MATE ROV COMPETITION 2022

TECHNICAL REPORT

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ABSTRACT

ITU ROV Team is an experienced team that has developed a remotely operated vehicle (ROV) and has been continuing to work since 2017. ROV that's been developed by the team can perform studies in areas such as ensuring public safety, protecting the underwater habitat and preserving historical artifacts.

ITU ROV Team consists of mechanical, electronic, software and organization sub-teams and has a structure that focuses on different disciplines. The sub-teams have worked on designing and producing the ROV type vehicle that will be able to fulfill the tasks to be assigned with the capabilities and obligations of different disciplines in the shortest time and in the best way. At the same time, the team has shown the necessary sensitivity about occupational safety and field safety during the production phase of the vehicle and during the operation.

ITU ROV Team is an open-source team. As it continues to learn from its large open-source community, the ITU ROV Team contributes and gives back to the community. All software and hardware designs can be accessed on the project's GitHub page, at https://github.com/iturov.
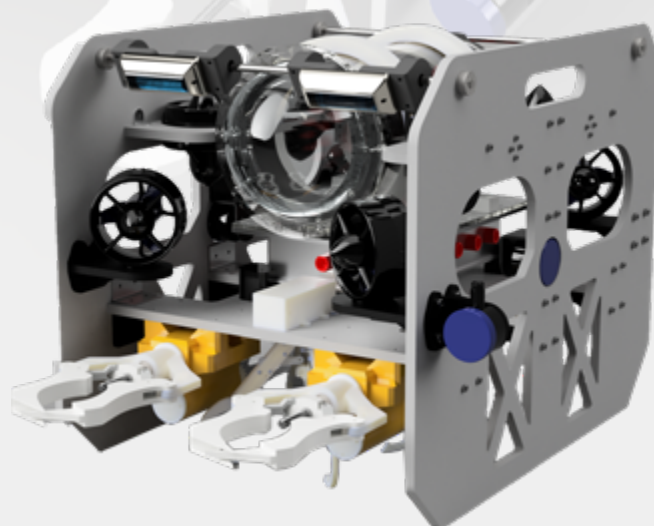
Figure 1 - Team

Figure 2 - Our Vehicle

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SAFETY

1. SAFETY

1.1 PHILOSOPHY

We believe that the most important factor on a workplace is safety. The number one priority in our workshop was to ensure and improve safety in tests, workshops, non-workshops, in short, the priority at every stage was to create a safe and comfortable space to work. It was not avoided to apply every precaution to prevent any harm to the team members and to prevent possible work accidents. For this reason, it was decided to apply the occupational safety protocols and procedures in place and completely.

Figure 3 - Safety Precautions

Figure 4 - Safety Precautions

1.2 SAFETY STANDARDS

No safety application was omitted during the production of the vehicle. In the workshops, it was not neglected to use personal protective equipment such as glasses, gloves, masks, earplugs suitable for the work (Figure 3), and also to have an emergency eye bath, fire extinguisher and first aid kit in the workshop. Warning signs and stickers were used in all work areas (Figure 4). In addition to these, experienced team members applied the rules to be followed within the workshop rules without skipping. Before starting work in the workshop, our team was given a short training (Figure 5) on occupational safety and the rules to be followed in the workshop, with the support of the ITU Occupational Health and Safety Club. Team members also need to use any tools, both in tests and in other work areas. vertical drill, milling machine, sander - they have taken care to create a suitable and comfortable working environment both for themselves and for others by following these rules. Personal protective equipment (PPE) such as goggles and gloves are used for eye protection while using equipment that may cause an accident. Electrical technicians also made the necessary controls and tried to prevent risks by identifying them. In addition, since the works were carried out during Covid 19 Pandemic, everyone continued to work with appropriate protection (Figure 5).

Figure 5- Safety Training

Figure 6 - Safety Precautions at Olympic Pool

1.3 SAFETY FEATURES

While paying attention to the technical features of the vehicle, security measures were not ignored. The position of the thruster on the vehicle is also positioned in such a way that it will not be damaged from the outside or harm the outside. In short, it is mounted in a way that does not interfere with the use of operators. In addition, all plastic clamps on the vehicle are shaved in a way that they cannot harm users. No sharp surfaces are left on the vehicle that could harm users. In case of any problem during the operation of the vehicle under water, the vehicle can be stopped quickly thanks to the emergency stop button on the ground station. In addition, during the operation of the manipulators on the vehicle, it is possible to cut the power of the manipulators on the vehicle from the pilot's control center. Besides, the following substances were applied based on safety.

• AC electricity is not used in the ground station; the ground station is completely isolated from the city network.

• All cables used have been selected considering the currents that will pass over them, and their cross-sectional areas have been taken into consideration.

• The electricity supply of ROV and Non-ROV devices is provided by passing through suitable fuses.

• All connectors used have been selected by considering the appropriate values.

• When the main vehicle's power is cut off, the battery inside the MicroROV is also completely disabled.

Figure 7 - Safety Precautions

1.4 SAFETY CHECKLIST

Startup Checklist

1. Check around
2. Keep power supply off
3. Connect the power cable to the ROV
4. Connect Anderson connectors to the power supply
5. Check electronic enclosure

Pre-Dive Checklist

1. Start ground station
2. Power up the ROV
3. Start the ROV
4. Control the electronic system from the control station
5. Put the ROV down and make sure people stay away from the thrusters
6. Put your ROV in manual mode
7. Activate ROV
8. Press the forward / backward bar forward to check that the vectored thrusters rotate freely

9. Press the up / down bar forward to check whether the vertical pushers rotate freely.

10. Disable the ROV.

11. Put the ROV in the water

12. Engage the ROV.

13. Check the entire vehicle again from the ground station (camera, electronic device ...)

14. Leak control

15. Buoyancy and stability control of the ROV

Diving Checklist

1. Start the timer

2. If the mission is completed, drop the ROV to the ground

If Balloon Found (If the balloon was found while the vehicle was running)

1. Turn off the power

2. Take the ROV out of the water

3. Check ROV and find problems

4. If the problem is resolved, restart the ROV

Incorrect Communication (If there is a communication deficiency)

1. Check communication

2. Start looking for a problem

3. Restart ground station

4. If ROV fails to restart, power off

5. Take ROV to ground

6. Check ROV and find problems

7. If the problem is resolved, restart the ROV

Post Dive Checklist

1. Wash the vehicle with clean water

2. If working in a sandy environment or seaweed, remove the sand and seaweed from the propellants.

2. ELECTRONICAL SYSTEM DESIGN

The design rationale of this year's vehicle emphasized modularity and upgradeabilty over anything else. The modularity is beneficial for users to perform maintenance easier compared to our competitors and provide quicker solutions without significantly altering the vehicle. All the wires are color coded with red wires signaling positive connections, black wires signaling grounds, yellow white blue and green wires signaling all kinds of switches and controls. The same coding is used with the thickness of the wires indicating the different current flows. The strict codes help with diagnosing problems with ease and troubleshooting without significant delays. All the PCB's designed in-house used are universal and can be used to drive various different components adding to the flexibility of our system.

2.1 GROUND STATION

The ground station is designed to provide a "plug and dive" solution to the operator within a secure manner. All parts, which are required to operate an ROV, are included in the ground station. These parts are protected from incidents that might occur during transportation and operation. The ground station consists of a Power Line Communication(PLC) PCB, one tether input, one 48V power input with an Anderson SBS50 connector, one fuse holder on the power input cable,strain reliefs for tether and power cables, one emergency stop button, one controller board, and all required controls (flight sticks, buttons, toggle switches). The ground station should be connected to a computer via a USB and Ethernet cable. Joysticks or gamepads are not required since the ground station already has all the required controls within itself and the controller board functions like a gamepad. Since controls are specially designed to operate an ROV, an operator can control the vehicle in all of its movement axes. If the computer connection is established, the ROV can be operated after 48V input and tether connections are done.
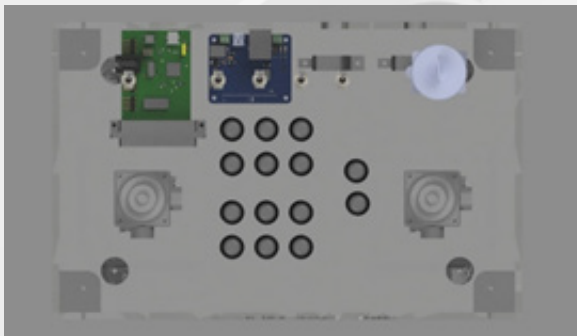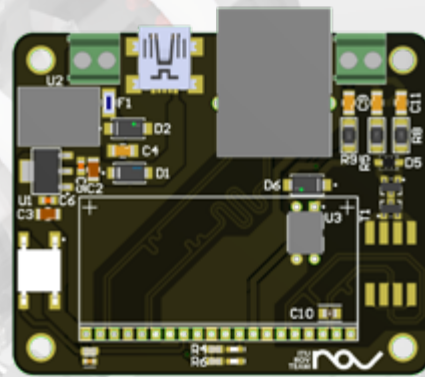

Figure 8 - Ground Station Top

Figure 9 - Power Line Communication PCB

2.2 POWER MANAGEMENT SYSTEM

2.2.1 Tether Specification

The connection between the vehicle and the ground station is provided by a tether cable. Tether cable consists of four wires; while the two wires of the tether cable supply power to the ROV, the other two wires enable the communication. The cross-section of the wires used for power transmission is 3.6 mm2. This thickness is calculated taking the power consumption of the ROV into account. In this thickness value two-way resistance measured to be 1/8 Ohm per 10 meters of cable. The maximum cable length was calculated with the minimum voltage requirement for the regulator to work. Wires used for communication are manufactured as 18 AWG twisted and screened with aluminum foil. This twisted pair is used as a connecting line for PLC PCBs. The jumper is designed to be neutral-floating to ensure the mechanical stability of the ROV and the connecting cable is manufactured to fit VDE0295 / IEC 60228 class 6 [1] standards.
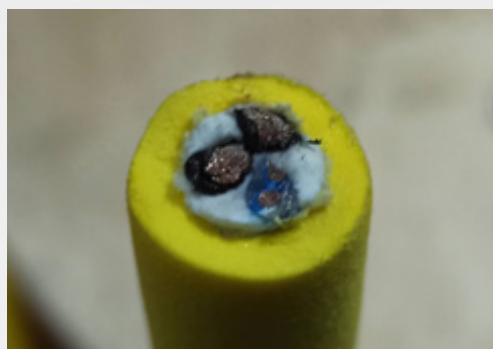

Figure 10 - Tether Cable

2.2.2 Regulator Carrier

In order to meet the power requirements of the vehicle, three Murata DCQ0150V2NBSC DC-DC converters were used to convert 48V to 12V in our vehicle. The high current values and high efficiency (96%) [2] that these regulators could provide were taken into account in the selection process. A PCB that uses XT60 connectors has been designed in order to distribute the power in a convenient manner. Two independent power supplies are designed to supply ESCs and the last one to supply the vehicle system.

2.2.3 ESC Carrier

A carrier PCB was designed to carry 8 ESCs. This PCB is specially engineered to deliver the power required by ESCs to control the thrusters. Power lines are supported with nickel strips which reduce heat generation and help to deliver of power. Control signals needed by ESCs are also carried over this PCB. ESCs and Regulators are housed in a specially designed aluminum box (Power box). This housing helps to ensure that the regulators and ESCs are cooled appropriately and prevents any interference of electromagnetic noise caused by the high power devices. Separate enclosures improve the modularity and upgradeability of the system by providing additional space for future changes including but not limited to: a battery driven vehicle system, a doppler velocity log (DVL), and additional sonars.
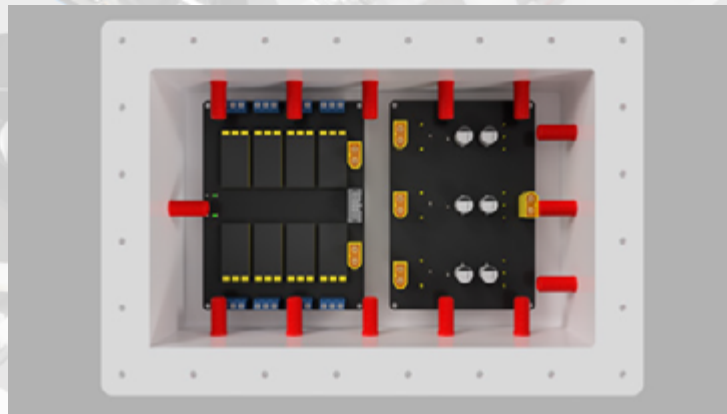

Figure 11 - Power Box

2.3 MAIN VEHICLE SYSTEM

2.3.1 Vehicle Computer And Communication

The selection of an on-board computer was made by taking multiple variables into consideration such as: software, interfaces, and communication protocols. Due to its ease of use and its ability to use a great range of software applications Jetson Nano single-board computer was selected. Jetson also helps with creating a suitable application area for our possible future studies.

The communication between the onboard computer and the ground station computer is established by the LAN connection. The physical connection is secured with a twisted pair wire in the tether cable and a pair of PLC PCBs which were designed in-house. The PCBs contain LX200V20 Power line communication modules on them. The LX200V20 modules are PLC modules that support Homeplug AV (IEEE 1901) Standards[3]. With this network connection, Jetson Nano broadcasts the data collected from the cameras and system units of the vehicle to the ground station via ethernet and can receive commands from the ground station.

2.3.2 Vehicle Controller Unit (VCU) And Peripherals

An STM32-based embedded vehicle control unit (PCB) was designed taking the various requirements of the vehicle into account. The PCB is designed with capabilities to perform ESC control/ vehicle stabilization and sensor communications with various auxiliary units on it. Due to the demands of this year's tasks FreeRTOS was the microcontroller software of choice. Also, this unit, which will be connected to the Jetson Nano vehicle computer via USB and UART interface, was designed to support Robot Operating System (ROS) protocols and enable real-time debugging, considering the flexibility factor. To drive the grippers, a PCB with its own microcontroller and three L6206PD013TR motor driver IC has been designed. This PCB is connected to the VCU via UART and works according to the commands sent by the pilot.

Sub-Units embedded in the Vehicle Control Unit(VCU) :
- Microcontroller:STM32H753VIT
- Main Inertial Measurement Unit(IMU): Bosch BNO055 Smart Sensor
- Auxiliary Gyroscope/Accelerometer : ISM330DHCXTR
- Auxiliary Magnetometer: HMC5883
- Temperature/Humidity Sensor: SHT30
- Auxiliary PWM Driver IC: PCA9685
- Auxiliary ADC-PWM-I/O Ports with variable voltage range
- Auxiliary Flash Memory
- 3.3V 4A SMPS Converter

To provide the 5V power needed by the onboard computer and other system units, a PCB with two separate SMPS circuits was designed. The SMPS circuits on the PCB convert the 12V voltage to 5V and each regulator provides a current output of up to 6A, so that vehicle systems can be supplied properly. One of the regulators is designed to supply only the Jetson Nano, and the other is designed to supply the remaining units such as the VCU, the sonars, and the sensors. Apart from these, a switching Mosfet is added to the PCB for future uses. For safety a 12A fuse was placed to the power inputs on the PCB.
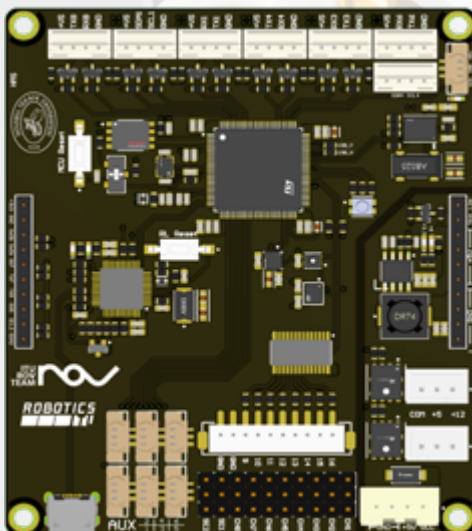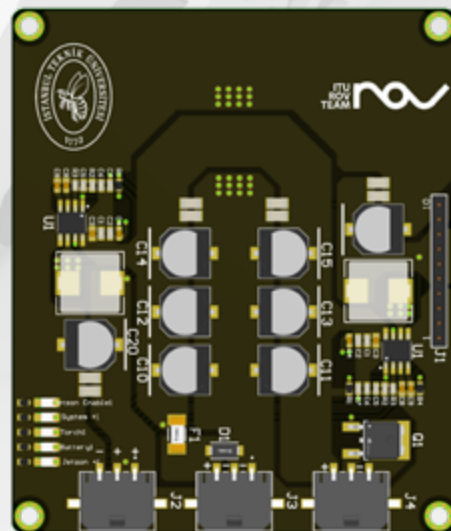

Figure 12 - Vehicle Control Unit

Figure 13- 5V Regulator PCB

2.3.3 Cameras And Sensors

The cameras and the sensors are selected in order to fit the needs of this year's competition to assist the pilot while operating the vehicle and performing the tasks. There are three USB cameras, three Ping Sonars(Altimeter and Echosounder), a BAR30 Pressure/Depth sensor, and various in-vehicle sensors such as Leak Sensors and a temperature sensor in the vehicle. The positions of these units on the vehicle were specifically selected to increase the vehicle's functionality and user's control over the vehicle.

MECHANICS

3. MECHANICS

3.1 DESIGN

An educated approach was used in the development of this year's vehicle. All of the design choices were taken with the guidance of the previous year's experiences. The components that were affected by the previous experiences include but not limited to are our chassis, grippers, propulsion systems, enclosures, and housings. Our experiences were used to effectively analyze the buoyancy of the vehicle and the static strength of the components.

Figure 14 - Exploded view of the complete assembly

3.2 CHASSIS

The chassis should be examined in two parts: decks and side panels. The side panels are designed to give the vehicle its rigidity while maintaining a clear path in front of the thrusters for better hydrodynamic flow. The bottom deck acts as a carrier and baseplate for the regulator box and is used in tandem with the side panels for stability in the horizontal plane. The material choice was HDPE for its ease of manufacturing with a water jet and low cost compared to other polymers.

Figure 15 - Chasis in CAD

3.3 ELECTRONICS HOUSING

3.3.1 Acyrlic tube and Trays
An acrylic watertight cylindrical enclosure is used to keep all electronics equipment safe except for the regulators and electronic speed controllers. A clear dome is used in the front section opening the lids when there is a problem. These tray designs are easy to assemble and disassemble as they can come out of the closed chambers in one piece when the lids are opened.of the enclosure to boost the field of view of the camera and provide a clear space for the pan and tilt functions for the camera. The enclosure and regulator box design are used to increase the number of penetrator holes to accommodate for the increased number of sensors present on the vehicle. The separate box and enclosure setup also help with reducing the number of connections inside making the tray more organized and easier to assemble and disassemble.

Figure 16 - Tray Render

3.3.1 Aluminum Casing
The weight of the box is 1502 grams. The box is made of 5754 aluminum due to its low density, tensile strength, and corrosion resistance. The box is bent at 3 sides on its side surfaces. TIG-welded. 3.25mm pure tungsten electrode was used for welding the box. The thickness of the box is 3mm, excluding the upper flange. Its flange is 5mm to increase its service life. Parts of the box were CNC laser cut and drilled. Holes are for thruster cables, system power cable, mains cable, and control valve. The box is closed with plexiglass material, which allows the circuits inside to be seen.
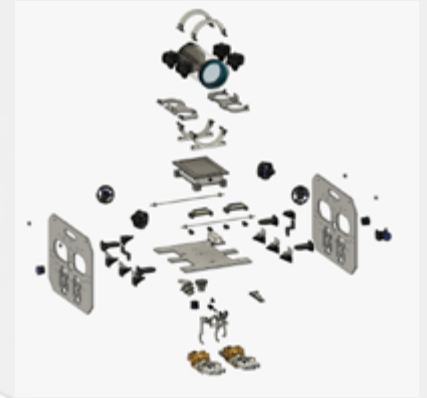

Figure 17 - Casing Render

3.4 GRIPPERS

3.4.1 Main Gripper

According to the analysis of our team, the demands of this year's competition required at least two separate main grippers to be present in this year's vehicle therefore two main grippers are designed to work together to achieve the tasks. The grippers required extensive sealing against water to work reliably and for this reason, all the parts that are in contact with water were made with polyethylene glycol (PETG). PETG is a non-porous polymer that is extremely easy to use with fused deposition modeling methods (FDM). PETG is also an exceptionally durable material.
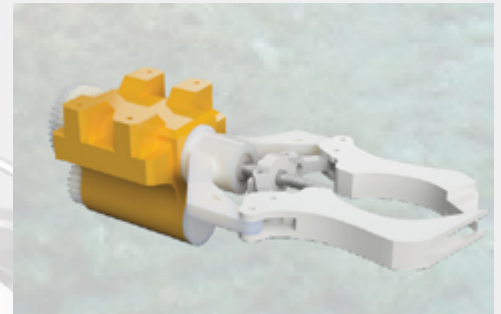

Figure 18 - Main gripper in CAD

3.4.1.1 Main Gripper Design

The grippers are driven with two 60 revolutions per minute (RPM) motors. The torque created by the first motor is transferred to the threaded shaft. The threaded shaft transmits its radial movement to the trapezoidal nut converting it to linear motion which pulls or pushes the gripper arms to close or open the jaw. The second motor is used to rotate the jaw in its roll axis. The radial movement from the second motor is sent to the shaft using a lower and upper gear wheel system. The shaft is then connected to the jaw using a flexible coupling which helps to correct axial misalignments and prevents unnecessary vibrations.

3.4.1.2 Static Analysis of Main Gripper

The gripper is analyzed for static durability, displacement, and buckling to gather information about the deformations and possible critical errors that might occur during operation. The simulations were designed and solved using Autodesk Fusion and ANSYS and were used to test the probable scenarios of vertical and horizontal loads on the jaws. The vertical forces are mainly caused by the weight of the objects being carried and the horizontal forces are caused by the normal force exerted upon the gripper arms by the objects. Using the projections of the simulations weak spots were determined and improved upon with new design iterations.
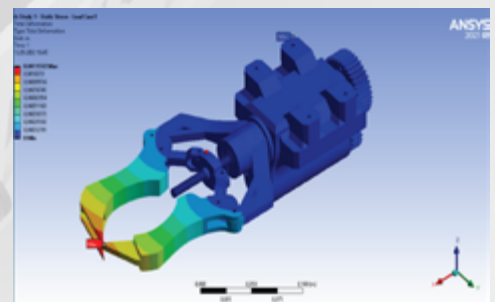

Figure 19 - Deformation of the main gripper

3.4.2 Bottom Gripper

Bottom Gripper is designed in Autodesk Fusion 360 and built using a 3D printer, from PLA in order to achive one of the goals in the competition which is collecting mort and carrying it into a bucket. Unlike the other grippers located on the ROV, Bottom Gripper has a different prensiple of working. Bottom grippers arms move parallel to each other. As can be understood from it's name Bottom gripper is located at the bottom of the ROV and front of the center.

MECHANICS

Two rigid identical arms are mounted under the bottom plate looking forward of ROV. One moving arm is mounted to a nut which is located on a rail which is mounted under the bottom plate. Motion is created by 12V 60RPM 90 degrees gearmotor turning a set of bevel gears which convert the motion and turn the trapezloid shaft and move the arm back and forth. Due to the fact that bottom plate is located between the Bottom Gripper, gearmotor is seperated from the rest of the gripper and it is waterproof. Hooks are specially designed to grasp the mort as easily as possible and make it as hard as possible for the morth to slip away. In this design hooks does not rotate around themself and move parallel to ground unlike the other design where the arms of the gripper rotate around their connection points to the body of the gripper. This motion and use insured us to be able to grasp the mort effortlessly.
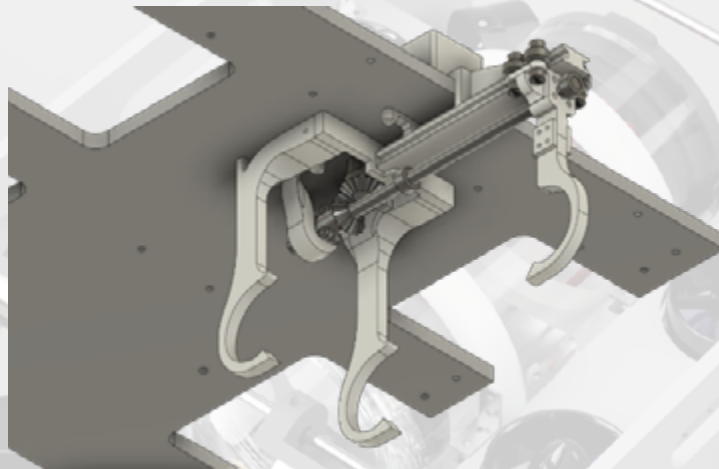

Figure 20 - Bottom Gripper in CAD

3.5 CAMERA HOUSING

The underwater camera housing was designed to be easily manufactured using cold casting methods. The cold casting method is preferred due to its water tightness even with the most complicated shapes. Due to the geometry of the camera, an FDM solution was not applicable. The geometry of the camera was modeled in our computer-assisted drawing (CAD) software and it was split into a negative and a positive mold to obtain a cope and drag pattern for casting. Two-component room temperature vulcanizing (RTV2) silicone was selected as it is one of the easiest mold materials to acquire. Polyurethane (PU) was the material of choice for the mold due to its flexibility and water resistance. However, PU is opaque which obscures the vision of the camera. To prevent visibility problems a plexiglass cover is then attached using a liquid gasket to the mold.

Figure 21 - Polyurethane Molded Stem Camera module

Figure 22 - Camera Module Disassembled

POLYURETHANE	EPOXY
Polyurethane resin is more resistant to cracking and therefore can be applied both indoors and outdoors.	Epoxy resin turns into a hard surface when dry, and it's only applicable indoors.
Polyurethane dries up in 2 to 4 days.	Epoxy resin drying up can take up to 8 days.
Polyurethane is flexible.	Epoxy resin is harder, therefore it is more brittle than polyurethane resin.
Polyurethane is more resistant to surface damage due to its flexibility.	Epoxy resin is more susceptible to scratches and indentation due to its hard nature.
Polyurethane is durable to high temperatures.	Epoxy resins are only durable to medium - high temperatures.

Table 1 - Comparison of polyurethane

3.6 PROPULSION

To ensure stability and maximum maneuverability 8 Blue Robotics T200 thrusters are used. Horizontal thrusters are placed at an angle so that it adds the agility of vehicle and enable rapid movement in necessary directions. To generalize the problem of thruster allocation and in order to make it possible to work with trial and error, functions with the parameters of forward and reverse thrust forces and thruster angles to the fore-aft axis are generated [4]. Functions used to analyze two motions are FT (forward thrust) and OPM (optimal angle for moments). FT function (will be referred to as η from now on) has 8 parameters for thrust force which exerted from experimental data and two rate constants to generate the decision mechanism regarding the balance between forward and sideways motion. Differentiating the η, optimal angle for motion along the x-y plane is obtained.

$\eta(\alpha, f1, f2, f3, f4, r1, r2, r3, r4, k, z) = \cos(\alpha) * (f1+f2+r3+r4) * k + \sin(\alpha) * (f1+f4+r2+r3) * z$

$d\eta/d\alpha = -\sin(\alpha) * (f1+f2+r3+r4) * k + \cos(\alpha) * (f1+f4+r2+r3) * z$

where f1, f2, f3, f4 regards forward thrust forces and r1, r2, r3, r4 are reverse thrust forces of each thruster; k and z are coefficients of forward thrust and lateral thrust respectively. k and z must have a sum of one to ensure a meaningful result. OPM function (will be referred to as θ from now on) needs two angles of a thruster to give an output of optimum angle for moments about the z-axis.

$\theta = 100 * (\cos(\alpha - \pi/4))$

where alpha is the angle of thruster about x and y axes [5].

Decision-making process for the optimal angle consists of trying the data for different motion scenarios with the functions and comparing the outputs of two functions for given values. During the decision-making process, 30, 60, 45 and similar angle values were tried. At the end of these trials, it was seen that the ideal angle was 45 degrees and the decision was made in that direction.

MECHANICS

3.7 ANALYSES

3.7.1 Structural Analysis

With our team's radical change in design rationale, all the previous analyses were rendered obsolete. This year's chassis is an antithesis to our previous chassis' as it is distinctively box-shaped and very rigid with substantially more supporting elements being present. The rigidity is essential to maintain the chassis' structural stability while still being able to bear the weight of the components. This rigidity required extensive displacement and buckling analysis to assure that the components are within our safety margins. The plates were assembled in our CAD software and analyzed as a whole assembly using ANSYS. All analyses suggested that the chassis were within our safety margins.
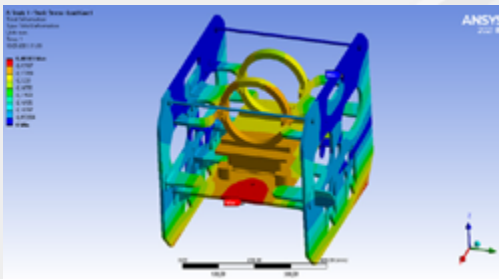

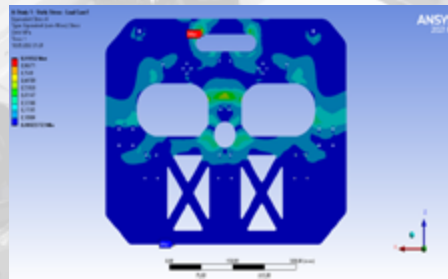*Figure 23 - Deformation of panels due to the vehicle's own weight*

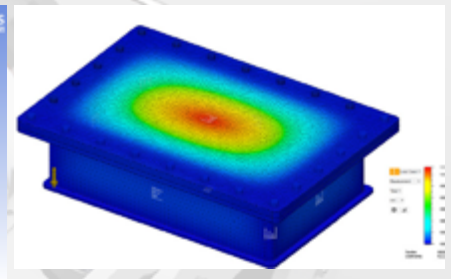*Figure 24 - Stress distribution of side panels when the propulsion systems are active*

Figure 25 - Analysis of the designed rectangular enclosure under hydrostatic pressuresystems are active

3.7.2 Stability and Buoyancy

Hydrostatic data were collected to analyze the stability and maneuverability of the vehicle. CAD designs and computational fluid dynamics (CFD) analyses were used to find the center of gravity and buoyancy center of the ROV. Archimedes' principle was taken into account to achieve static equilibrium ($F_{BUOYANCY} \geq F_{GRAVITY}$). The weight and displacement of the ROV came out to be 19,500 grams and 21,760.02 grams respectively. In light of these values, it can be concluded that the vehicle has achieved neutral hydrostatic stability and it is floating. The neutral hydrostatic stability suggests that a ballast system or any buoyancy foam is not required and all the thrusters are submerged in water. Another critical aspect of a vehicle's underwater stability is longitudinal and transverse centers of gravity and buoyancy. The center of gravity and center of mass are shown in the figures below. Since the locations of the centers of mass and volume are important to achieve overall stability, it was a priority to keep the center of mass below the center of buoyancy in the frontal plane and closer to the stern in the longitudinal plane. As a result, our vehicle has positive initial stability, id est, it comes back to its original position in the frontal plane whenever the external forces are removed.
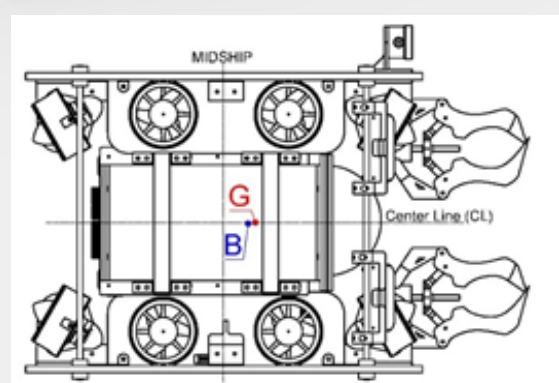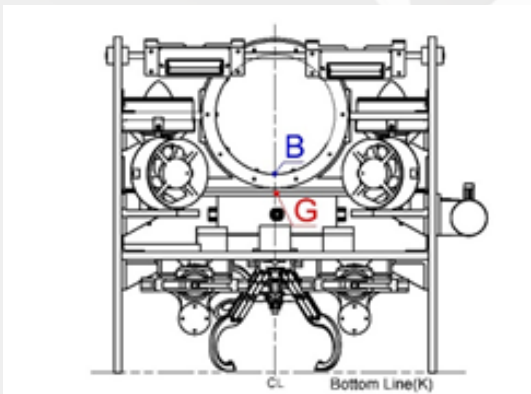

Figure 26,27 - Locations of the center of gravity and buoyancy center

Centers\Axes	x	y	y
Buoyancy Center (B)	21.118 mm Front	1.956 mm Starboard	237.78 mm
Gravity Center (G)	10.844 mm Front	0.542 mm Port	263.472 mm

Table 2 - Distances from the centers of axes to the buoyancy and gravity.

To show that the difference between the metacentric height and height of the center of gravity from the keel line is positive, GM must be calculated with the help of the measurements from the table and the equation GM = KB + BM - KG . Since KB > KG, vehicle's righting moment is positive. Thus, tendency to roll while maneuvering is to a smaller extent

4. SOFTWARE DEVELOPMENT

4.1 GROUND CONTROL STATION

Ground control station is the main element of ROV control, which consists of a linux-based computer with two monitors and a custom control box. Control box contains many buttons, joysticks and switches to control the ROV's movement and external parts of the ROV. This includes parts like gripper, lights, camera gimbal servos. Also, communication and power transmission to the ROV can be made by ground station. On the computer we are using a special user interface that was made by us. This interface gives flexibility, speed and comfort for the control of the ROV. On the other hand, Ground Control Station is portable and has a quite easy setup so we don't need many things to control our vehicle.

4.2 USER INTERFACES

We have designed the interface in a way that will meet the requirements of the given tasks and at the same time will allow us to easily access the features of our ROV. This interface is split into 2 parts. One is for the pilot to see the ROV 's point of view, bottom of the ROV and the other camera angles to see movement of the grippers. The other part is for the co-pilot to make the tasks easier to control. For the missions in the competition, there are different functionalities like taking photos, concatenating photos, switching the mode to the autonomous, mapping which can be activated via our interface. In addition, the vehicle's connection status, armed/disarmed status, and sensor data can be seen from the interface. In brief, the user interface is designed to ensure the maximum comfort and performance while controlling the vehicle.
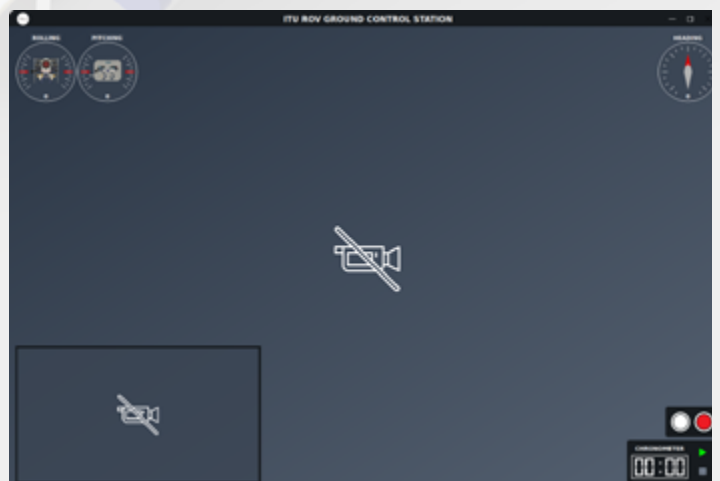

Figure 28 - Copilot User Interface   *Figure 29 - Pilot User Interface*

SOFTWARE

4.3 COMMUNICATION

This year, our team implemented the robot operating system, ROS, which is indispensable for robot applications, in order to make communication with the vehicle easier and more modular. ROS provides us the services someone would expect from an operating system, including hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management. It also provides us tools and libraries for obtaining, building, writing, and running code across our vehicle and top-side computer. Thanks to these features of ROS, it has become easier to write codes such as complex thruster positioning, sensor fusion, PID implementation and adjustment on vehicle axes. ROS is using a common protocol called TCPROS, which uses standard TCP/IP sockets. Code-blocks, nodes with ROS term, can simply publish or subscribe messages using this protocol. ROV and top-side computer communication carried out by the two Fathom-X modules over a single pair of wires in the tether cable. This module provides us a high-speed, long-distance Ethernet connection between ROV's computer Jetson Nano and top-side computer.

4.4 SIMULATION ENVIRONMENT

ROS offers us the most suitable simulation environment for underwater vehicles with its own simulation tool named Gazebo and an open-source uuv_simulator package specially created for underwater. Gazebo allows us to make an exact copy of the vehicle into the simulation environment. In addition, the data of sonar, IMU, pressure like sensors in the vehicle can be simulated according to the world in the simulation. Thanks to the uuv_simulator package, the physical conditions in the water environment can be simulated and vehicle torque and thrust calculations can be made. Thanks to these, we were able to test autonomous tasks before the vehicle was completed, and this saved us a lot of time in preparation for competition.
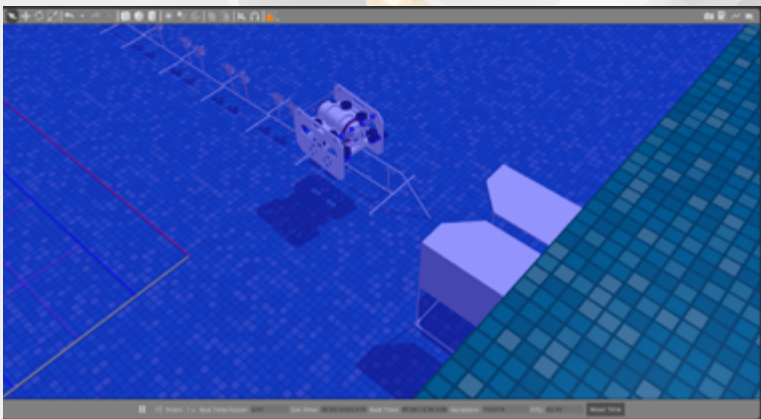

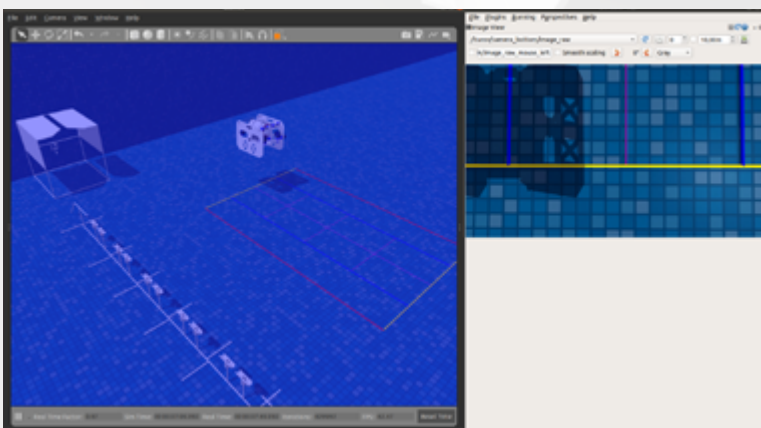*Figure 30 - ROS - Gazebo Simulation Environment*

Figure 31 - Endurance Mission Tests in Gazebo

4.5 THE SOFTWARES WHICH WERE DEVELOPED FOR COMPETITION TASKS

4.5.1 Task 1.4 - Piloting into "Resident ROV" docking station

After all tasks are completed, the vehicle switches to autonomous driving mode and turns the direction of the vehicle towards the docking station according to the data it receives from the IMU sensor. According to the data it receives from the sonar, the vehicle tries to match the docking station location it recorded when starting the mission. When ROV arrives at the station, software detects the red pipe and moves towards it with image processing tools of OpenCV library for perfect docking.
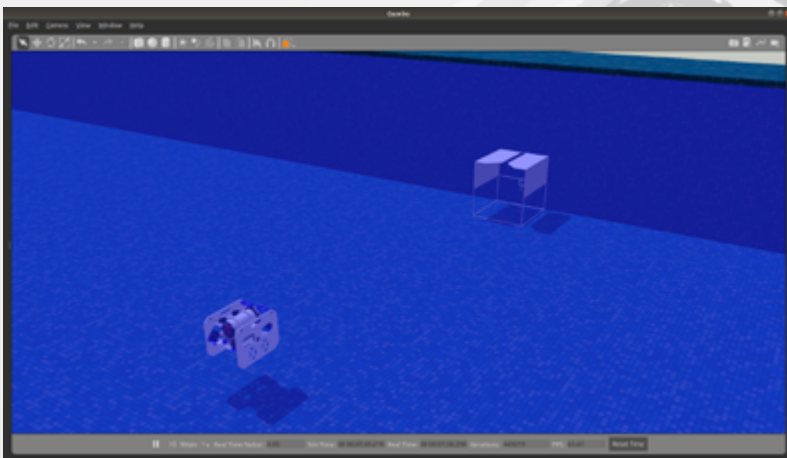

Figure 32 - ROS - Gazebo Docking Station Mission Simulation Test
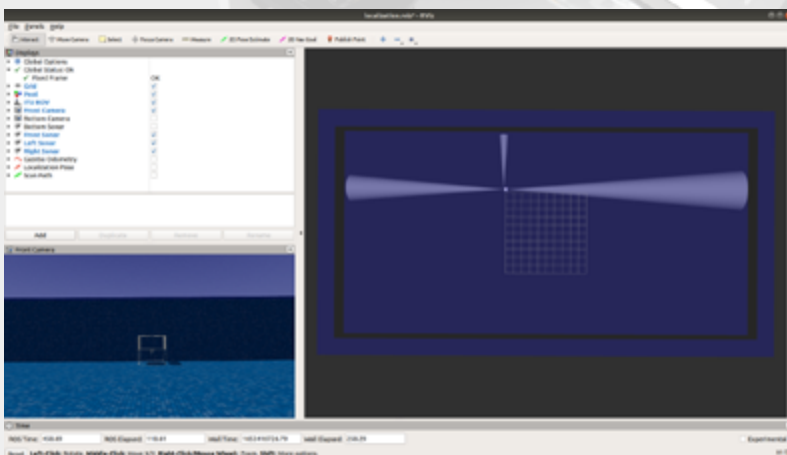
Figure 33 - ROS - RVIZ Docking Station Mission Simulation Test

4.5.2 Task 2.1 - Inspecting an offshore aquaculture fish pen

In order to inspect an offshore aquaculture fish pen, we used the OpenCV library in Python. We needed to obtain the contour effect to follow the rope. The Hough Transform is a useful tool for shape analysis like lines. This method can detect lines' critical points. During the lateral movement of the vehicle in order not to lose focus from the rope we had a sonar sensor in front of our ROV, which helped us to control the distance between the ROV and the wall. We also have an IMU sensor which provides our ROV to stand and move parallel through the wall.

Figure 34 - Fish Pen

SOFTWARE

4.5.3 Task 2.2 - Maintaining a healthy environment

In this task, we decided to train a machine learning model using the Darknet. Firstly, in terms of the training time, we preferr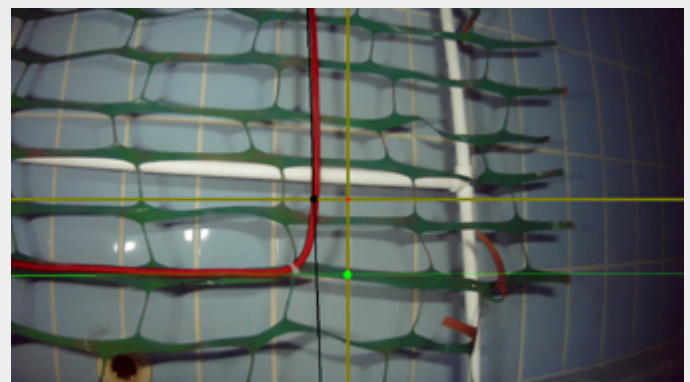ed Google Colab for the best performance and the highest accuracy. We decided to use Google Colab but we were not sure which machine learning model will give faster and more reliable results. Therefore, we trained various machine learning models such as SSD-mobilenet, Yolo4-tiny and RetinaNet. The SSD and Yolo4-tiny had shorter training times and also had a higher number of images they could process per second. RetinaNet was not able to process images as quickly as we expected. We did not achieve the high accuracy we wanted in distinguishing dead and alive fish. Among these machine learning models, the Yolo v4 satisfied us with its accuracy rate. We decided to solve the problem of the insufficient number of images it can process per second by using Nvidia's CUDA technology.
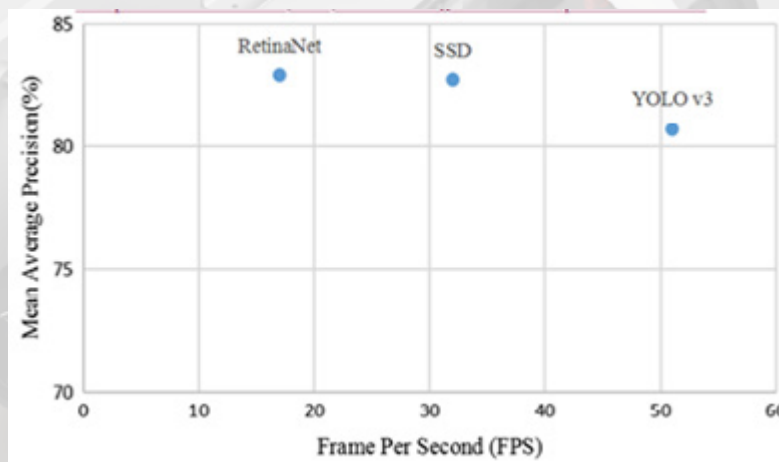
4.5.4 Task 2.3 - Measure fish size

In order to accurately measure the length of the fish by image processing, we decided that we needed a reference in order to relate it to the length. We knew that the fish's width wouldn't vary so we could measure the length by its pixel ratio to the width. Firstly, we had to detect the fish. We achieved this by one main principle; the fish's color. We observed that the white prop fish sticks out underwater in contrast to the darker pool background. We filtered the video using HSV values and masked the image so that only the fish shows up on the screen. Then we had to draw a bounding rectangle around the fish's contours. When we compare the width of this drawn rectangle with the width of the fish, we obtain the actual length. After doing the necessary calculations and finding the biomass of the cohort the mission is complete.
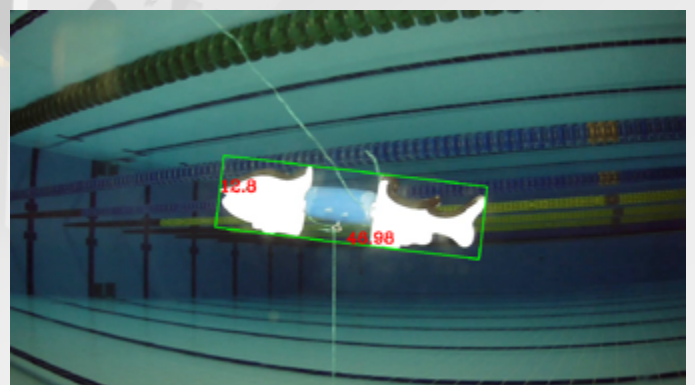

Figure 35 - Fish Measurement

4.5.5 Task 3.2 - Endurance22 - Flying transect line

Our software makes our ROV fly a transect line autonomously. We determine the orientation and forward speed of the vehicle according to the blue pipes on the map that we detected with the OpenCV library. Besides these, we maintain the depth of the vehicle according to the data we get from the bottom sonar sensor. The second part of our software allows us to map the area of the wreck ship that the vehicle passes over on the display screen during autonomous movement of the vehicle.[6] In this part, to detect horizontal red lines which help us to map, we trained a YOLO

Figure 36 - Transect Line

AI model.[7] During the training process, we collected 3000 photos of task equipment under different conditions. We trained our YOLO model with Google Colab and the training process took about 9 hours. Moreover, we take advantage of Nvidia's CUDA technology to process more frames in 1 second by using GPU instead of CPU.[8]
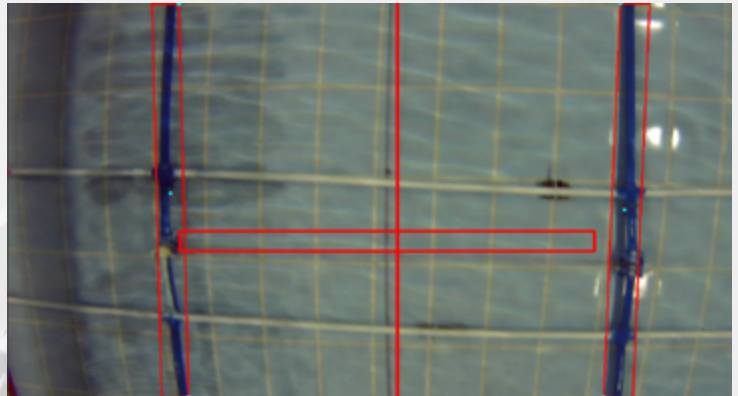
4.5.6 Task 3.2 - Endurance22 - Photomosaic and Mapping

Mapping the wreck and creating the photomosaic mission can be divided into 2 lower-level missions. These are obtaining each rectangle correctly and searching for the wreck parts in each rectangle. In order to obtain each 8 rectangles in the most correct and fast way possible, the algorithm will work real-time. Meaning, the map will be created as the ROV continues its path. The algorithm will crop each rectangle that is side by side while following the path and crop the frames from the middle. Resulting in the left rectangle and right rectangle. This will be done in each step as we pass over the red lines. In each cropped rectangle we will find the brown color intensity. This way if the intensity is higher than the predetermined threshold value the algorithm will mark this rectangle in the map.
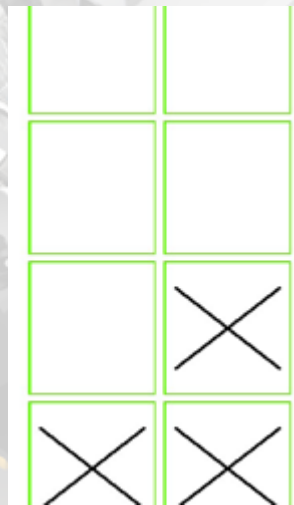
Figure 37 - Photomosaic and Mapping
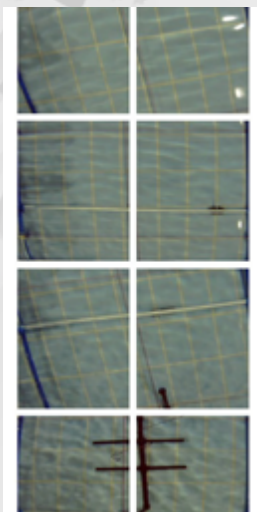
Figure 38 - Photomosaic and Mapping

4.5.7 Task 3.2 - Endurance22 - Wreck Length

One of the missions of Endurance22 is finding the length of the shipwreck from bow to stern in the search area. We will find the minimum area rectangle so that we find ratio between long side and short side of rectangle that covers wreck in image. In order to achieve that we separated the shipwreck from the background with the color masking method of the OpenCV library, and drew the smallest rectangle around it. The short side length of the wreck is 30cm as stated in prop building instructions. This value is multiplied by the ratio between the long and short sides in the image. At the end, the length of the wreck is found. And all missions of the Endurance task will be completed.
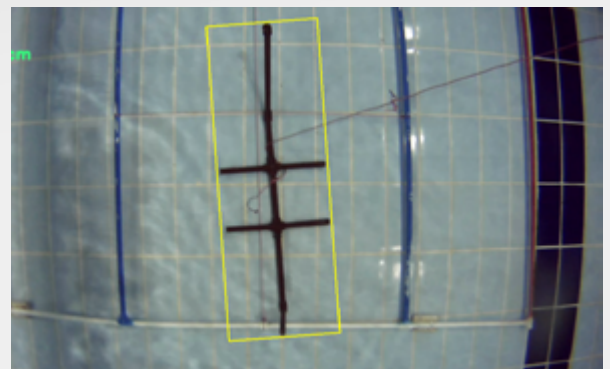
Figure 39 - Wreck Length

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4.6 SOFTWARE OF FLIGHT CONTROLLER

The software of the STM microcontroller-based flight control board, which was produced specially for our ROV, was written in the STM Cube IDE application using C and C++ programming languages. Since there was a lot of processing to be done, multi-tasking was applied using the FreeRTOS system instead of sequentially taking operations on the microcontroller. Thanks to FreeRTOS, the signals sent for the sensor and motor driver, which have process priority, were given priority in terms of software, and we gained acceleration in communication with multitasking. The communication between the flight controller and the Jetson Nano was provided via the ROS communication protocol over UART. Thanks to the internal memory on the flight controller, the parameters related to the vehicle can be dynamically changed and saved by the Jetson Nano UART communication.

5. ORGANIZATION MANAGEMENT

5.1 COMPANY ORGANIZATION

The ITU ROV Team was established within the ITU Robotics Club, which consists of students from different disciplines and from various faculties. The team consists of four technical teams: Mechanics, Electronics, Software, and Organization. Each team has a sub-team leader who keeps communication with each other and submits their reports directly to the CEO. Mechanical and electrical teams are also divided into some groups to focus on a specific part of the ROV. These groups are control station, gripper, and floater. Each sub-department works in communication with the other sub-team and informs the department leader about the developments.

5.2 PROJECT MANAGEMENT

In our team, in order to facilitate project management, we used Gantt chart for monthly processes and Trello for weekly processes, and we adjusted the processes according to the deadlines we predetermined. We divided our preparation process into three parts as the design phase, production phase, and testing process. During the design phase, we made our drawings for the production of mechanical parts in the FUSION 360 program. We also used the FUSION 360 program to analyze the strength of the vehicle. By making use of the error mode and effects analysis (FMEA) method during the design and production process of the vehicle, we tried to improve the vehicle continuously and to eliminate the problems that may occur as much as possible. During the production phase, ROV's main equipment such as cameras, chassis, and power converter were brought together before the tasks were determined. When the requirements of the missions were determined, work was started to develop equipment to complete the tasks. First of all, the task stations to be designed were brainstormed. Later, on our vehicle, which was assembled, mission equipment such as gripper, flagger, valve converter was added. Fusion 360 program was used to design and manufacture this equipment. During the production phase, it was preferred to produce parts that are easy to produce as much as possible and will not harm human health. We aimed to reduce the cost by producing the parts in the team room by choosing the production parts from the materials that can be produced easily. Two handles were added to the top plate of the vehicle for easy portability and a connector was used to make the power cable detachable from the vehicle. In our testing process, we worked on completing the officer as soon as possible. For our impermeability tests, we subjected our vehicle to an 8-bar pressure test. To test the missions, the Istanbul Technical University Olympic Swimming Pool and the Faculty of Ship and Marine Sciences Ata Nutku Ship Model Experiment Laboratory were used. In order to make our software and designs accessible within the team and to share with the robotics community, our work was shared on GitHub.

5.3 CORPORATE RESPONSIBILITY

As ITU ROV Team, we want to create awareness about underwater technologies in our country. We participate in maker events and technology fairs held for this purpose. In addition, we provide consultancy to primary and high schools on ROV and other underwater systems.

Figure 40 - Meeting with our sponsor GISBIR

Figure 41 - The Meeting of ITU ROV Team with Mavigün College Students

In addition to our efforts to raise awareness of the underwater world in our country, we donate saplings to our sponsors through the TEMA Foundation, which aims to protect nature. We have donated 81 saplings for our sponsors until now.

Figure 42 - Certificate of the Sapling Donation Our Sponsor-1

Figure 43 - Certificate of the Sapling Donation Our Sponsor-2

CONCLUSION

6. CONCLUSION
6.1 TESTING AND TROUBLESHOOTING

This year, the ITU ROV Team has tested everything it has produced and designed not only after the construction phase of the ROV but also during the design and construction phase of the ROV. Our team, which has increased its experience every year, has determined in advance which subject we should concentrate on and how we should work and has intensified its tests in these areas. Our team, who pays particular attention to impermeability and works on this topic, has achieved successful results on the tests. We have used many areas for testing, and the areas we use are ITU Olympic Pool and Ata Nutku Ship Model and Experiment Laboratory. Every part of the vehicle produced during the vehicle's construction was tested in these areas to measure and observe its response in water. Our ROV has tested such workability after every part added on it until the ROV is ready. When the vehicle construction phase is over, our vehicle has been tested in these two areas every week. The weekly tests focused on piloting and the running performance of the ROV. First of all, everything is tested and, its performance on the vehicle has been researched. All these tests have a significant effect in getting our ROV its current efficiency and appearance. In problem-solving, the focus has been on working on the emerging problem immediately and producing solutions as soon as possible. We can examine the troubleshooting process in 3 stages: troubleshooting, fixing, and resolving the problem. As the ITU ROV Team, we find it appropriate to solve the problems we have in this way. If we could not find a solution from these stages, we looked at the problem from a broader perspective and looked for new solutions by expanding our solution pool.

6.2 SUSTAINABILITY

We believe in a team that cumulatively passes knowledge from one generation of engineers to another. For this reason we value sustainability of our team . In order to achieve sustainability we partner with high schools in our region and make them presentations regarding underwater systems and remotely operated vehicles. During these presentations we also try to engage our audience into joining our team once they have graduated from high school. This ensures that our team will have passionate volunteers to work with us in the future.

6.3 REFLECTIONS

"This is my second year in ITU ROV Team and, I am glad to be a part of the administration of this team. I have improved myself in ROS, PyQT etc. By working with this team, I think have I earned many skilss at both management and engineering. It was like the simulation of my future life." - İbrahim KÖSE

"Being a part of this team gave me something I never knew I needed. This team helped me explore my passion for mechanical design and enabled my creativity in a healthy and accepting environment. Creating a vehicle from the ground up has helped me understand the elements of an efficient workflow. The skills I have learned as a member of this team, such as CAD, manufacturing methods, and organizational planning, are all applicable to my career as a future engineer. Being part of a team like this was one of the things a university student needs to experience in their student life to have fun, learn, and get ready for their career." - Ege Can Özşen

ACKNOWLEDGEMENT

APPENDIX

Appendix A - Ground Control Station Diagram

Appendix B - Electrical System Integration Diagram
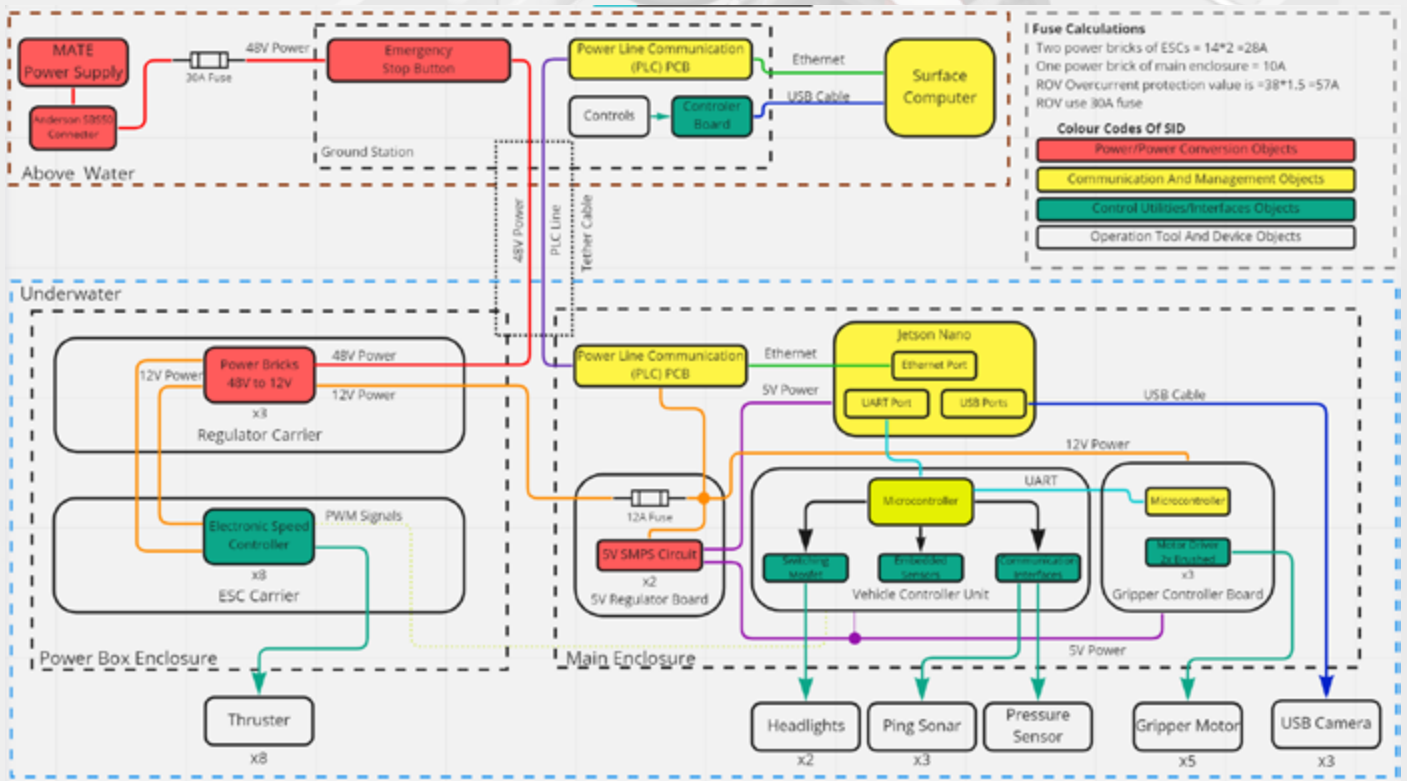
Appendix C - The Vehicle Flow Diagram

APPENDIX

Appendix D - Vehicle Communication Diagram

Appendix E - Gantt Chart

» March 20, 2022: Submission deadline for Marketing Display
» March 20, 2022: Deadline to register for a scheduled time slot for the company's Engineering Presentation, which will take place between March 26 , 2022
» March 20, 2022: Submission deadline for the company's Product Demonstration and Safety Inspection videos

APPENDIX AND
REFERENCES

Appendix F - Budget

State	Expenses	Amount USD	Number	Total
Purchased	Epoxsy Resin	14.55	2	29.1
Purchased	RTV2 Silicone	48.13	1	48.13
Purchased	Polyurethane Resin	13.34	2	26.68
Purchased	Quick Setting Epoxy Glue	-	5	12.12
Purchased	Alumium Sheet (8mm*1000mm*2000mm)	206.12	-	206.12
Purchased	Polyethylene Sheet	33.95	1	33.95
Purchased	Quick Setting Adhesive Kit	3.64	5	18.2
Purchased	Insert Nuts	-	50	5.81
Purchased	Nema 23	23.04	3	69.12
Purchased	Pleksi Protector	65.47	2	130.94
Purchased	608 Ball-Bearing	2.42	12	29.04
Purchased	Acoustic Insulation	2.06	10	20.6
Purchased	Coupler	2.42	8	19.36
Purchased	Steel Shaft m8 1 m	3.96	4	15.84
Purchased	Vibration Isolation	2.27	5	11.35
Purchased	Spindle Motor	8.49	1	8.49
Purchased	Acrylic End Cap (130 mm, 12 holes)	9.99	1	9.99
Purchased	O-Ring Flange (130 mm)	32.99	1	32.99
Purchased	Underwater Optical Glass Dome Lens (130 mm)	42.99	1	42.99
Purchased	Waterproof PMMA Tube (130 mm diameter, 400mm length)	27.77	1	27.77
Purchased	M10 Big Cable Penetrator	4.9	18	88.2
			Mechanical Expenses Total:	$ 886.79

State	Expenses	Amount USD	Number	Total
Purchased	Jetson Nano Developer Kit B01	143.10	1	143.10
Purchased	DG832 Function Generator	479.34	1	479.34
Purchased	AATech ADC-3306D Regulated Power Supply	190.99	1	190.99
Purchased	Oscilloscope	179.06	1	179.06
Purchased	Programmable Solderin Iron	110.78	1	110.78
Purchased	J-Link EDU	92.93	1	92.93
Purchased	Beaglebone Black 4G	67.01	1	67.01
Purchased	Logic Analyzer	8.21	1	8.21
Purchased	UT-201+ True Rms Digital Inductive Pickup	35.52	1	35.52
Purchased	Silicone Mat 440mm x 310mm	10.52	1	10.52
Purchased	5 m USB 2.0 Connector	8.36	2	16.72
Purchased	2D-11E Pcb Holder	8.60	1	8.60
Purchased	STM32 Processor Kit NUCLEO-L432KC	14.00	2	28
Purchased	48V to 12V 30A IP68 Regulator	28.53	1	28.53
Purchased	Circuit Board	1000.00	1	1000.00
Purchased	NUCLEO-H743ZI2	71.15	1	71.15
			Electonical Expenses Total:	$ 2,470.46
			Total Costs:	$ 3,357.25

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