Team Tiburon

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Abstract — Team Tiburon majorly focused on learning and improving during this coronavirus pandemic. Tiburon 4.0 is known as Makara. Some specifications are different from Tiburon 3.0, which was known as Hammerhead. This time the frame dimensions are 84x44x39 cm3 which is a bit more than Hammerhead. The weight and buoyancy are 20.28 Kgf and 23.18 Kgf. This time our computing unit is the NVIDIA Jetson TX2, which is different from the previous models. Another change from the prior Model is in Degrees of Freedom which is six this time. The additional features are a Streamlined Body, Permanent Face Sealing and Increased Speed. This time, there is a heuristic algorithm to auto-tune PID, shifting to object detection models and DVL in the armoury for better localization.

I. Introduction

Formed in 2014, Team Tiburon is an interdisciplinary team from The National Institute of Technology, Rourkela, that works towards designing and developing AUVs (Autonomous Underwater Vehicle) capable of performing many tasks without a human pilot. And we take pride in announcing that we have been actively developing bots capable enough to perform complex operations such as dropping, grabbing, and torpedo shooting as deep as 10m. Moreover, we take part in various Student AUV competitions at both National and International levels. Our Team is responsible for the structural design of the AUV. The design procedure starts with brainstorming and research to collect new innovative ideas, followed by Computer-aided design (CAD) to visualize the three-dimensional model, Finite Element Analysis(FEA). Computational Fluid Dynamics(CFD) to validate the design and test the mechanical parameters and finally procure raw materials and products for manufacturing. The main aim of our team is also to make the bridge between the software stack of the AUV and the outside world. NVIDIA Jetson TX2 is our main processing unit. Along with peripheral microcontrollers, it forms the control unit, responsible for various tasks the AUV can perform. The electronics stack comprises five custom made PCBs designed in Autodesk Eagle. Their standout features are compact size, stacked design and power efficiency. We have also incorporated protection features like overvoltage, under-voltage and short-circuit protection. The circuits are thoroughly tested for stress and functionality and revised before deploying them inside the AUV. Our Team also develops modular and error-free software, to get the vehicles working for challenging tasks. We are the ones who manage to make the AUV capable of completing various tasks underwater. The software is mainly written in C, C++ and Python. We also accomplish the use of a simulator that provides a virtual testing environment. Currently, the team is using the Unity3D game engine as a base for the simulator. Robot Operating System(ROS) is mainly used for inter-process communication. In contrast, OpenCV and some deep learning techniques are used for image processing. A set of packages is combined, giving autonomy to the vehicle and making the decisions. Last but not least, we test the software on the vehicle in real situations, mostly consisting of testing the vehicle in the swimming pool.

II. Competition Strategy

Competition Strategy : We improved some strategies based on what we learned in the 2019 venture. We continued using the Robot Operating System(ROS) framework as before for inter-process communication. Earlier CV was used to perform image processing algorithms, now improved using Machine Learning and Deep Learning techniques to detect various objects like gates and bins. PID tuning all 6 degrees of freedom, namely Surge, Sway, Heave, Pitch, Roll, and Yaw, was improved by the heuristic Ant Colony Optimization(ACO) algorithm, which yielded better results in less time. The acoustics part that was not implemented previously is getting managed by using hydrophones, which helps to detect the pinger and other objects in the environment. The images from the two horizontally placed cameras help us calculate depth similarly to human binocular vision. With the help of DVL, the vehicle can quickly locate and maneuver to the target.

Earlier, we used to implement the methods in the pool available on the campus. However, due to the

COVID-19 pandemic, the pool was inaccessible to most members. We tried our methods (previous and improved ones) in the simulated environment using the Unity engine/Gazebo simulator to minimize errors before working out in the real world.

We completely redesigned our electronics circuit this year from a single PCB approach to a modular one consisting of five different PCBs which enables us faster debugging and assembly of components. Apart from that, even though fully capable of running our previous bot, it had several issues which were addressed in the new circuit. The major issues such as power wastage of available power and lack of protection features which were addressed this year. Due to modifications in electronic components, more effective cooling systems were employed using heat pipes.Hull was made lighter by using S glass to increase speed and decrease power consumption, frame design was inspired by Tesla Cybertruck and bot's front face was covered with farrings which was efficient in minimizing drag.

III. Vehicle Design

A. Mechanical

1)Basic vehicle frame design and material selection criteria :
The frame is designed to be compact and modular to reduce drag force down to a minimum and provide efficient hydrodynamics. The frame design borrows some inspiration from Tesla's Cybertruck model. Aluminium is used as the material of the frame due to its lightweight and easy machining ability. The frame is trapezoidal (from the side view). The design of the frame is such that each elementary structure (hollow box and aluminium rods) can be separated from each other. It allows us a never-before level of flexibility in adjusting dimensions depending upon the requirements.

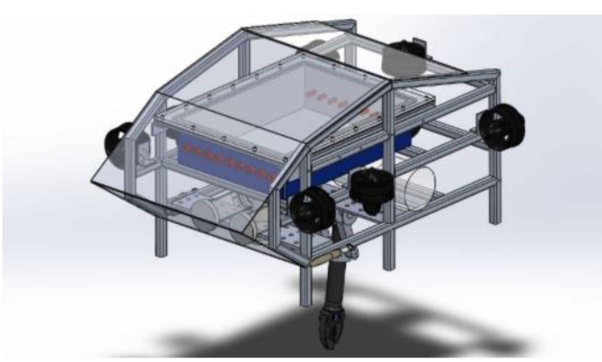

Fig. III.A.1 Isometric View of Bot

*2) Hull Design:*The hull design is aimed to provide high strength and rigidity while keeping the weight to a minimum, so we went for an S Glass box-shaped enclosure.

The hull is divided into two layers one for electronics and circuitry and the other for battery enclosure. The material of the hull is chosen in such a way that it does not crack at a depth of about 10m. This is thoroughly tested by simulation in ANSYS Static Structural by applying hydrostatic pressure equivalent to a depth of 10m underwater.

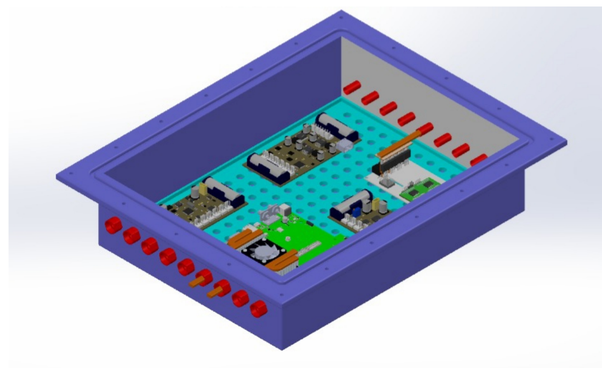

Fig. III.A.2 Hull Design

Both its ends can be easily opened to access the electronics inside. The design also provides watertight sealing to the bot. In case of an accidental failure, the electronic components are placed on a perforated and tapered base plate. This ensures the circuit's safety in case of leakage as the water first collects at the bottom of the base plate.

3) Camera Hull Design: The camera hull is made of acrylic. So similar simulations were performed on the camera hull in ANSYS as done in the main hull to ensure structural integrity.

4) Object Dropper and Grabber: A very simple mechanism has been employed to drop the required objects from the vehicle. In our mechanism, a BO motor is mounted to a PVC pipe. When the motor rotates, the obstruction causing the object to stay is removed, and hence the object falls. Newton Subsea Gripper, developed by BlueRobotics, is used.

5) Torpedo: The torpedoes are in the shape of a hollow cylinder of 10mm diameter and are 3D printed for high accuracy. A pressure-based system is used to launch the torpedoes by a tank with prefilled pressure of 30Pa. The torpedo is connected to the tank through PU fitting pipe passing through a coil actuating solenoid, which on receiving the command opens for about 10 milliseconds, thus allowing the air to pass from the tank to the torpedo through the PU fitting pipe.

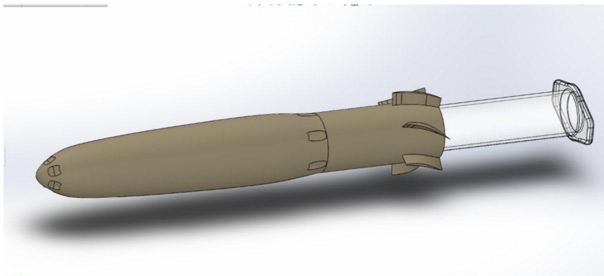

Fig.III.A.3 Torpedo Design

6) Cooling System: The thermal system consists of a quasi active cooling system. It helps us provide better cooling without having a heavy toll on our batteries. The primary method of heat transfer is conduction. There are other minor sources of heat, which are cooled by convection due to the circulating air.

The cooling system primarily consists of heat pipes paired with internal cooling mechanisms present in some components. The heat pipes help in the easy and continuous flow of heat out from the hull via the heat sinks present in the ICs and Jetson. Jetson has an inbuilt cooling fan which benefits a lot from this cooling system by providing it with a viable heat sink in the otherwise closed environment.

In the earlier models, we did not emphasise a dedicated cooling system as heat released by electronic components of our previous renditions was manageable. We have used better and more powerful ICs and a Jetson in our new vehicle, primary heat sources. Each is connected to heat sinks and further connected to heat pipes. Furthermore, the heat pipes are in contact with the water outside directly for further heat transfer. There is a cooling fan within Jetson that helps us circulate the air in the hull, which is in contact with heat sinks, and heat pipes help in faster cooling and allow circulation of cool air.

B. Electronics

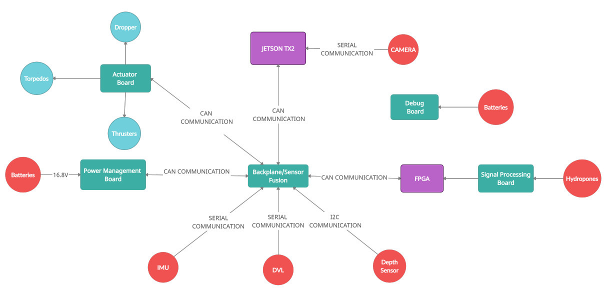

Fig. III.B Overview of Electronics Subsystem

Though the previous version of our electronics stack met all the requirements perfectly, but, it also has its issues that we have addressed in this years rebuild.

One major issue was power management, previously we used to power the thrusters using one battery and the rest of the circuit using another battery.This caused the thruster power to run out quicker than the other, which reduced our bots runtime and efficiency, so we switched to a single power source this year. We now use a single battery at a time, and after it runs out, we switch to another using hot swap controllers.This results in increased run-time and better power management.

This year, we have decided to change the Microcontroller platform from ATMEL to STM32 line of microcontrollers giving us the flexibility to use High processing power where required or Low power usage if needed.

Last years stack missed critical security features like Under and overvoltage protection, current spike and overcurrent protection. So we have added this protection using eFuses and TVS diodes. The thought of security leads us to the Kill switch, last year we used a REED switch as a kill switch which was an extremely unreliable, and had a lot of false firing issues, this year we switched to a better and more reliable waterproof physical button as a kill switch.

Another major issue was the lack of any Debugging data,making any sort of debugging a major pain in the buttocks, so we have introduced an independently powered (2x18650 cells) custom made debugging board, which allow us to keep track of Voltages of various nodes of the circuit along with current going to each thruster and temperatures of ESCs. This data will be sent to the main CPU using CAN protocol (which will also be the standard protocol all over the stack), then the CPU can use this data in intelligent decision making like shutting down parts of the stack in case of local errors and saving the rest of the circuit and AUV, the board will also have an EEPROM to store all this data for later use in analytics.

Following the debugging line of thought, in our previous stack making any kind of repair was also difficult, so this time we have decided to replace a single PCB with various modularized PCBs making it easy to replace the problematic board with a replacement much like any other commercial electronics gadget. Also, this allows our debugging board to execute the local shutdown of unimportant components in case of an error in the board.

1) Power Management Board: As already discussed, due to galvanic isolation, we powered the Thrusters with one battery and rest with the another. The Thruster battery discharged fast, decreasing runtime and efficiency. So, this year a smart battery management system was incorporated which used 2 10000 mAh LIPO battery packs but one battery at a time.After a battery discharges to a minimum preset level we switch batteries with help of a hot swap controller and an STM32f103c8t6. This board is also responsible for the generation of different voltage levels,i.e. 12V,5V and 3.3V to meet the requirements of different components across our circuit.

2) Backplane/Main Board: All the different boards are connected to the main board using high density connectors which are controlled by STMH745ZI-Q. This board communicates with JETSON TX2.

A high-quality, reliable Inertial Measurement Unit (IMU) is a crucial part of any autonomous underwater vehicle (AUV). Previously our AUV had to rely on accelerometer and gyroscope signals to obtain velocity and position values, which was giving lots of error in determining the exact position. So to assist our previous IMU, we are installing Doppler Velocity Log (DVL) in Makara which serially communicates to the CPU. Erroneous velocity values that are impossible or unlikely are filtered out. For samples when no values are received, the program extrapolates until a real value is received.

Furthermore, to provide an accurate way of measuring depth, a pressure-based depth sensor was also added to our AUV which communicates with STM32 microcontroller through I2C.

3) Actuator Board: The AUV has support for 10 thrusters, and also we have incorporated MOSFETs to drive solenoid valves for torpedoes. We use a mix of T200 and T100 thrusters, controlled using BlueESC. We are also planning to introduce current sensors to measure the current going to individual thrusters, thus helping us get an approximate idea for the speed of thrusters as we cant have an encoder on the thrusters.

4) Debugging Board: In our previous circuit, we used LEDs to debug circuits which made troubleshooting difficult and time-consuming. So, in the new circuit, we introduced an independent debug/protection board with an onboard OLED screen powered with an independent power supply. This board contains an STM32f103c8t6 microcontroller which monitors voltage, current and temperature at all important nodes using LTC2990. The data acquired is stored in an EEPROM which can be used for later debugging. Our circuits have also been incorporated with TPS2660x efuses to ensure circuit protection. These efuses can also be controlled by the debugging board in case of any emergency.

5) Acoustic Board: In our previous bot, we tried making passive sonar for locating the pinger with hydrophone and RaspberryPi with external ADC, but that did not turn out to be working. So This time we planned the whole Acoustic signal processing part based on FPGA. We designed our own Analog frontend board which has, Adjustable Bandpass filters, Amplifiers with Adaptive gain control, and High-speed ADCs which connect to the Eclypse Z7 FPGA board. We find out the pinger heading by finding the Time Delay of Arrival of signals. FPGA can communicate to onboard Computer via Ethernet or CAN bus.

There is an onboard AVR microcontroller ATMEGA328p that controls the Frontend gain and filtering also controls various power rails within the board. This board has its local power distribution to meet the special requirements of the board.

C. Software

The main aim of the software subsystem is to develop modular and error-free software, to get the vehicles working for challenging tasks. The majority of the control stack and navigation stack is programmed using C++ only, while the perception stack using C++ and Python.

We are currently using the Robot Operating System(ROS) for all the inter-process communications. In addition to that, OpenCV, along with various deep neural networks and state-of-the-art AI approaches for perception. And a set of packages is combined, giving autonomy to the vehicle and making the decisions. Furthermore, the team shifted from Unity3D game engine to OSRF Gazebo Simulator for virtual testing and simulation. Last but not least, we test the software on the vehicle in the swimming pool with custom props to expose the AUV to a realistic environment.

1. Perception Stack :

1.1 Object Detection (YOLOv3/v5):

Apart from the preprocessing and postprocessing of the image stream that is done by OpenCV(an open-source computer vision) library, we are using Yolo(You Only Look Once, a Convolutional Neural Network(CNN) based on DarkNet architecture) for object detection. This allows us to accurately identify the objects with complex textures or shapes from a greater distance. Yolo is trained on a large dataset of images and videos collected from test runs and past competitions. In addition, we have applied various image augmentations to impart variations and increase the dataset size. As a result, we achieved very encouraging results of above 87

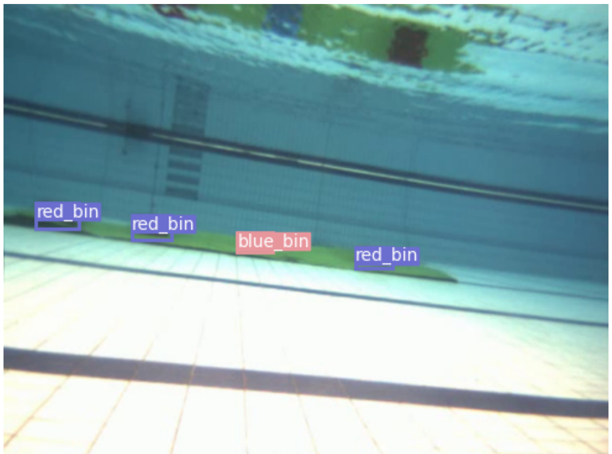

Fig. III.C.1.1.a Multiple Bins Detection

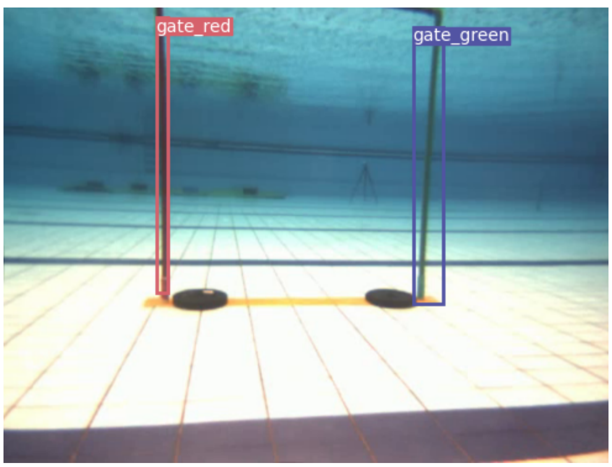

Fig. III.C.1.1.b Gate Detection

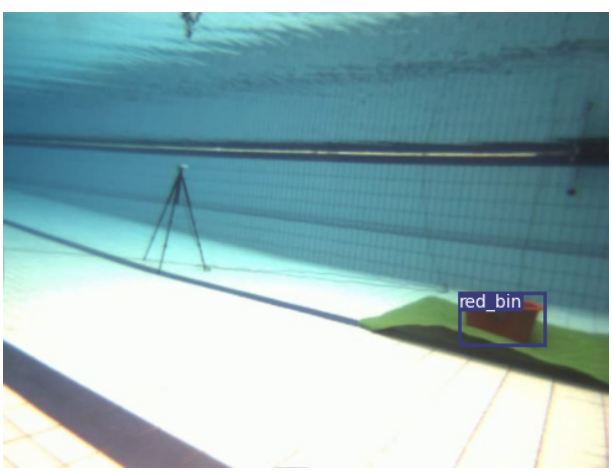

Fig. III.C.1.1.c Single Bin Detection

1.2 Pre-processing Techniques:

a) Glare Removal: Another challenge observed during test runs is the glares and the water wave reflections on the bottom surface. To solve this issue, we have proposed an algorithm that calculates the median and the mean variations of the RGB values for a certain number of images, thus equally spreading the uneven intensities. As a result, we get clearer images with the least glares and reflections.

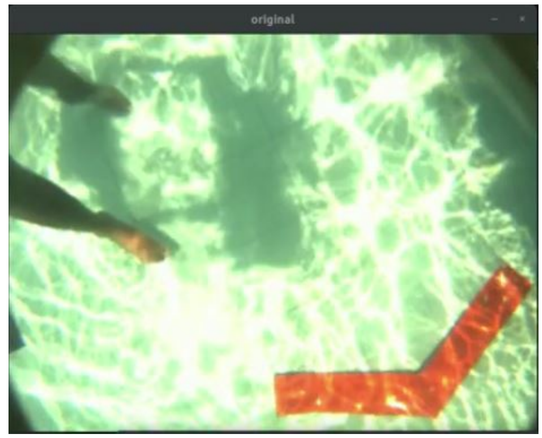

Fig. III.C.1.2.a.I. Original

Fig. III.C.1.2.a.II. Glare Removal Algorithm Applied

b) Color Correction: We learned about various environmental challenges, such as underwater visibility, during our Robosub 2019 venture. The image below shows the original visibility and color of the water taken from the AUV and the corrective measures we have implemented. We manipulated the weights of the individual RGB channels to attain a better watercolor. This method is called Stretching. We have also implemented the Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm to increase the image contrast.

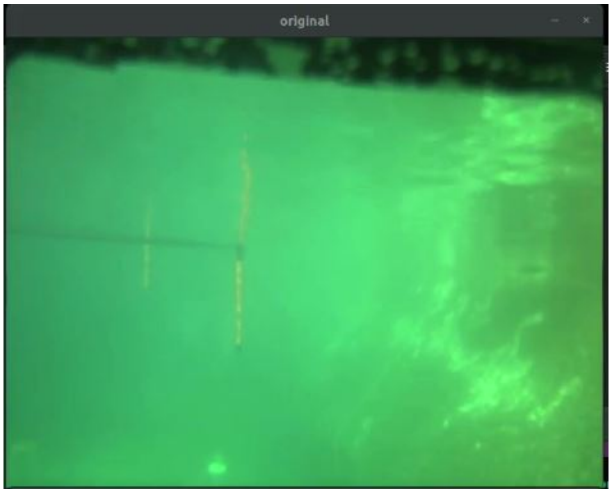

Fig. III.C.1.2.b.I Original

Fig. III.C.1.2.b.II Stretched

Fig. III.C.1.2.b.III Stretched + CLAHE

1.3 Model Optimisation:

The perception stack is mainly carried out by object detection methods using deep neural networks. However, there has always been a trade-off between accuracy and real-time fps. We have approached this problem with model optimization, using quantization by implementing state-of-the-art quantization-aware training methods. This approach simply converts all float32 weights and activations to int8, thus drastically reducing the model size and the inference time. Furthermore, this enables us to use low-power computing devices and stack multiple models in our pipeline without compromising performance.

1.4 Stereo Vision:

The team encountered various challenges related to depth estimation for precise manipulation during the simulation phase. To address such challenges, we came up with a stereo vision option. It uses two front-facing cameras, horizontally displaced to capture two differing views of a scene. By computing the disparity, we obtained a depth map as well as the point cloud. This will improve our torpedo shooting, precise manipulation of the robotic arm, and localizing objects in proximity.

2. Navigation Stack:

2.1 PID Auto-tuning:

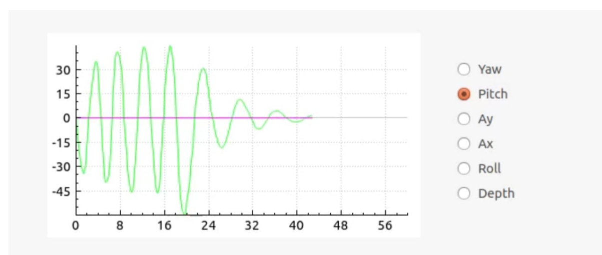

Fig. III.C.2.1 (Results of PID auto-tuning on one DOF - pitch)

The team is currently shifting from manual PID tuning to auto PID tuning algorithms based on Ant Colony Optimization (ACO). At first, the algorithm generates some random values and minimizes the error generated from a cost function. Then, the best values from this generation are used as parents for the next one. This iteration goes on until we get the optimal value.

2.2 Underwater Localization:

Underwater localization has always been a challenge for AUVs because of the incapability of inertial sensors to calculate linear velocity accurately due to high noise at the accelerometer. In order to tackle this challenge, the team will be using Doppler Velocity Log (DVL), which can provide updated velocities using various acoustic measurements.

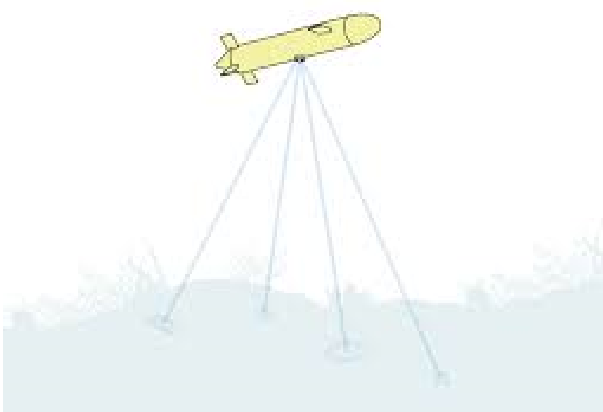

Fig. III.C.2.2.a Path finding by DVL

Sensor data from several sensors such as DVL, Inertial measurement unit(IMU), point cloud from stereo vision, even measurements from electronics components are sensor fused to achieve accurate localization results.

A typical approach we use to generate pathway using DVL :

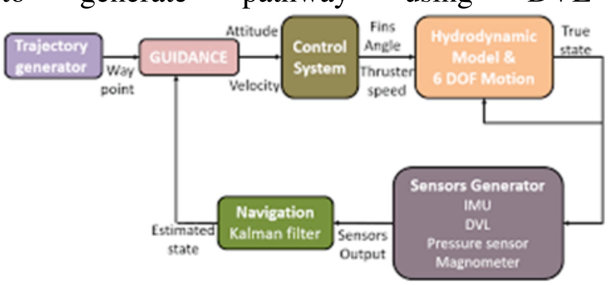

Fig. III.C.2.2.b Architecture for pathway generation

IV. Experimental Results

Analysis of the battery hull and main hull using ANSYS Static structural was done considering pressures at a depth of 10m for all possible materials taken into consideration initially.Then appropriate materials were chosen, thereby giving results of the factor of safety of given structures well above 3(S-Glass was chosen for main hull and battery hull). Thermal analysis of heat pipes used in the cooling mechanism was done using ANSYS - Steady state Thermal. The cooling system proved efficient to dissipate the heat generated by the electronics.

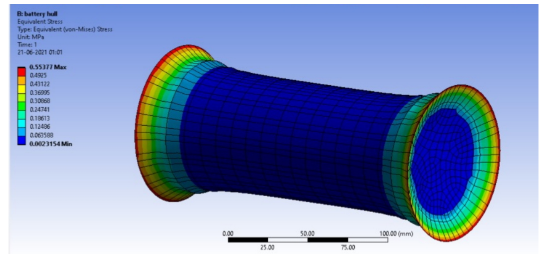

Fig. IV.1 Equivalent Stress Analysis of Battery Hull

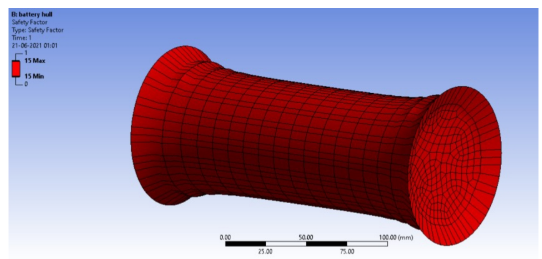

Fig. IV.2. Factor of Safety results of Battery Hull

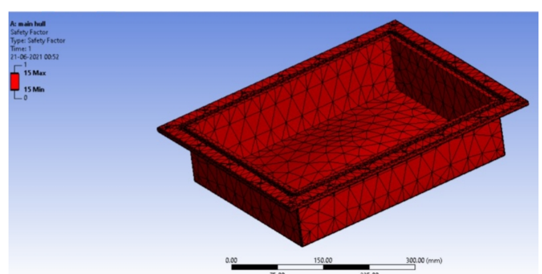

Fig. IV.3. Factor of Safety Results for analysis of Main Hull

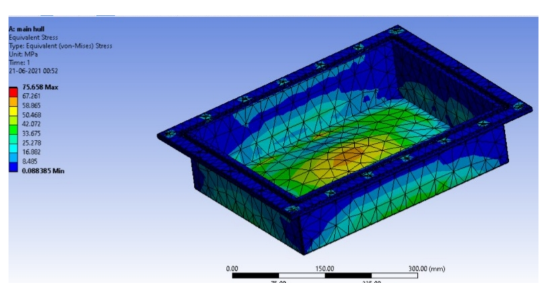

Fig. IV.4. Equivalent Stress results for analysis of Main Hull

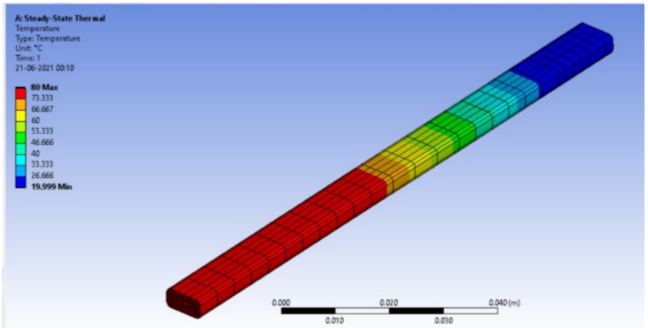

Fig. IV.5. Temperature Gradient results for Heat pipe cooling ICs

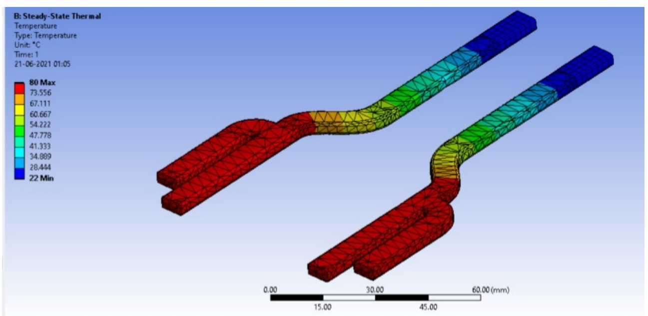

Fig. IV.6. Temperature gradient results for heat pipe cooling JETSON

V. Acknowledgement

Foremost, Team Tiburon would like to express our sincere gratitude to the Department of Mechanical Engineering for providing us all the support during these trying times. We would also like to thank Prof. Haraprasad Roy for the continuous support for our project and research, and for his immense patience, motivation, enthusiasm, and sharing with us his immense knowledge. His guidance helped us all in these trying times.

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Appendix A: Component Specification

Component	Vendor	Model/Type	Specs	Cost(if new)
Thrusters	Blue Robotics	T200, T100 Thrusters	5 pounds of thrust	$119
Motor Control	Blue Robotics	Basic ESC	30A brushless ESC	Reused
Actuators		Single Shaft DC Motor	6V	Reused
High Level Control	Student Design	PCB		-
Battery	Gens Tattu	Lipo Battery	4s 14.8V 20000mAh	Reused
Converter	Robu	LM2576 Buck Convertor	Input 3-40V,Output 1.5-35V	Reused
Regulator	Texas Instruments	7805	Input 7-38V, Output 5V	Reused
CPU	NVIDIA	JETSON TX2	256 core NVIDIA Pascal GPU,ARMv8 (64-bit) Multi-Processor CPU Complex	$1052
Internal Comm Network	Student Design	CAN		-
External Comm Interface		LAN	6-16V, max-power 135W	-
Inertial Measurement Unit(IMU)	VectorNav	VN-100	3-axis Gyros, Accelerometers, Magnetic Sensor	Reused
Doppler Velocity Log (DVL)	Teledyne	Pathfinder	Resolution-0.01mm/s	$20000
Camera(s)	Edmund Optics	Point Grey	USB 3.0 , Max-Power 135W	Reused
Hydrophones	Aquarian Audio	H1C Hydrophone		$139
Depth Sensor	Blue Robotics	Bar30 High-Resolution 300m Depth/Pressure Sensor	2.5-5.5 volts, operating range-0-30 bar	Reused
FPGA	Digilent	Eclypse Z7	ZYNQ-7000	$499
Gripper	Blue Robotics	Newton Subsea gripper	SKU: NEWTON-GRIPPER-ASM-R2-RP , HS Code: 8501.10.60	$493
S-Glass	Rajnikant Hardwares	Rectangular Box Type(1 cm thickness)	41cm * 31cm * 10.5cm - 5kg material	$30
Aluminium Tubes	Gujarat Mining	Square Tube	20cm *20cm * 2cm - 2.8kg material	$10
Aluminium Plates	Rajnikant Hardwaress	Square Plates	250mm * 250 mm * 2mm -1.8 kg material	$5
Acrylic Plates	Rajnikant Hardwares	Square Plate	250mm * 250mm * 2mm- 0.26kg material	$20
Heat Pipes	Digi-Key electronics	ATS2169-ND	ATS-HP-F6L150S30W-029, Flat Heat Pipe 30W 3X8X150MM	$30