by day. A large portion of our waterbody is full of wastes. Most of the small fishes use corals as their habitats. To tackle this predicament active monitoring of aquatic life is imperative. Corals are dying around the world due to Coral Mining, Climate change and other abusive actions by human. Most ROV (remotely operated vehicle) available in the market are of vertical propeller type that uses second propeller for the sole purpose of maintaining depth. These ROV are ballast free and the lack of ballasts hugely limit the air tight payload capacity as buoyancy in these systems are a function of continuous power. The use of ballast tanks can change and hold the buoyancy passively without using any more power after the required buoyancy is achieved. Thus, allowing for a larger payload to be carried without losing any power for underwater hovering for long duration.

A desktop software is built to view the field of view of the submersible drone and to send the control signal to the Submersible drone through Tx module. Control signals in the form of RF waves sent by the Tx module is received by the Rx module. Rx module converts RF waves to corresponding signals and send them to the Dive controller through Raspberry Pi. Upon detecting the particular signal propulsion control, heading control and depth control is activated to control yaw, pitch, depth and forward movement of the submersible drone. Camera connected to the Raspberry pi transmits the live video to the laptop for navigation. Another camera stores the video and is processed later to segment two types of corals in a powerful computing machine.

6.1 Conclusion

CNN algorithm was implemented by keras segmentation model using unet architecture in google colabs platform. 300 images were used for training the keras segmentation model. Accuracy obtained during detection was 90 percent. Ballast was able to withstand 50 psi pressure. Overall weight of the submersible drone is 14 kg with full ballast and 12 kg with empty ballast. Desktop application was built using Qtcreator to navigate the drone remotely. The diaphragm pump is able to pump 8 liter per minute. The PCB is able to give required signals for the operation of all the components. The servo signal values are set to 0 and 70 for elevator mechanism and 30 to 100 for rudder mechanism for proper movement. The current drawn by the bldc motor at full load is 30 Amps. 3d printed propeller was able to generate enough thrust to move the submersible drone.

6.2 Future Scope

The following are the future scopes of the project:

- Autonomous underwater surveillance.
- AI based inspection and repair of dams.
- Underwater construction assistance.

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