Technical Design Report

Rahul Nath Raghunathan
Department of Ocean Operations and Civil Engineering
Norwegian University of Science and Technology (NTNU)
Ålesund, Norway
rahulnr@stud.ntnu.no

Vebjørn Bjørlo-Larsen
Department of ICT and Engineering
Norwegian University of Science and Technology (NTNU)
Ålesund, Norway
vebjorbj@stud.ntnu.no

Michal Edward Malisz
Department of Ocean Operations and Civil Engineering
Norwegian University of Science and Technology (NTNU)
Ålesund, Norway
michalmalisz@hotmail.com

Sai Rana Thattavelil Sunilkumar
Department of Ocean Operations and Civil Engineering
Norwegian University of Science and Technology (NTNU)
Ålesund, Norway
sairt@stud.ntnu.no

Pethigamuwage K Hemaka Malshan Perera
Department of Ocean Operations and Civil Engineering
Norwegian University of Science and Technology (NTNU)
Ålesund, Norway
pkmalsha@stud.ntnu.no

Nicolò Oreste Pinciroli Vago
Department of ICT and Engineering
Norwegian University of Science and Technology (NTNU)
Ålesund, Norway
nicoloop@stud.ntnu.no

Kaung Htet San
Automation Engineering
Norwegian University of Science and Technology (NTNU)
Ålesund, Norway
alonelay@gmail.com

***Abstract*—This report depicts the development proposal of Autonomous Surface Vessel from NTNU, Ålesund. The proposal has been designed to participate in both national and international competitions (e.g. RoboBoat) conducted by RoboNation and AutoDrone. This report outlines the basic mechanical and electrical studies regarding the initial design of the ASV.**

***Index Terms*—ASV, AI, Autonomous, RoboBoat**

I. Introduction

This Technical Design report is based on the development of an Autonomous Surface Vessel intended to participate in competitions such as RoboBoat and AutoDrone. Since there have not been previous development of ASV available to the team, every aspect of the ASV had to be developed from scratch.

Even though we were only starting out, we wanted to have an ASV platform that is modular and extensible. We decided to use Robotics Operating System as our base of the software, as it is open source and hold great potential in the long run for modification. Similarly, on the mechanical side, it was decided to use the college's CNC Milling machine to accelerate the development of the hull for the test purpose.

As for Electrical and control side, we decided to use the drone autopilot Pixhawk.This meant that we had to spent less time on coding for basic test setups as Pixhawk has great initial support for basic autonomous missions. However, for advanced tasks, proper understanding of Pixhawk's native code is required. This is a trade-off that we had to make for setting up a boat in a very short time of around 1 month which could be tested for the first mandatory mission.

II. Competition Strategy

A. Autonomous Navigation

On the Autonomous navigation end, we have only aimed at the first mandatory task of the competition where we have to move through a channel demarcated by buoys at the start and the end.As the starting point of the buoys is given through GPS coordinates of the centre and the ASV is localised through its own GPS coordinates, the shortest path between goals is calculated using A-star algorithm. In order to maintain the heading between points a simple PID controller is implemented.

III. Design Creativity

A. Boat design

The design of our boat has been debated from three standard types, a mono hull, a catamaran and a trimaran. The initial idea was to go for an trimaran, due to its good stability, seakeeping, large enough deck area and space in the hull. This was deemed to be harder to manufacture after consultation with some teachers. A mono hull is much harder to balance for small sizes and thus has been disregarded quickly. The go to design is an catamaran.

We wanted to go quickly into testing, so we designed a simple hull large enough to house all important equipment. The hull's dimensions were within the limits of our available foam for milling by CNC. The limits are a box of length of 1.0m, beam of 0.5m and a depth of 0.1m. Two boxes has been used to create the top and the bottom layer of the hull, the layers have then been glued together.

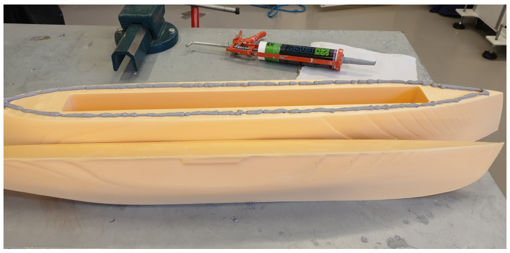

Fig. 1: Hull model in parts

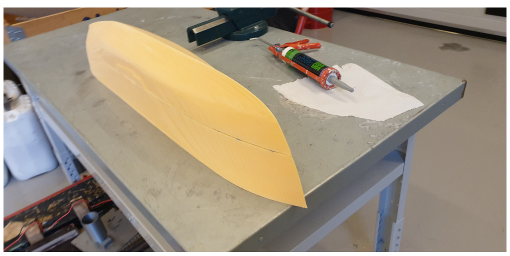

Fig. 2: Glued hull model

We had an estimated displacement of around 17kg. Our desired block coefficient is around 0.4 and a prismatic coefficient of around 0.7. The light ship weight is calculated by sinking the entire hull down to its total depth of 0.2 metres. We can then use the wetted surface area and multiply it with a thickness of around 2mm, which gives us an estimated total volume of the hull. The density of E-glass type of glass fibre is around $2540kg/m^3$, thus the total estimated weight of the hull would be around 3 kg. This is a value that is bound to change.

Below is a simple table of hydrostatic value for an future glass fibre version.

Displacement	17.0 kg
Length	1.0 m
Beam	0.5 m
Depth	0.2 m
Wetted Area	0.508 m^2
Waterplane Area	0.248 m^2
Prismatic coeff.	0.730
Block coeff.	0.484
LCB	0.468 m
LCF	0.458 m
KB	0.077 m
KG	0.12 m
GM_V	0.224 m

TABLE I: Hydrostatic table for draft 0.12m

Loading condition for our foam based boat can be seen in table (II).

Item Name	Mass	Long. Arm	Trans. Arm	Vert. Arm
Battery stb.	1.5kg	0.458m	0.1916m	0.1225m
Battery port	1.5kg	0.458m	-0.1916m	0.1225m
Prop. SW	0.156kg	0.02m	0.168m	-0.057m
Prop. SE	0.156kg	0.02m	-0.168m	-0.057m
Prop. NW	0.156kg	0.98m	0.168m	-0.057m
Prop. NE	0.156kg	0.98m	-0.168m	-0.057m
Diverse eq.	2.0kg	0.458m	0.0m	0.26m
Weight SW	3.0kg	0.08m	0.168m	0.1225m
Weight SE	3.0kg	0.08m	-0.168m	0.1225m
Weight NW	3.0kg	0.86m	0.168m	0.1225m
Weight NE	3.0kg	0.86m	-0.168m	0.1225m

TABLE II: Loading condition for foam boat

Below is a table containing hydrostatic values for our existing ship.

Displacement	17.6 kg
Length	1.0 m
Beam	0.5 m
Depth	0.2 m
Wetted Area	0.604 m^2
Waterplane Area	0.339 m^2
Prismatic coeff.	0.732
Block coeff.	0.357
LCB	0.469 m
LCF	0.438 m
KB	0.079 m
KG	0.132 m
GM_V	0.211 m

TABLE III: Hydrostatic table for draft 0.122m

Hull design and hydrostatic calculations have been done using MaxSurf [1] and a 3D model of our boat design is done with Siemens NX [2].

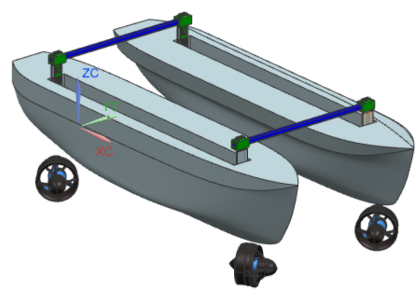

Fig. 3: 3D model - Siemens NX

B. Propulsion System

There are mainly two configuration we have looked into namely:

1) Conventional rudder and propeller configuration
2) A four thruster configuration

After carrying out research and study it was found that, a four thruster configuration was better to operate the vessel as it offered much greater thrust to weight ratio at the same time making it easy to control with more precise movement which is essential in maneuvering in tight spaces.

These four thrusters will be used to control:

- Surge: Longitudinal travel along horizontal plane
- Sway: Lateral movement along horizontal plane
- Heading: Rotation about the vertical axis

This will result in three degrees of freedom as shown in the figure below,

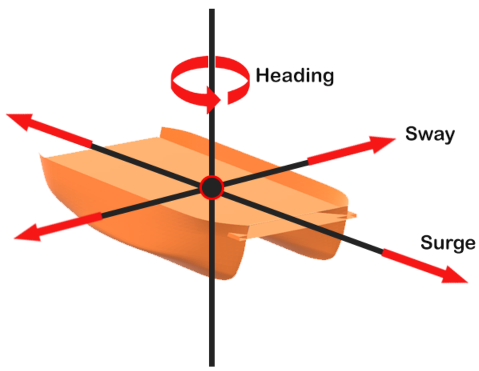

Fig. 4: Degrees of freedom

1) Thruster Specification: Factoring in cost, availability and performance characteristics without compromising the functionality of promised propulsion requirements to execute the given task was at-most control and precision as possible we have chosen T200 from Bluerobotics (Refer: [3]). This meets the requirements for the project with acceptable diameter, voltage, current, thrust, availability and reliability. Main technical parameters are given as:

- Diameter: 100 mm
- Voltage : 7-20 volts
- Current : 24 -32 Amps
- Thrust : 5.25 kg f*

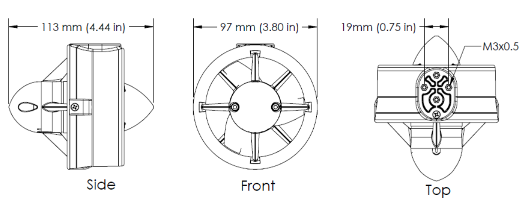

Fig. 5: Bluerobotics T200 Dimension Drawings

2) Thruster Characteristics: The thrust and efficiency characteristics are two important factors for the thrusters, which is plotted against the Electronic Speed Control by Pulse-width modulation (ESC PWM). This characteristics is obtained from the manufacturer (Refer: [3]).

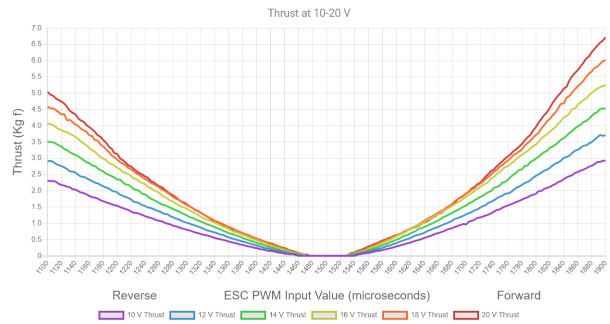

Fig. 6: Thrust vs ESC PWM

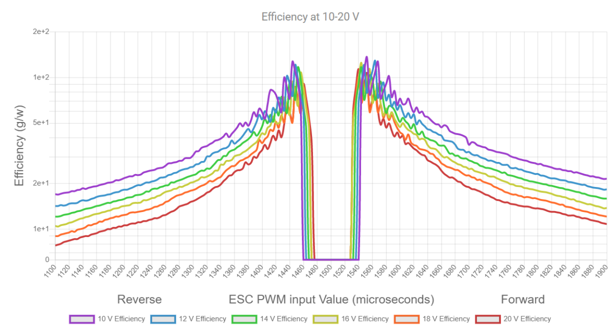

Fig. 7: Efficiency vs ESC PWM

These characteristics will give us an idea about the thrust and efficiency variations along with voltage steps.

The operational ESC input along side the thrust and efficiency variation which is instrumental in the constructive optimization of the system is determined though this curve study. Also we get the response of the thrusters with different voltage inputs. By this study we have a broader understanding of the performance window (optimal performance operability points) of the thrusters.

3) Thruster Layout: Thruster orientation is a crucial factor in which the overall efficiency of the configuration is pivoted upon. There two layouts that we have considered under four thruster configuration.

- Conventional Layout
- Vectored Layout

In the **Conventional layout** the thrusters are oriented in rectangular layout with two each, parallel to each other at each ends. (Refer: Fig 8). In the **Vectored layout** these thrusters are oriented at an angle (α) with the directional vector, with each pair in same configuration at the vertices rather than the ends.(Refer: Fig. 9).

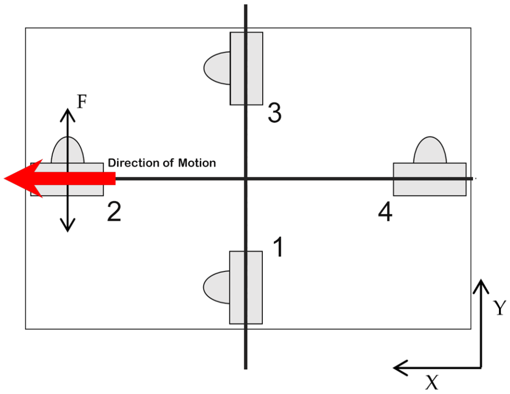

Fig. 8: Conventional Layout

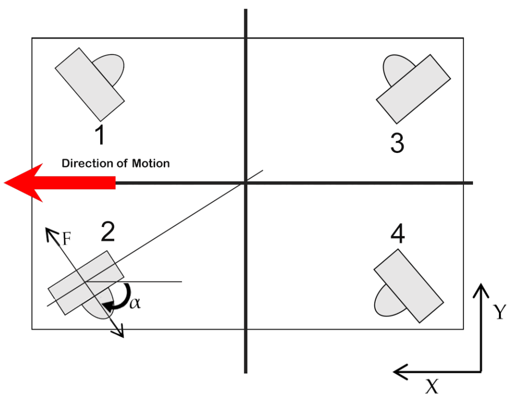

Fig. 9: Vectored Layout

For accuracy in control of surge, sway and heading the vectored layout is the best because of the positioning of the thrusters that amplify the control thrust (The thrust that is relevant in producing the turning moment). This proven vectored design is been accepted widely in industrial ROV design for its advantages such as:

- Vectored Layout has a higher thrust than the Conventional Layout.
- The Vectored Layout also have a higher tolerance to fault. (Refer: [5] and [4])

Due to all this advantages, Vectored layout is implemented.

C. Software Architecture

The software architecture is based on ROS.The boat utilises ROS Packages such as "MAVROS" for Pixhawk, "realsense-ros" for Intel Realsense Camera and ROS Navigation stack.

Even though we started with Pixhawk code base for initial tests, we had to assess the inner workings of the Pixhawk to modify its functionalities. For example, the motor commands could be controlled through Mavlinks RC channel commands as well as using proper ROS approach. This was tested using the custom built packages.

During the initial work, GUI's were designed to test out boats motor functions and well as to test the positioning capabilities of boat in water using a Way point plotter. We also use existing open source softwares such as Mission Planner and QGround Control to plan and test the missions of the boat.

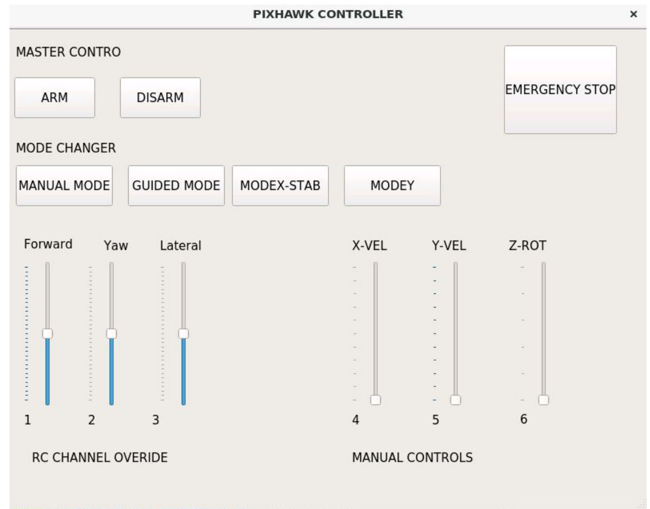

Fig. 10: GUI for testing Motors

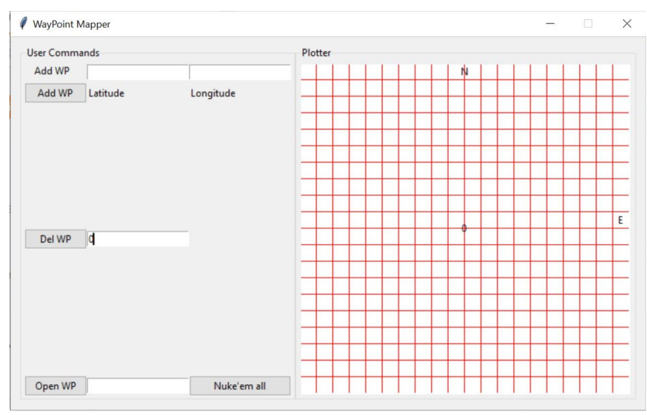

Fig. 11: GUI for Dynamic Position Test

The ROS runs on a Jetson Nano and Pixhawk and camera is connected to it. While the Nano runs the ROS Master node, the information from Camera and control signals was configured to be transmitted ROS Network configuration. This was needed for us to analyse what's exactly happening during tests and many setup was new to us. This was expected as we want to find out through trial and error.

For object detection and mapping of the local area in front of the ASV, a combination of OpenCV, Intel® RealSense™ SDK and YOLO real-time object detection is used.

YOLO detects objects in real-time using a neural network. To train the network we plan to use a training set of images taken from videos of previous competition, as well as video from our own testing on the testing days if required. The trained network is used with OpenCV for the actual detection. OpenCV grabs frames from the camera and passes them through the network.

To map the area and to find obstacles, hits from the object detection are tracked and placed using the image coordinates and depth information from the RealSense camera using the RealSense SDK. With this map we can perform path planning and correct the current velocity of the ASV to hit the desired target.

D. Electrical

Components of our boat includes D435 Real Sense Camera, Jetson Nano, four thrusters, Pixhawk, GPS and AHRS. D435 Real Sense Camera and WiFi is connected to the Jetson Nano for processing information from camera and receiving signals from Ground Station. Pixhawk is connected to Jetson Nano and manages GPS, AHRS and Thruster. The circuit are designed based on the power draw of each component. The maximum power draw is from the thrusters and is the deciding factor of the battery life of the boat. With 15000 mAh battery capacity, our boat is able to run for around 30 minutes.

References

[1] Maxsurf maximize vessel performance.

[2] Nx for design streamlines and accelerates the product development process.

[3] bluerobotics. bluerobotics t200. *https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster/*, 2020.

[4] Edin Omerdic and Geoff Roberts. Thruster fault diagnosis and accommodation for open-frame underwater vehicles. *Control engineering practice*, 12(12):1575–1598, 2004.

[5] Sheldon Rubin. Mini-rovs, going where no rov has gone before. In *2013 OCEANS-San Diego*, pages 1–4. IEEE, 2013.

APPENDIX

A. Components and Team

Component	Vendor	Model/Type	Specs	Cost(USD)
Electrical and Mechanical Specifications				
ASV Hull Form	Handmade from foam	Catamaran		50
Propulsion(Thrusters)	BlueRobotics	T200(4 Nos)	5.1 kgf Thrust	824
Waterproof Connectors	Local Shop			10
Computer	Nvidia	Jetson Nano		199
Camera	Intel	Realsense D435		180
Controller	mRobotics	Pixhawk 2.4.6		199
WiFi	DLink			College
GPS	mRobotics	U-blox Neo M8N		68
Team				
Team Size	11			
Expertise(Hardware vs Software)	5 vs 4	Business: 2 members		
Programming Language	Python,C++			

B. UML diagram of the boat