BRACU Duburi AUV Technical Design Report

Brac University (BRACU Duburi)

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***Abstract*—For RoboSub 2024, BRACU Duburi plans to deploy Duburi 4.1 which has been built focusing on efficiency and reliability of the AUV. This has been achieved through thruster repositioning, improvements in a more streamlined torpedo and waterproof grabber. A more compact internal architecture has been implemented with modularity in mind and based on a swift and reliable communication system. In addition, a new power distribution system, and a more efficient MOSFET switch has also been integrated to the electrical subsystem. Moreover, the upgrade to Jetson Orin Nano has also showcased a huge leap in computational performance and greater accuracy in autonomous underwater object detection has been achieved through advanced ML techniques. All the new improvements have been thoroughly tested and integrated into the vehicle according to our strategic goal to complete all the tasks successfully.**

I. COMPETITION STRATEGY

Based on the previous experiences of RoboSub, our strategic plan for RoboSub 2024 comprises fixing last year's shortcomings and introducing efficient and optimal changes to gain as many points as possible. Vital changes to all the components from electrical, software, and mechanical to course traversal plan have all been fine tuned for the best results.

A. Competition Strategy: Fast Serviceable System

The BRACU Duburi team from the past experience in RoboSub 2022 & 2023 have greatly focused on system ability to adapt to any unforeseen [3] scenarios. This was done keeping in mind the previous learning of the team. The team has done multiple quality of life improvements to ensure ease of access and fast restoration of the system to ensure maximum uptime. The improvements that were improved were:

- Backup software sub-system on standby for easy swap - ensures a smooth transition in a crisis.
- Leak sensors have been installed throughout the AUV hull to prevent loss of essential components faced during RoboSub 2023.
- Redundant components have been removed from the overall system.
- Gauges installed throughout the AUV to observe vital information such as temperature, voltage and system status information.

B. Competition Strategy: Task Execution

1) Rough Seas—Coin Flip

The AUV will start on the dock by facing towards the gate to register the required IMU and Compass measurements. For extra points, we will position the rover following the coin-flip outcome. Regardless of the position, the AUV will dive down to the previously set depth then according to the error value of the AUV it will reposition the AUV towards the **Enter The Pacific-gate** task and commence forward.

2) Enter the Pacific—Gate

We have strategized to complete the gate task in two stages. In Stage 1-Phase 1, when approaching has a search algorithm in place that will first search for gates. The path that the AUV will follow to search for the gate will be partially determined by preset variables alongside conditional requirements. The AUV will then move to Stage 1 Phase 2, where the Machine Learning based system will search for the gate object as a whole and align the AUV using visual homing methods. In Stage 2, the AUV will detect the predetermined marker's(CW/CCW) side, align the AUV to the center of the object, and then move onwards. With the help of our IR-based object avoidance system, it will detect the object and dive. BRACU Duburi attempted yaw in last year's competition and to accumulate additional style points, we aim to take advantage of our new T200 thrusters and their changed positions to attempt a roll while passing the gate. The team will aim for the maximum possible points for style.

3) Hydrothermal Vent—Buoy

Similar to the previous task, 'Hydrothermal Vent' will also be executed in multiple stages. Stage 1 will detect the Buoy using the ML-based System. The AUV will turn towards the direction of the Buoy and start searching while doing a crab walk movement. Once detected, the AUV will align itself with the Buoy and proceed forward. With the IR-based system, it will ensure the buoy is directly in front of the AUV and proceed onto stage 2, which will be circumnavigating the buoy. The AUV will do it multiple Phases. Starting off the AUV will come backwards from the Buoy and the AUV will go left/right then go forward then right/left, after that come backwards and lastly ending with a left/right turn. Creating a boxlike path doing it. Once done circumnavigating, the AUV will move to the next task. feeds.

C. Mapping -Torpedoes

The AUV will position itself at the direction of the Mapping Task. It will commence forward searching for the vertical board. Once the AUV detects the task it will use a visual homing approach to align with the board itself. Once done it will divide the board into 4 segments keeping the corners with smaller holes as point of contact. Firstly the AUV will approach the smaller hole on the top. The AUV will align with the hole of the first small hole. Then move forward and launch the Torpedo through the hole. Once completed the AUV will move backwards to reposition for the next task. Once done it will change the depth to a predetermined level. Once that depth is reached the AUV will repeat the same process as the first hole for the 2nd smallest hole on the opposite corner. Once the AUV is done launching both the torpedoes it will move backwards and shift the AUVs depth to prepare it for the next task that will be the bins.

a) Ocean Temperatures—Bin

The AUV will move towards the bin task and detect the bin with the front camera until it is not visible in the frame for a predetermined time. The AUV will switch to the bottom-mounted camera and will align the AUV with the proper hot or cold-colored segment accordingly. Then it will release its droppers in the determined position and move towards the next task.

b) Collect Samples-Octagon

At the completion of all required tasks, Duburi will move to the octagon. Once reached, the AUV will switch to the bottom cameras and detect the samples using computer vision. After the samples are identified, they are picked by the grabber, and then the AUV proceeds to detect any nearby basket. The AUV will attempt to align the AUV with the basket and then will release the object by opening the end effector. If Duburi fails to complete the task in a predetermined amount of time, it will abort and come to the center of the octagon and finally resurface from that point.

II. DESIGN STRATEGY

Building on the knowledge from last year, we noted the areas where we lost points and made necessary adjustments to improve the performance in the determined areas. This section highlights and elaborates on the changes implemented to the electrical, mechanical, and software subsystems of Duburi 4.1 and how it enhances our AUV compared to 2023.

A. Mechanical Subsystem

1) Material

The body of the hull is built with Marine 5083 grade aluminum. We kept the material from last year due to its low density, high strength-to-weight ratio, resistance to corrosion, and good thermal conductivity. The top enclosure along with the front and bottom camera openings are sealed with acrylic windows having brass frames to ensure visibility from outside. Despite a higher cost and production time, the main body has lasted more than a year without accumulating any rust. Hence why, the material is reused this year as well. [2]

2) *Hull Design and Volume*

The team has also retained the octagonal shape of the hull because of its low drag when operating in reverse and equal flow of the surface turbulence. While the reduced internal volume made the internals really packed to the brim, we realized the compactness far outweighs lack of mobility. The smaller size meant lesser difficulties pertaining to quick and extreme maneuvers.

Fig. 1: BRACU Duburi 4.1

a) Propulsion system

Upgrading to T200 thrusters has been a game changer in terms of efficiency due to its more powerful motors that are more powerful and reliable. We also rearranged the depth thrusters to be further apart from each other in order to increase Duburi's maneuverability, stability and agility. While submerging, Duburi used to pitch upto 10° front as the four depth trusters were in closely mounted, rendering them to act as a single thruster. The AUV now can descend perfectly stable without tilting. In addition, the rover is now capable of performing the six degrees of freedom: roll, pitch, yaw, heave, surge and sway. Therefore, we are able to achieve greater maneuverability. The added metal mounts for the new thruster orientations have increased the weight of the AUV, resulting in a loss of bonus points for weight but compensates this by providing ability to make tough maneuvers.

b) Torpedo

This year, the team had developed a more streamlined and hydrodynamic torpedo to ensure we gained maximum points during the Mapping task. The CFD results of the new torpedo as opposed to last year shows a massive improvement in terms of drag reduction (see 7). The distance traveled by the torpedoes have also increased from barely 1 feet to a maximum of 5 feet now. Changing the material to plastic coated with machined aluminum for the material's lightness and higher rust resistance [potential reference] has improved the life expectancy of the torpedoes.

Fig. 2: Torpedo Launching System

3) *Grabber*

Our previous grabber was unable to work efficiently underwater for a long while. Hence, by designing a customized grabber made up of machined aluminum, and most importantly - adding a waterproof enclosure, we have increased the timespan to almost 10 times. The grabber has also performed nearly perfectly despite being submerged in water for four hours at a time. This increase in reliability is also crucial for our future underwater exploration endeavors as the grabber can endure a decent amount of pressure and still perform accurately. The grabber will be mainly used to assist the AUV to retreive the objects from the Octagon task.

4) *Dropper*

We used gravity to our advantage and designed a simple system that releases the dropper at the signal that is received with Duburi 4.1 moving upwards simultaneously to ensure a perfect landing. The dropper is also made from the same materials as the torpedo. This will help us to reuse a single dropper multiple times in the water without accumulating rust. This is both design and cost efficient for us.

The design choice was made considering the precise drop and also keeping in mind the tendency of round objects rolling to a different path.The new design is as follows.

Fig. 3: Dropper System

B. Camera placement

The cameras on the AUV are mounted at the front and one at the bottom. Most AUV's have the camera's mounted outside the main hull or have a dome shaped enclosure. We opted for a internal camera setup considering a few factors such as:

- Distortion due to dome shaped enclosure
- Unavailability of waterproof camera.
- Flexibility in terms of camera choice due to no limit in terms of space as most cameras can view through the window.

The approach for two camera system was to avoid design complexity. But This also decreases the overall viewing angle. A movable design could cover a wider area.

C. Electronic Subsystem

1) Battery pack

For this year the AUV has gone with a complete Lithium Polymer battery setup. The design choice was made to compensate the added weight by using lighter batteries compared to the previous years. Earlier where the team developed a lithium ion battery pack, that although was a cheap and cost-effective solutions but its added weight was a major drawback.

2) Power Sense Module

This year we have introduced a power sense module that allows the rover to function without major electrical disturbance. As the power sense module has low voltage cutoff and high amp protection. This works as a safety mechanism for the AUV ensuring the batteries do not degrade over time. Furthermore this also ensures the electronic system is not damaged with high power flow.

3) Magnetic Switch

As opposed to the previous switch which uses the rocker mechanism to cut off power, we upgraded to a magnetic switch. Even though the rocker switch had its advantages - for instance, it was easy to use, very visible underwater, and cheap to implement - it was susceptible to mechanical damage and failure. On the other hand, a MOSFET-based kill Switch utilizes an SR latch made of two NAND gates for logic; we can use two magnetic switches (one for “ON” and another for “OFF”) thus minimizing the chance of false activation. Using an N-Channel mosfet the system can trigger a relay for power cutoff. We also switched to Solid State Relay for improved reliability as we found reliability issues with a normal relay during stress testing. In addition, having a built-in voltage regulator in the circuit we do not need a separate power source for powering the logic Circuit. See Figure 15 for a detailed mechanism description in Appendix C.

4) Modular Division

Duburi 4.1 has a cleanly designed internal system now, enabling proper debugging during testing and future developments. An upgraded ESC mount is used to ensure adequate space for dexterous mobilization. The ESC board is also now divided into two parts, which take advantage of the side walls of the main housing. Furthermore, a stacked approach is followed to utilize the remaining limited space in the AUV. Buck/boost converters are kept in front under the Jetson Orin Nano and Raspberry Pi 4 stack away from the Fathom X Tether interface board which is a new addition to the communication of the AUV. A switch is used for interconnection with all the SBC in the internal system. Under the SBC stack, a power distribution board is placed. As a result, all the components in the AUV have been made accessible.

Fig. 4: Internal electronics structure

5) Microcontroller

This year the team went along with an ARM based Pixhawk as its microcontroller to work as the slave board that will execute the commands sent by the vision system. The choice was made considering our past experience as the Pixhawk utilizes mavlink protocol. It allows the team to completely migrate the whole system to python Although the solution is expensive but it provides a far greater communcation compared to other solutions available.

6) Communication system

Previously BRACU Duburi used a fiber optic based solution to communicate between two ends (AUV-Ground stations) while doing a survey run. The fiber optic provided a really fast and reliable connection in regular cases overall but had a major drawback which was that it was susceptible to damage if bent. It had an element of uncertainty to it. Hence last year we switched to a FathomX Tether interface board paired with FathomX cable for a reliable connection. It uses the principles of Power over Ethernet hence it can be used with any other off the shelf wiring solutions as well. Making it really accessible in terms of failure. It also has about 80Mbps of transmission speed with about 5-10ms propagation delay on heavy loads.

D. Software Subsystem

Several substantial improvements have been implemented in our software subsystem to enhance the autonomy of our AUV and reduce training time. These improvements span from dataset diversity and training pipelines to utilizing advanced techniques and a few hardware upgrades.

1) Computational System

Previously used Jetson Nano has been upgraded to Jetson Nano Orin which has eight times the CUDA cores, 6-core Arm Cortex-A78AE CPU, a new generation 4GB LPDDR5 RAM and far greater memory bandwidth]. This leap in hardware has reflected in time efficiency during training huge amounts of data which has been reduced by 30 times. Moreover, the 8 times computational power is evident in the jump from 40 to almost 400 FPS rate from both our cameras. Beside preparing for RoboSub 2024, we intentionally made a costly decision with upgrading to Orin in order to support our deep sea research as well.

2) ROS System Update

From last year's experience the team has got an upper edge with the use of a ROS Based system. The core system still runs on ROS Noetic but the team is slowly migrating the system to a ROS 2 based system. The major advantages that we noticed was cleaner code base, easier troubleshooting of the system overall and reliable code command flow. Apart from that ROS allowed the team to fix the bridge between control software and computer vision software. This also eliminated a major the team faced previously which was connection drop between the two pieces of code. With the implementation of ROS the team was able to pinpoint ongoing issues.

3) Computer Vision System

a) Model Training

We have made significant refinements in terms of our training strategy this year. For instance, We have upgraded our computational infrastructure from last year's system. This improvement drastically increased our training efficiency. We have successfully conducted training on alternative systems and are now endeavoring to deploy these advancements on Jetson. This optimization has dramatically reduced our model training time, cutting it down from 10-12 hours to a mere 1-2 hours, which not only enhances our efficiency, but also allows us to iterate and refine our models at a much faster pace.

III. TESTING STRATEGY

Our team doubled down on the importance of testing and fine-tuning Duburi 4.1 in a swimming pool setting similar to that of the competition ground. We wanted to ensure optimal performance and reliability through consistent recreation of the designed tasks. With coherent integration of new components and subsystem implementation, we made sure Duburi 4.1 would have an agile performance in RoboSub 2024.

A. *Torpedo Launch*

With more hydrodynamic torpedos designed this year, we managed to reduce almost 40% drag. CFD results for 2023 and 2024 are given in Appendix B12. We sought to refine the target accuracy and seamless launch this year. The reliability of the launch was first tested and calibrated to maximum accuracy and then Computer Vision was implemented in order to integrate the reliability of the torpedo attack with the successful locating of the target point. A more detailed outline is added in Appendix X.

B. *Grabber*

The team tested different iterations of the grabber before settling on this. The unit test consisted of payload weight capacity tests, longevity tests and grip test as a mode of stress testing. The new grabber surpassed all the tests and could perform with ease. Furthermore the new grabber was tested for leaks by submerging it for extended period of time.

C. *Six Degrees of Freedom*

Repositioning our back thrusters came with their own set of difficulties. We have considered multiple thruster orientations until the current design choice. Afterwards, through calibration and repeated tests, we managed to achieve a perfect roll performed by the AUV. The redesigned control algorithms allows for a better pitch, roll, yaw, sway, surge and heave movement. The rover has also been tested to stabilize during moderate to heavy turbulence, which had not been previously achieved.

D. *Computational System Stress test*

This year having access to two computational units we have had the opportunity to assess the training and realtime fps. We have seen a massive increase in performance as the Nvidia Jetson Orin Nano is far superior compared to our previously used Jetson Nano. We have experienced increment in both detection FPS as well as training time reduction. The team has also tested temperature differences in both the computational system's operation. The Jetson Orin Nano maintains a more stable temperature when in operation.

IV. FUTURE PLAN

BRACU Duburi has already stepped into the realm of marine robotics. BRACU Duburi initiated it's first ever open water testing in Saint Martin's island this year. BRACU Duburi currently has reached 10 meter depth and aims to push to 30meter depth to facilitate deep sea exploration and study aquatic life in the Bay of Bengal.

ACKNOWLEDGMENT

BracU Duburi would not have been made possible without the unwavering support, resource providence, and financial assistance of Brac University - especially our acting Pro Vice-Chancellor Dr. Syed Mahfuzul Aziz, the Chairperson of the Department of Computer Science and Engineering Dr. Sadia Hamid Kazi and our Registrar Dr. David Dowland. BracU Duburi is also a reflection of the relentless hard work and sheer brilliance of the individuals who have made up the team throughout the years. The entire team of BracU Duburi is immensely grateful to our advisor Dr. Md. Khalilur Rahman Sir for being a constant beacon of guidance and his continuous support for the project's development. In addition, a massive thank you to our co-advisors:Adnan Sabbir, Sayantan Roy, Nayem Hossain Saikat, ATM Masum Billah, and Md Mahfujul Haque Sourov for their guidance, mentorship, and dedication to the success of the AUV.

The progress made on Duburi 4.1, and the leaps of improvement would not have been possible without the dedication and perseverance of our team members. The team not only persisted through the numerous failures during pool tests, but they were also always quick on their feet with alternative and even better plans.

We would like to acknowledge our sponsors who have believed us in our each endavour and have guided us through the journey, We would like to express our gratitude to Robi Anxiata Ltd. Nortek Group, VectorNav, BlueRobotics, The Robotics Club Of BRAC University and JustDot3d for all their support .

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[3] SM Minoor Karim, Oishee Fatima, Samia Abdullah, ATM Masum Billah, Md Mahfujul Haque Sourov, Shaownak Md Ibne Shahriar Talukder, Nazmul Haque Omi, Umama Tasnuva Aziz, Ahmed Mahdi Uddin, Partho Protim Sarker, et al. Bracu duburi auv technical design report.

Appendix A: Component Specifications

Component	**Vendor**	**Model/Type**	**Specs**	**Custom/Purchased**	**Cost**	**Year of Purchase**
ASV Hull Form/Platform	Built In-House	Custom Aluminium	-	Custom	$ 509	2023
Waterproof Connectors	BlueRobotics	Potted Cable Penetrator	Penetrator	Purchased	$ 108	2022
Propulsion	BlueRobotics	T200 Thrusters	T200 Thruster	Purchased	$ 1600	2024
Power System	Tiger	5400mAh Lithium Polymer Battery	Lipo Battery	Purchased	$ 130	2022
Motor Controls	BlueRobotics	Basic ESC	Basic ESC	Purchased	$ 288	2019
CPU	Nvidia	Nvidia Jetson Orin Nano	Nvidia Jetson Orin Nano	Purchased	$ 499	2024
Teleoperation	-	-	-	-	-	-
Compass	VectorNav	VectorNav VN200	Vectornav VN200	Purchased	Sponsored	2022
Intertial Measurement	VectorNav	VectorNav VN200	Vectornav VN200	Purchased	Sponsored	2022
Unit (IMU)	VectorNav	VectorNav VN200	Vectornav VN200	Purchased	Sponsored	2022
Doppler Velocity Logger(DVL)	Nortek Group	Nucleus 1000	Nucleus 1000	Sponsored	Sponsored	2023
Camera(s)	BlueRobotics	Low-Light HD USB Camera	Low-Light USB Camera	Purchased	$ 198	2021
Hydrophones	-	-	-	-	-	-
Algorithms: Control	-	-	Thresholding, PID, Kalman Filter	Custom	-	2021
Vision	-	-	Transfer Learning	Custom	-	2021
Localization and Mapping	-	-	-	-	-	-
Autonomy	-	-	Machine Learning, IMU Heading	-	-	2022
Open-Source Software	-	-	ArduSub, Python Libraries	-	-	2023

APPENDIX B: MECHANICAL ANALYSIS

Fig. 5: Redesigned Manipulator

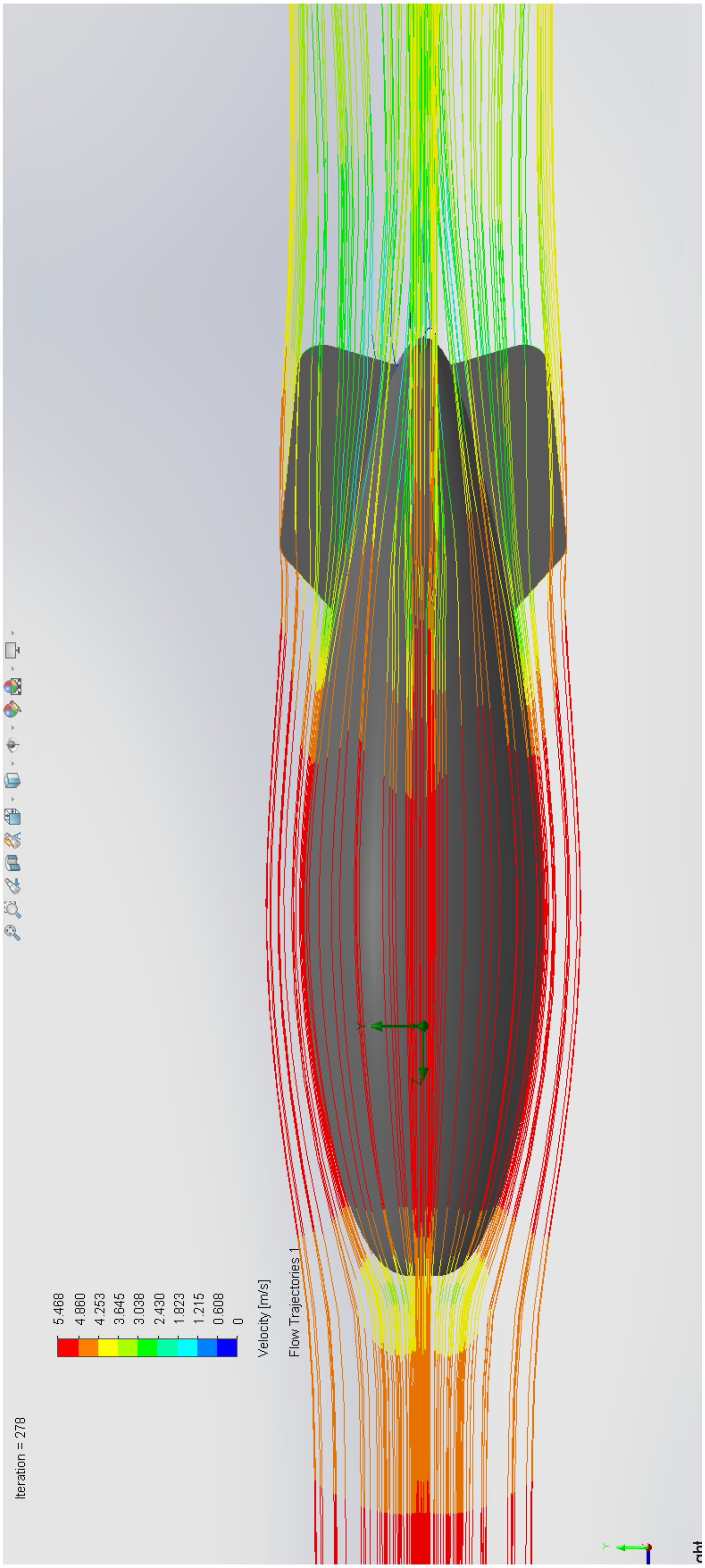

Fig. 6: Flowline Analysis of Torpedo

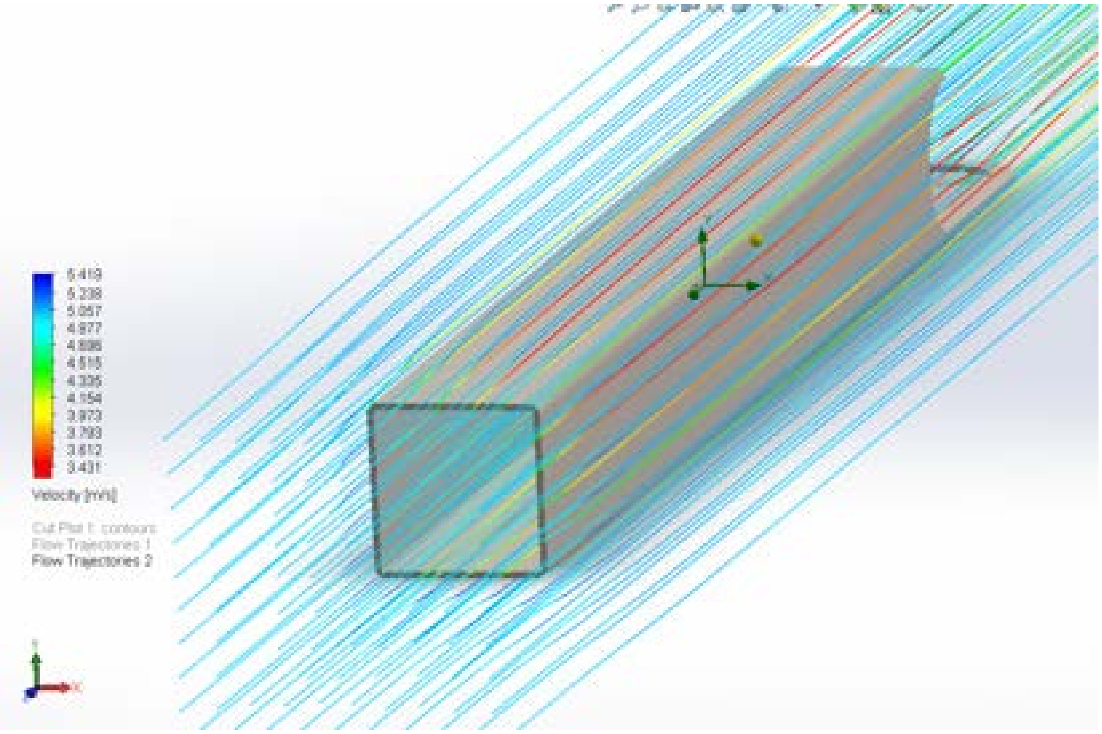

Fig. 7: Flowline Analysis of Old Torpedo

Fig. 8: Vorticity Analysis of Torpedo

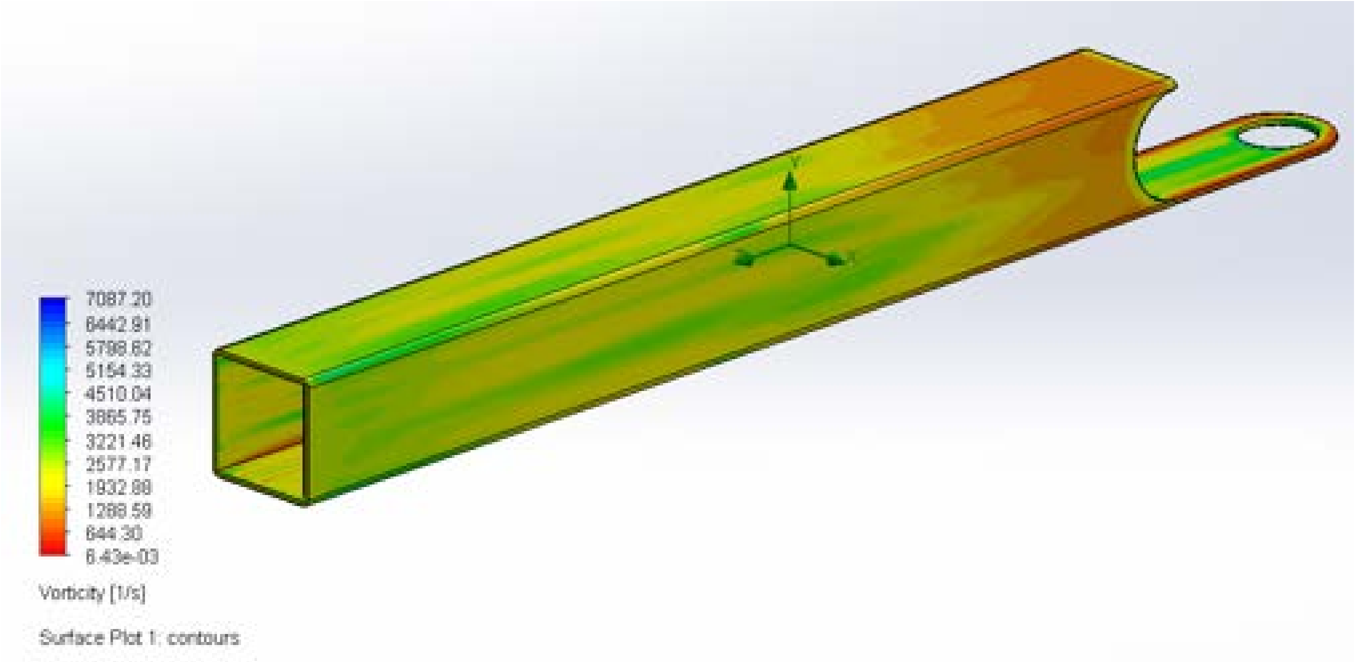

Fig. 9: Vorticity Analysis of Old Torpedo

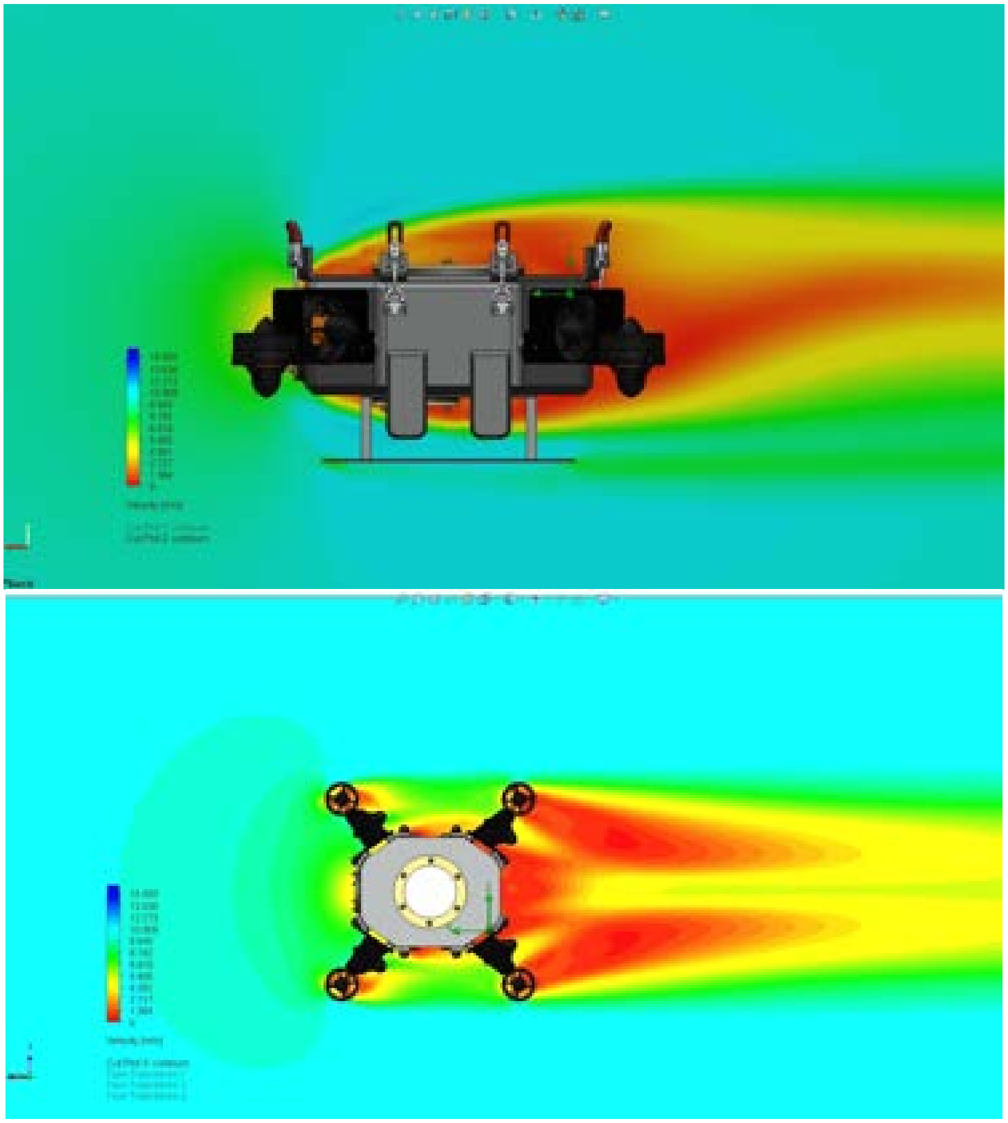

Fig. 10: Fluid flow over different regions

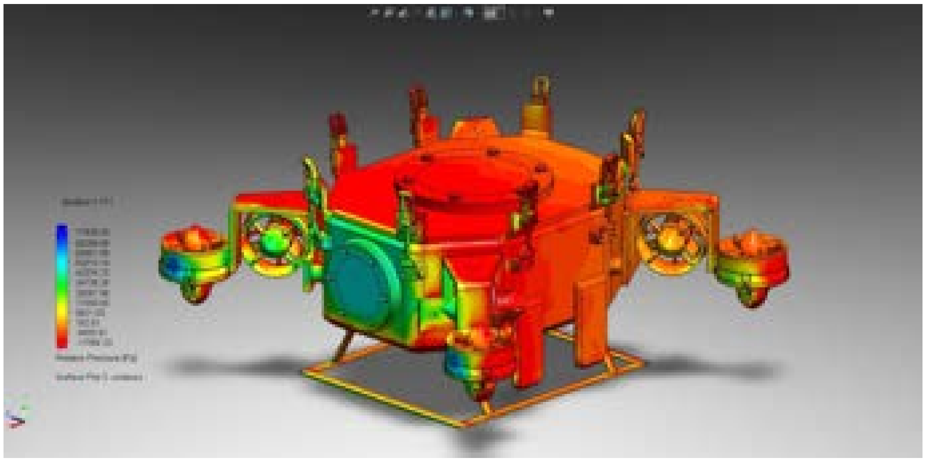

Fig. 11: Pressureplot of BRACU Duburi

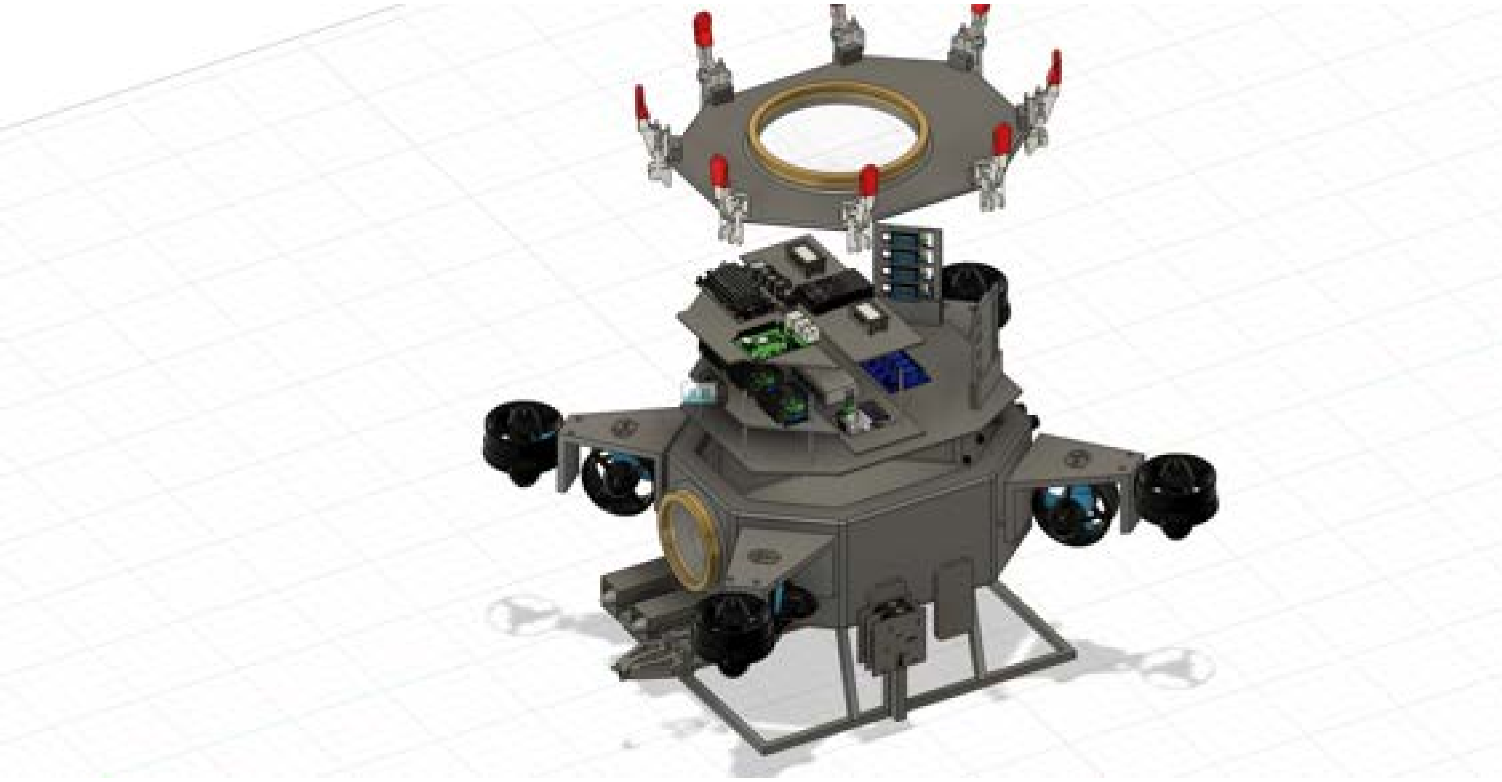

Fig. 12: BRACU Duburi Burst View

APPENDIX C: ELECTRONIC SYSTEM ANALYSIS

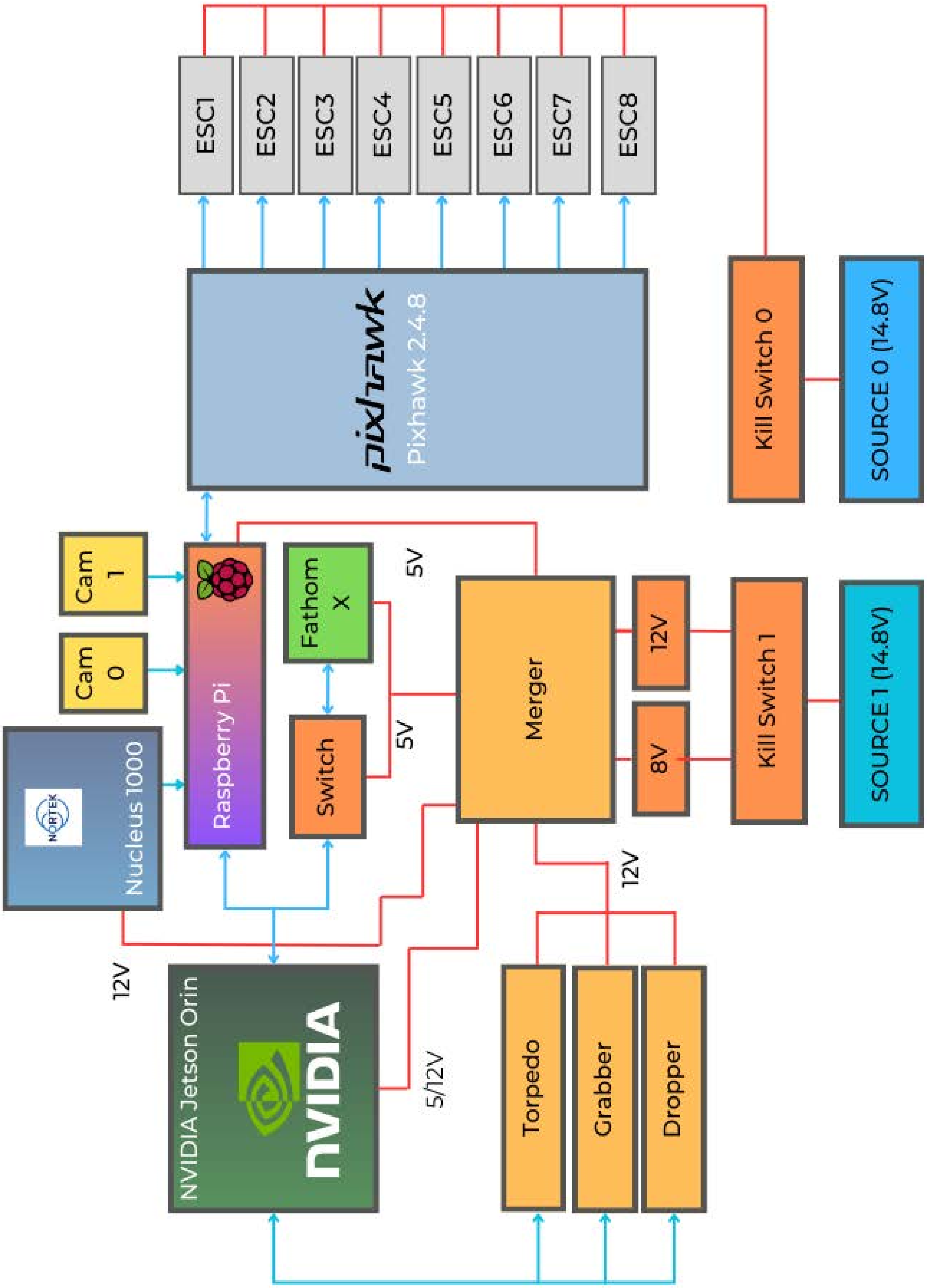

Fig. 13: Power Flow Diagram

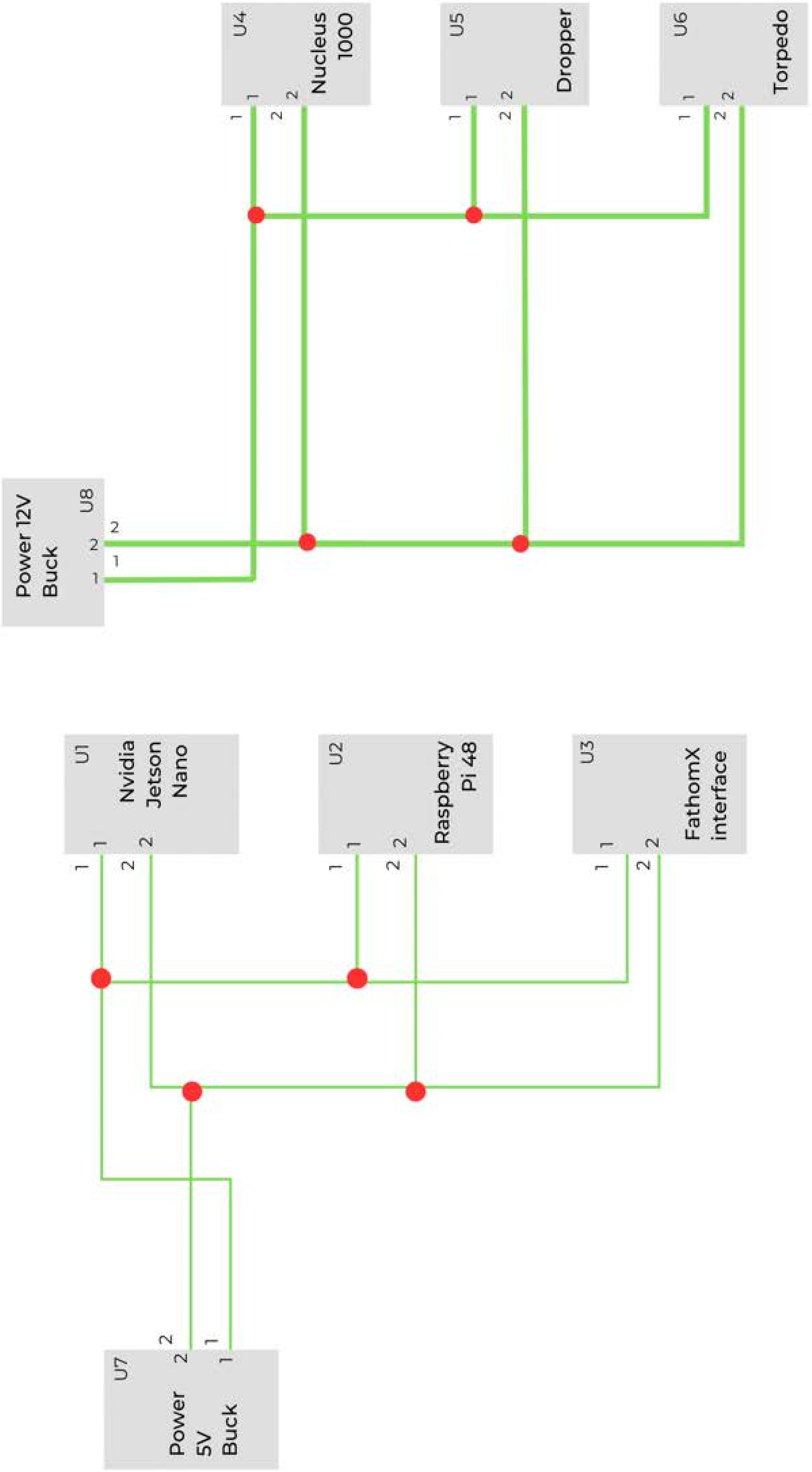

Fig. 14: Power Distribution Board

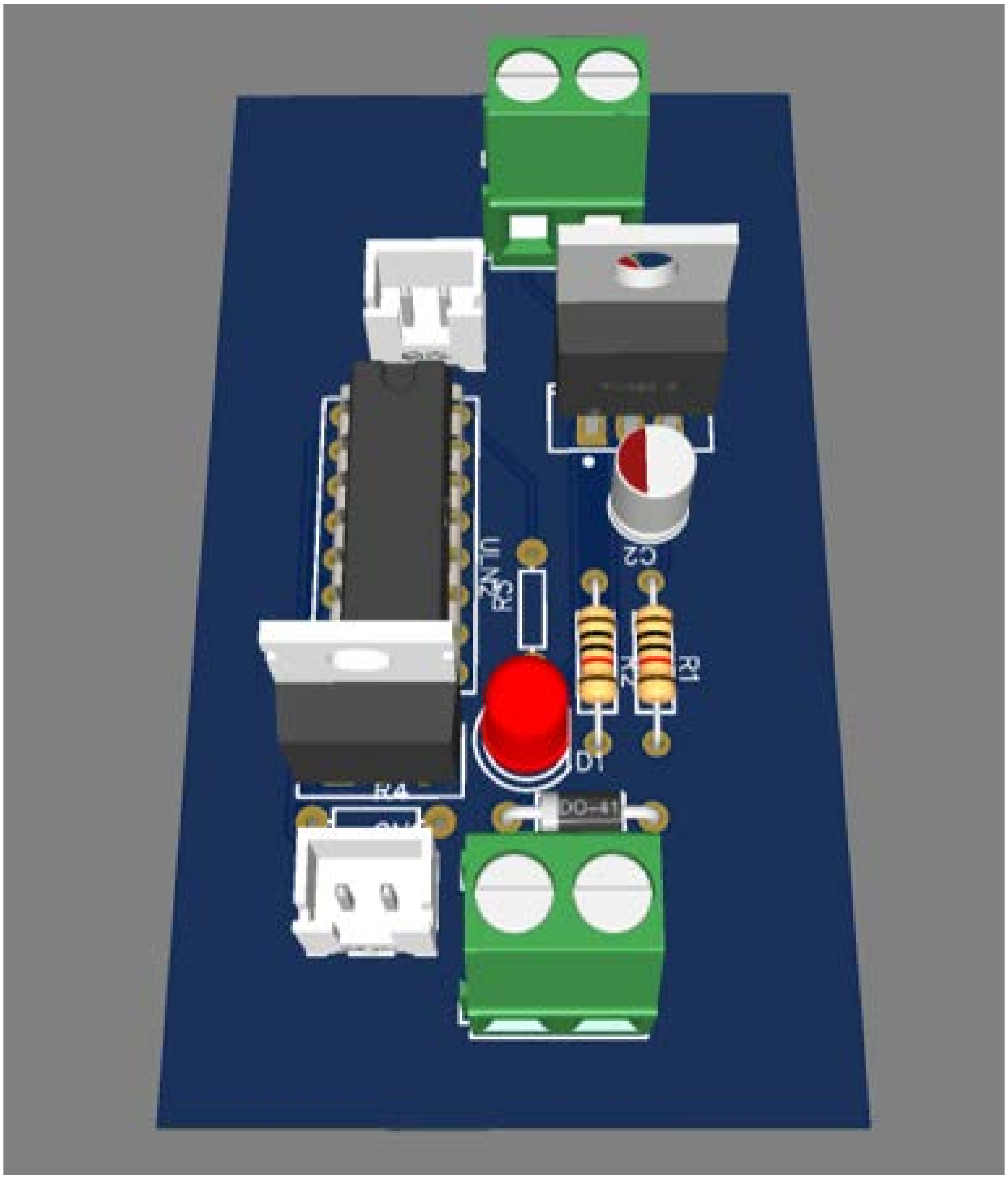

Fig. 15: Latch Based Kill Switch

APPENDIX D: COMPUTER VISION TRAINING STATS

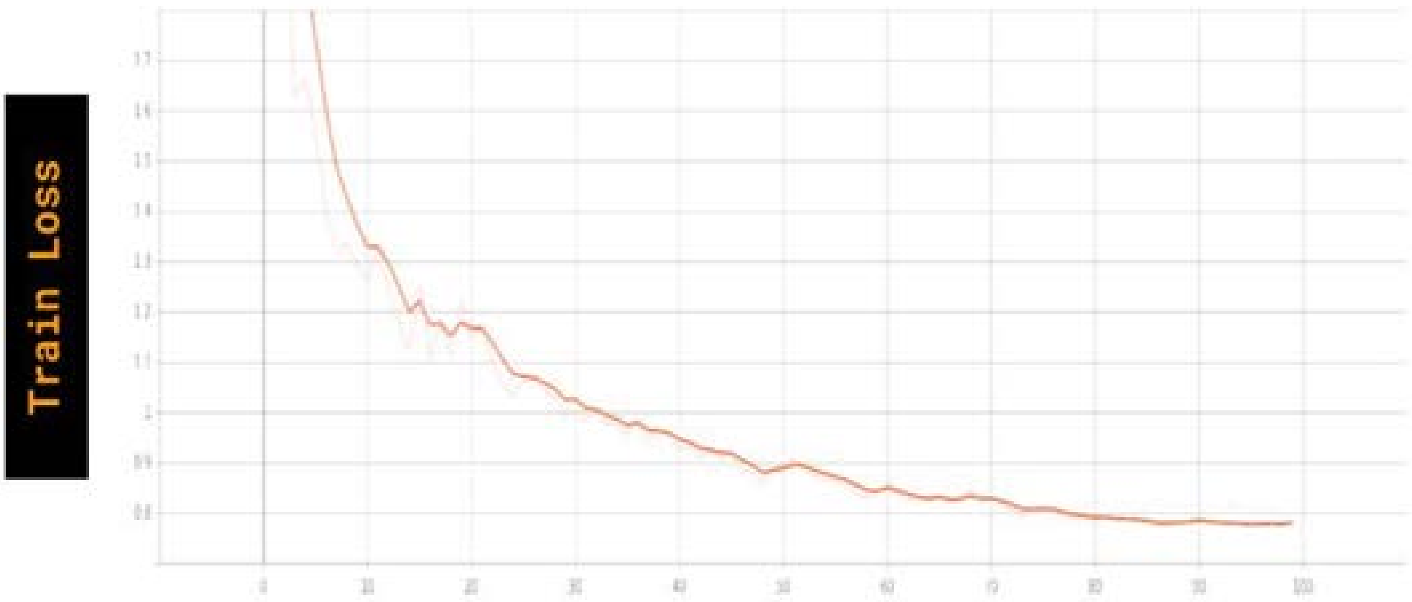

Fig. 16: Training validation loss over 100 epochs

Fig. 17: Training vs validation loss over 20 epochs on Jetson Nano

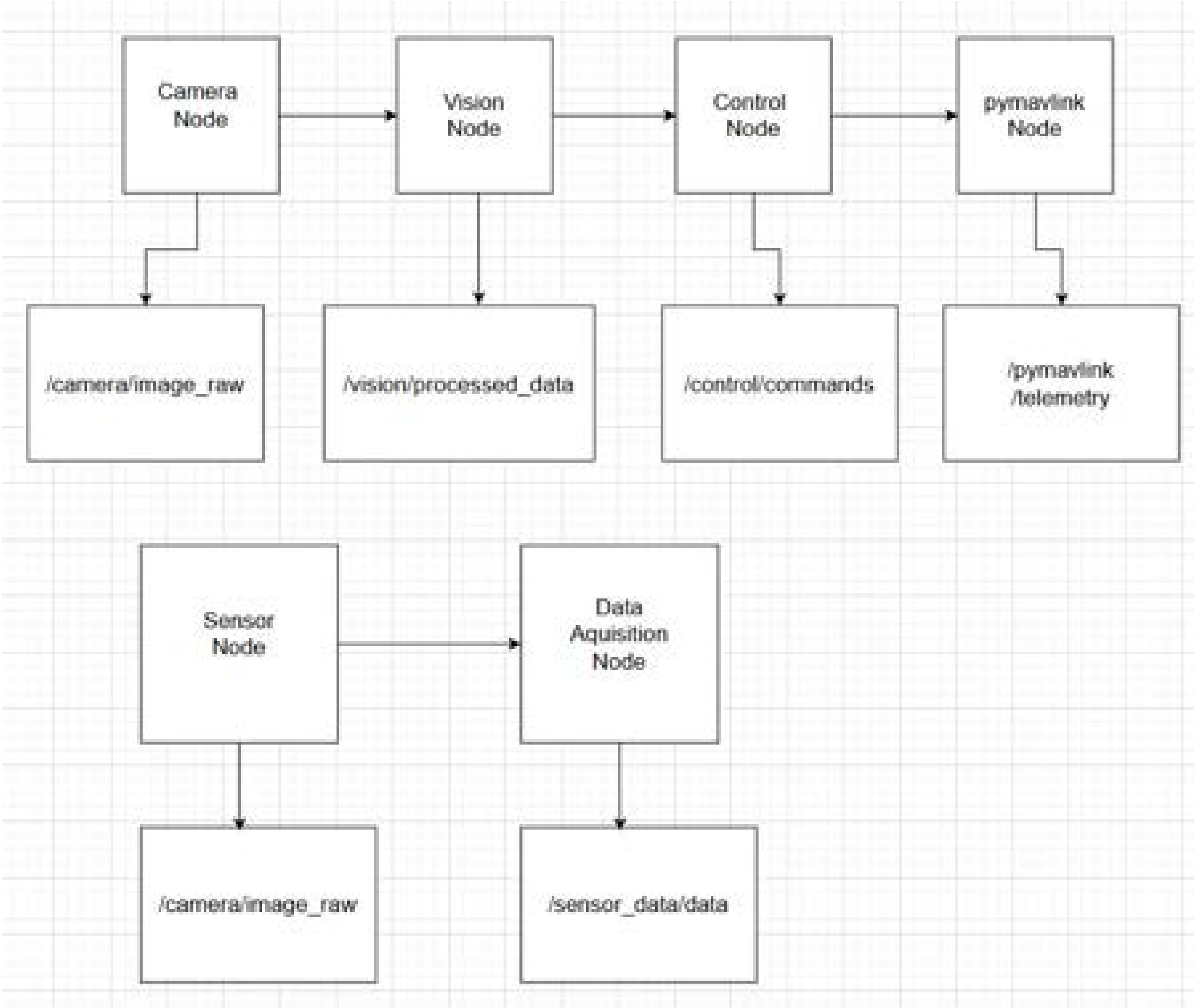

Fig. 18: Software Architecture

APPENDIX E: OUTREACH PROGRAM

BRACU Duburi has focused this year on delivering the magic of robotics to the young generation and to the people who do not have access to the technology. BRACU Duburi held outreach programs titled **”Robotics for impact”** which aimed to deliver basic knowledge of robotics to the school going kids. We were able to reach a staggering amount of approximately 11000 students this year through our program.

Fig. 1. Robotics showcase in primary and high schools

Furthermore as a part of our initiative we reached the remote areas as well. We reached out to the local community in Saint Martin’s Island to showcase and spread the joy of innovation to the underprivileged population. The goal was to inspire a generation of young inventors.

Fig. 2. BRACU Duburi demonstration in Saint Martin's island.

The intrigued children of Saint Martin's island at our home stay eager to figure out the mysteries of the little diver. Showering us with questions we never thought of as adults, things we never could've anticipated can be done with our AUV. To the locals it was **"Jadu"** which translates to magic.

Fig. 3. Curious Children at BRACU Duburi's homestay