Istanbul Technical University Autobee RoboBoat 2022 Technical Design Report

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Abstract—VesselBee is a autonomous trimaran designed by ITU Autobee. Low draft, low displacement and hydro-dynamic trimaran designed for Roboboat 2022. This paper mentions about our competition strategy, design criteria and engineering decisions made specifically for Roboboat 2022. Starting from mechanical prospects till the software enhancements made over the land-based vehicles which team specialises for 6 years. Also includes our unique approach to propulsion and manufacturing techniques on vessel design.

I. Competition Strategy

Since our foundation at 2016, Autobee has always competed with previous year's Autobee. Beginning to USV journey for the first time in it's history, we have achieved to be finalist in Turkey's biggest USV challenge. Our goal is to become Turkey's best in 2022 and after that in Roboboat 2022. After 7 years of experience on land we had so much experience for certain areas such as image processing, ROS and manufacturing techniques. With given experience we have assessed all the given tasks and managed to come up with unconventional strategy.

For this year's event we have decided to complete task 1,2 and 3 completely and decided not to do tasks 4 and 5. With this decision we have aimed to collect points from weight of the vessel and Thrust vs Weight section from the competition. This decision also allowed us to aim for the fastest task 1,2 and 3 completion. For these purposes image processing had to be sharp and accurate. We have used over 5000 labeled pictures from our testing for machine learning. Pictures were taken from the vessel, on the very same camera we plan to use on competition and during morning, noon and evening hours. Also pictures were taken from pool conditions from ITU Olympic Swimming Pool with reflections included to further training.

In addition to this decision vessel was kept small and hydro-dynamic. With only 16.14 kg of displacement, 4.2 Newtons of resistance on 3 Knots and 17.3 Newtons of resistance on 6 Knots, vessel is specialized for the strategy. Given strategy is a risky one, given that we could finish all the given tasks yet we have decided not to and we are ready to take the risk to challenge this years participants for the lightest and fastest autonomous vessel on the competition.

II. Design Creativity

A. Mechanical

When starting with hydro-dynamical design first certain criteria has to be decided such as platform area, stability, maneuverability and complexity. Platform area can be decided by number of onboard sensors that needs to be stationed outside of the hall for maximum affect. Needed stability can be managed by the turn radius's and magnitude of sharp corner that vessel has to maneuver around. Finally, complexity will be understood by deciding materials, manufacturing processes that are available and investment that can be made toward the hull production.

- Hull Selection: After discussion on the design criteria, it was discussed whether using a single hull or multiple hull would provide the best performance, considering the competition rules and duties for the selection of the hull form. As a result of the researches and studies, speed, deck area and stability data were evaluated and it was decided to use the trimaran form. The most important factor in choosing a trimaran is the need for a stable boat for the successful performance of the tasks in a short time. Thanks to the side hulls, the inclination of the boat is greatly reduced. In terms of maneuverability, it is known that the maneuverability of trimaran boats is lower than monohull boats. When the advantages and disadvantages are examined, trimaran was preferred because the importance of stability for the competition comes before the maneuver.
- Hydrostatics Calculations: Electronic inventory and rest of the requirements can decide total displacement of the boat. We have calculated with body included between 15- 20 liters of water needs to be displaced. Design that we have managed to come up with has 120 mm of waterline and 16.14 liters of displacement. CB has planned to be under 0.5 and calculated at 0.260. Froude Number at 3 knots has been calculated 0.443. Rest of the hydrostatics has been provided at Table.X.
- Hydrodynamics Calculations: Next step is to decide desired speeds. Desired speeds are the main factor in ship design. When electronic inventory and image processing considered our team has decided that cruise speed should be around 0.6-1.0 m per second. Yet due to some task's scenarios trimaran should be moving between 1.2-3.2 meters per second to be able to finish the task faster. The resistance values it is exposed to at these speeds are also important in shaping the design. The resistance values of the

Displacement	16.14	kg
Volume	15743632.5	mm3
Draft Amidship	120	mm
Immersed Depth	118.1	mm
WL Lenght	1240	mm
Beam Max extents on WL	808.4	mm
Wetted Area	512272.6	mm2
Max Sect. Area	23791.7	mm2
Waterplane Area	266461.1	mm2
Prismatic Coeff. (Cp)	0.534	-
Block Coeff. (Cb)	0.260	-
LCB Lenght	600.2	mm
LCF Lenght	541.6	mm
L/B	3.237	-
B/T	3.243	-

TABLE I
Calculations of the Hydrostatics

boat were calculated by ANSYS CFD. The resistance values of the calculations are given in Figure-x. Pressure distribution caused by resistance is given in Figure 2.

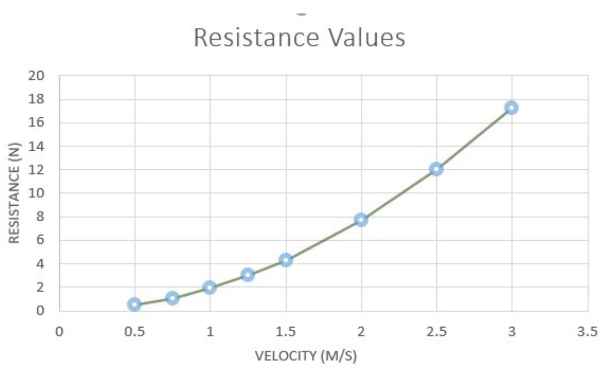

Fig. 1. Resistance Results

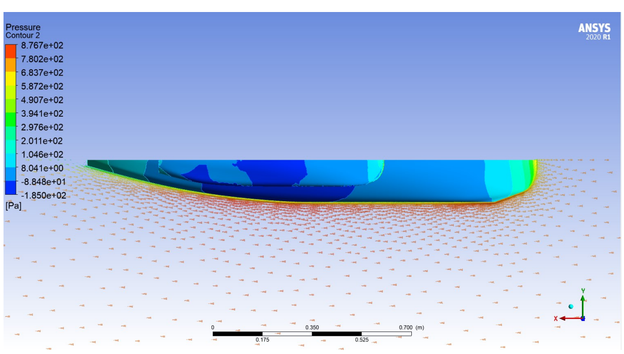

Fig. 2. Pressure Contour of Hull

- Thruster Design: The propellers were made with OpenProp code on MATLAB with a design suitable for the parameters of our vehicle. The hydrodynamic values of our propeller were checked using CFD programs such as ANSYS and OpenFOAM. The propeller we produce as a portable has been tested in the circulation pool in the Ata Nutku Experiment Laboratory in our school. The propellers revised in this way allowed the boat to accelerate better. Propellers and thruster body was designed around DXW2838 300 KV motor with voltage range of 3-6s (11.1V-22.2V). Being waterproof and having peek 350 Watt power was the main decision for these spesific motors. Total thrust was tested as 2,89 kg force at 4250 RPM with 4S 14.8 Volt battery. The render image of the designed thruster is given in Figure 3.

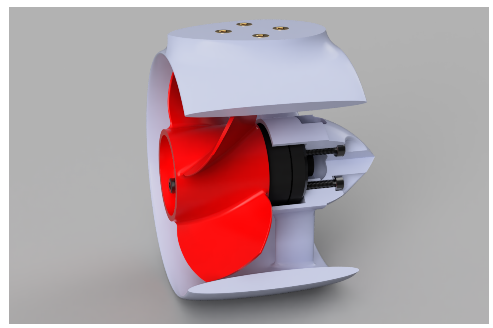

Fig. 3. Thruster Design

- Hull Production: We decided that a high Froude trimaran design would serve us best because of the amount of platform required and stability. The complexity of this selection will not cause any problems because the production technique has been decided as FDM 3D Printing. Since there are so many FDM printers around and in sizes, we decided to manufacture from PLA and post-processing to ensure a waterproof and rigid body. The body will be manufactured as blocks and then assembled as shown in Figure 4. The final state of the boat, whose design has been completed, is given in Figure 5.

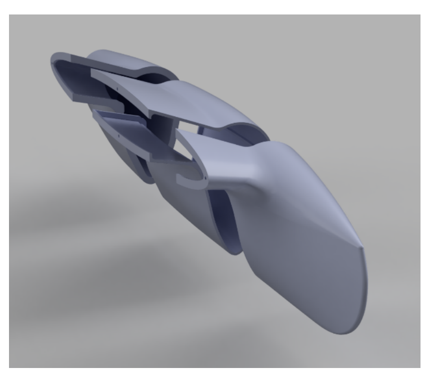

Fig. 4. Blocks of Hull

- Final Design and Assembly: Final design ends up with processed body parts glued, assembled, primed and painted. After hull being mechanically finished, cables gets feeded through the entire hull. After cabling finished, electronics and rest of the sensors would be attached to their specific location.

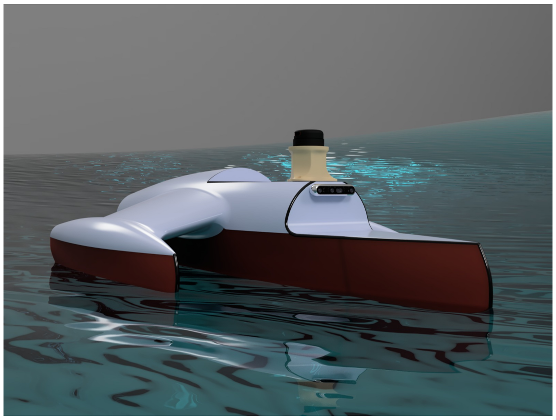

Fig. 5. Final Trimaran Form

B. Electrical

a) Power Distribution: Power distribution is managed by MATEK FCHUB-6S. Which is designed for maximum of 6S (22.2V) and 184 amps. Decision for high-voltage, high-current PDB was to ensure components to not get warm inside the hull and supply regulated 5V, 9V, 12V power lines across the boat. Power connection diagram has given in Figure 6.

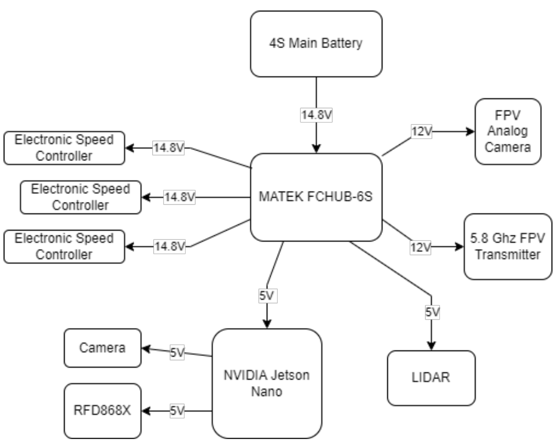

Fig. 6. Power Connection Diagram

b) STM32: The embedded software also creates an interface layer for the high level software to control vehicle or to collect sensor data by use of Rosserial[1]. This enables all features of the motherboard to be accessible on the ROS network. Thanks to this RTOS based embedded software, all such features can be prioritized and scheduled in the task scheduler, to offer improved efficiency and a modular system.

Fig. 7. HEX Orange Cube

C. Software

It is necessary to perform the tasks and control the sensor activities on the vehicle. Based on this, there are certain points that need to be focused on. Odometry is needed to control the vehicle and to determine the navigation for the autonomous tasks that it needs to perform. In the field of software, we have studies in the field of image processing depending on the acquisition and optimization of odometry and the tasks we have to perform afterwards. In the process until the test platform is created, it is the duty of this team to provide a simulation environment by needing it.

a) Control & Navigation: Odometry information is required for navigation of the vehicle. Odometry information of the vehicle is provided by the Pixhawk Cube Orange on it. By working together with the GPS and IMU sensors in Pixhawk, the pose, orientation and velocity information of the vehicle is provided and localization and mapping operations are performed according to these data.

The solution model of the 2 tasks being planned will be as follows:

> Task 1: In this mission we plan on finding the biggest green and red buoy meaning the closest ones using our trained model for object detection. We calculate the middle point of these buoys and send the two buoy points and middle point to our decision machine. The decision machine firstly corrects the orientation of our boat and then passes through the red and green buoys. If the model detects a yellow buoy it moves accordingly to avoid it by still heading between the red and green buoys.
>
> Task 2: In this mission, we aimed to detect colour of image which is assigned before time slot begins. Thus boat goes through the appropriate docking bay. To avoid contacting docking bay, we calculate the middle point of two pipe before entering the docking bay. Firstly the boat corrects its position as middle point

[1] wiki.ros.org

of two pipes stay in the middle of the camera frame. Secondly, we calculate area of the detected image and boat enters to docking bay until area is not greater than the threshold area we gave.

Task 3: In this task, since our time will start if it passes between the green and red buoys, the scanning process of the marked buoy during this period will be in opposite positions by making the marked buoy rotate around counterclockwise by providing both LIDAR and imagery in the fastest way possible. It is aimed to complete the relevant task by planning to pass in this way.

b) Object Detection Structure: In order for the vehicle to perform autonomous tasks, it must distinguish the distance, shape and color features of the obstacles in its vicinity and act in line with this information. In the vehicle, these operations were carried out using LIDAR and camera. While the visual features of the obstacles are processed with Opencv in line with the images from the camera, the distance information to the surrounding obstacles is determined by LIDAR. Also YOLOv4 artificial intelligence technology is used to detect obstacles to get a more accurate result.

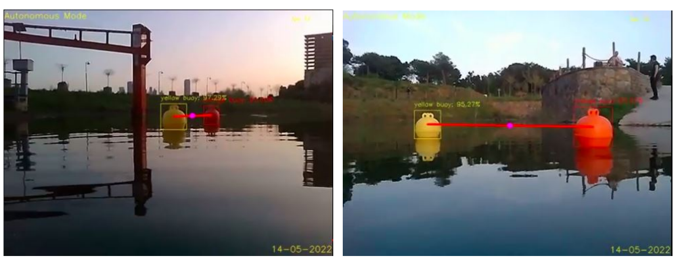

Fig. 8. Sample Detections

c) Simulation: Mass (kg), Volume (m^3), Center of Gravity (x, y, z), Center of Buoyancy (x, y, z), Moment of Inertia, Added Mass, Linear and Second Order Damping Matrix that we defined to give realistic and consistent results for our simulation , Thrust Positions (x, y, z), Sensor Positions (x, y, z), 3D Model of the Vehicle (x, y, z), Dimensions and Density information of the vehicle, graphic design via Maxsurf program, CFD (Computational Fluid Dynamics) analysis and obtained using a set of test setups. In addition, all sensors (such as IMU, Magnetometer and Lidar), cameras and thrusters on the vehicle were modeled with their parameters and created in the simulation environment, all details were carefully processed in order to obtain a realistic result. In the process of designing the simulation system, kinematic and dynamic models were used.

C/C++ and Python is used as software language in our tool. The reason for using Python is that it works in harmony with the extra modules we will use. Low level processing of the vehicle will be handled by Pixhawk. ROS (Robot Operating System) provides autonomous control of the vehicle and meets the simulation environment needs of our vehicle during the development phase with its sub-addons such as gazebo and USV simulator.

III. Experimental Results

Computer Vision:

At the point of image processing, object detection using only OpenCV was considered in the early stages of this process. However, when this situation was tested, it was determined that the vehicle could not meet the requirements of tasks. Therefore, it was decided to train an AI using the classification method. From this point on, it is aimed to make the accuracy rate the most stable. In line with this goal, many real-life tests have been carried out. The main reason underlying all these processes is that the vehicle detects objects at an optimal level without any problems.

- It is based on the detection of colors at an early stage, when only OpenCV is used. When this situation was tested, it was observed that the undesirable points located on the background of the buoys were detected as buoys. Therefore, this method is not approved. Subsequently, the trained artificial intelligence was tested in the Roboboat mission prototype installed on the lake. In this process, it was determined that the vehicle was weak at some points in the detection of objects and these deficiencies were quickly corrected.
  Manufacturing Process:
  When designing hull to be 3D printed there are couple of areas to pay attention. We have experimented with different types of materials such as, PLA, ABS, PETG etc. While our testing we have come to conclusion that PLA would be the best choice. When considered ABS was extremely hard to print in large sections due to creep and warping, PETG on the other hand was extremely easy to print yet when tried to be sanded or glued it was a very difficult material. There for our decision was PLA due to being easy to print, glue or sand. Yet it had its disadvantages such as being low heat tolerant material and soft in comparison to other 3D printable thermoplastics.

Acknowledgment

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TABLE II
Component Specifications

Component	Vendor	Model/Type	Specs	Cost(if new)	Year of Purchase
ASV Hull Form/Platform	3D Printed PLA Hull	VesselBee Trimaran	LOA = 1.24 m, D = 0.25 m, T = 0.12 m, B = 0.75 m	108 USD	2022
Waterproof Connectors	-	-	-	-$	-
Propulsion	3D Printed PLA Prop and Shroud	Thruster Body	∅80mmx65mm	-$	2022
Thruster Motors	DXW	Motor	2838 300 KV 3-6S	54 USD	2021
Power System	Tattu	LiPo	4S 5200 Mah 35C	126 USD	2022
Motor Controls	HobbyWing	ESC	40A V4 Brushless	165 USD	-
CPU	NVIDIA	Jetson Nano	GPU: 128-core NVIDIA Maxwell™ architecture-based GPU CPU: Quad-core ARM® A57	182 USD	2019
Teleoperation	RFDESIGN	RFD686x	Long range >40km,1 Watt (+30dBm) transmit power	373 USD	2019
Compass	HERE	HEREPRO Multi-RTK	Nav. Update Rate: Up to 20 Hz for RTK Position Accuracy: RTK 0.01 m + 1 ppm CEP Heading Accuracy: 0.4 degrees	935 USD	2022
Intertial Measurement Unit (IMU)	HEX	Orange Cube	32bit ARM® STM32H753 Cortex®-M7 with DP-FPU 400 Mhz/1 MB RAM/2 MB Flash	454 USD	2018
Doppler Velocity Logger (DVL)	-	-	-	-$	-
Camera(s)	WaveShare	USB Camera	5 MP, CCD=1/4 inch, F:2.8	14 USD	2019
Hydrophones	-	-	-	-	-
Algorithms	GPS + Compas Navigation System, Object Avoidance	-		-$	-
Vision	Image Processing OpenCV Library and ML	-	-	-	-
Localization and Mapping	RPLIDAR	LIDAR	0.15-12 meter	508 USD	2022
Autonomy	-	-	-	-	-
Open-Source Software	-	-	-	-$	-