DESIGN AND DEVELOPMENT OF AN AUTONOMOUS UNDERWATER VEHICLE - LAPRAS 2.0

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ABSTRACT:
LAPRAS is the flagship Autonomous Underwater Vehicle developed at Delhi Technological University.Using the insights from Robosub 2021 , Lapras 2.0 has enhanced upon the capabilities of its predecessor. Manipulators have been upgraded for better dynamics in autonomous operations.Vision algorithms have been finely tuned which has led to a massive improvement in the success rate of object detection .

I. COMPETITION STRATEGY

We chose the G-Man side to complete our tasks as the distinct colour schematic of the G-Man side made it a source to provide more accurate vision algorithm results. For the gate task, when the AUV is in yaw manoeuvre trying to find the direction to surge into to cross the gate, we simply detected the orange ends of the gate and calculated the relative difference between both the sides to transitionally and rotationally align our bot and move towards the centre of the gate. When the distinct features of Bootlegger and G-Man come into the view of the camera, the algorithm shifts to the detection using the models we trained for object detection in YOLOv5. For the path marker, after identifying it using colour thresholding, we applied the concept of HoughLinesP and HoughCircles to detect all the 3 edges of the path marker and give a path to the bot.

For the buoy task, the correct side is identified using model training we implemented using YOLOv5 and then the distance estimation algorithms ensure that the bot touches the buoy and returns back.

For the bins task, firstly the bot searches for the location of the bins using the colour of the lid, then the correct side is identified using the object detection and then the marker is released, the bottom camera and colour thresholding algorithms are used to check whether the marker was dropped in the correctly.For the torpedo task, the correct side is identified using object detection and using contour detection and the comparison of areas, we identify the smaller and bigger openings.

For the octagon task, first the AUV detects the table and then the bottles which it later picks up by the gripper, after surfacing, AUV performs the yaw manoeuvre to find the correct table to place the bottle.

Figure 1.1 - Cad render of Lapras 2.0

II. DESIGN RATIONALE

A. MECHANICAL DEPARTMENT

1) Frame

The frame is the primary structure in a vehicle, providing support to all mounted entities. The overall frame features 4 parts: 1 base plate, 1 battery support plate and 2 side plates. The base and battery support plates are connected through custom 3D printed ABS mounts. The base plate holds the main hull, front camera hull, 4 heave thrusters, 2 sway thrusters, torpedo launcher, front camera and gripper assembly. Each side plate holds one surge thruster each. The battery support plate holds the battery enclosure, bottom camera hull and dropper assembly. Eight thrusters are used to get control over all the six degrees of freedom of the AUV.

2) Manipulators

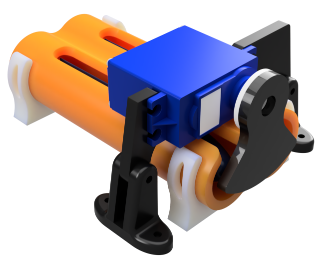

Figure 2.1: Design Render of Torpedo Launcher

The design of Lapras 2.0 torpedo launcher is very compact due to incorporation of a spring-launched mechanism for providing launch thrust. The assembly has 2-parallel tubes for holding the projectiles placed adjacent to each other. A servo is mounted above the tube and is fitted with an Aluminium 6061-T6 obstruction plate. The servo rotates the obstruction plate by 30 degrees in either of two directions, clearing the opening of a barrel and the torpedo is launched by compressed spring.

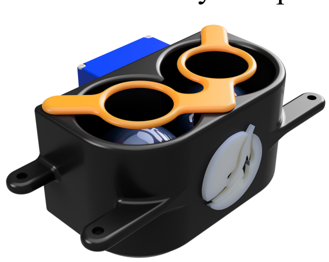

Figure 2.2: Design Render of Dropper

The dropper assembly is powered by a single servo mounted behind the marker housing. Both dropper tubes placed adjacent to each other ensuring high accuracy during dropping sequence. A marker is dropped by 30 degrees rotation of a heart-shaped obstruction plate in either of two directions, clearing the path for its drop. The dropper body is made up of 3D printed ABS plastic.

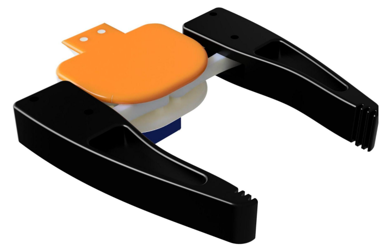

Figure 2.3: Design Render of Gripper

The design of the gripper focuses on simplicity, reliability and modularity. The outcome of the design process is a 2 claw parallel gripper. It features 2 claws, 2 driver links and 2 coupler links. The driver links have spur gears at the ends and are meshed together at the base, the coupler links do not possess any gear and their primary function is to support the claw and restrain its movement. The design allows for gripping and object upto 90 mm wide. The entire assembly is 3D printed using ABS plastic. Compared to our previous rotatory fingers design, this parallel gripper is capable of gripping larger and more complex shaped objects.

B. ELECTRONICS DEPARTMENT

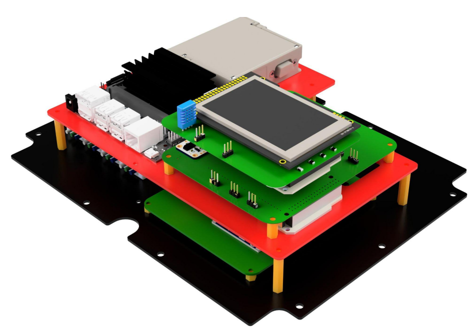

Figure 2.4:Electronics Stack

The embedded stack has been developed keeping in mind design rationales such as robustness, modularity, space constraints and ease of debugging.

1. Power

A Power Distribution Board (PDB) was designed to power all the electronics inside the vehicle. The 12VDC input is used to power the GPIO board. PDB has buck converters that convert the input voltage to 7V and 5.1V respectively. A DPDT switch has been used as a kill switch, connected between the GPIO board and the PDB, to halt the operation of the vehicle.

2. Battery monitoring system

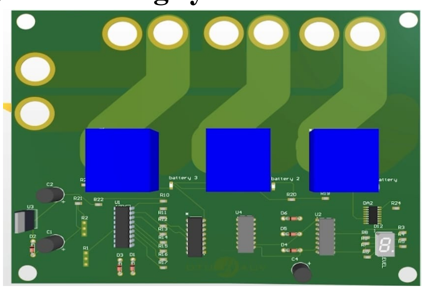

Fig 2.5 Battery Monitoring System

Three Lithium polymer batteries (4 cells) with a total capacity of 30000mAH were chosen for the input power. A custom battery monitoring system PCB was designed, which continuously monitors the cell voltage and the total voltage of each battery and cuts it off from the circuit as soon as it reaches the threshold voltage (3.1V). The system is low power, cheap, and provides a visual indication of the battery levels and the battery currently in use.

3. GPIO board

A GPIO board has been developed for the integration of sensors and actuators. The Arduino Mega 2560 has been used as the microcontroller and is powered through the PDB. In turn, the Arduino powers the sensors on the GPIO board, receives the sensor data and provides the PWM inputs to the Electronic Speed Controllers and the Servo Motors as well.

For the sensors, we have used ACS712 Current Sensor, Bosch BNO055 IMU, and the BAR 30 pressure sensor. Here, the current sensor has been used to monitor the current draw of the servo motor, using which we can detect whether an object has been gripped or not.

Appropriate connections have been made to provide the required inputs for the debug board. Apart from this, the GPIO board also powers the ESCs through the PDB to ensure easier and more flexible connections.

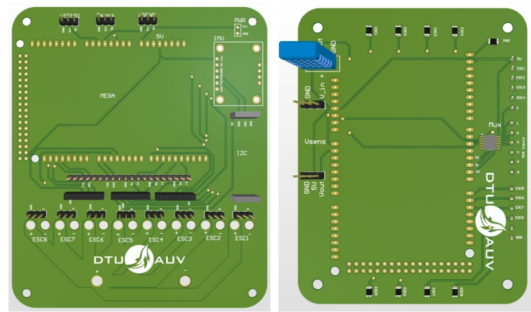

Fig 2.6 GPIO and Debug board

4. Debug Board

A Debug Board was developed to make our system more interactive with the use of an LCD Screen and several LEDs. The Debug board receives several inputs from the GPIO board including PWM inputs to the ESCs, the voltage across several components on the GPIO board, and that of the DHT11 temperature sensor on the Debug board. These are checked to ensure appropriate operation of the AUV An 8-to-1 Multiplexer IC has been used to interface these with the voltage sensor. This ensures fewer components and hence a compact system. Several LEDs have also been used to indicate the ESCs operating at any given time.

5. Acoustics

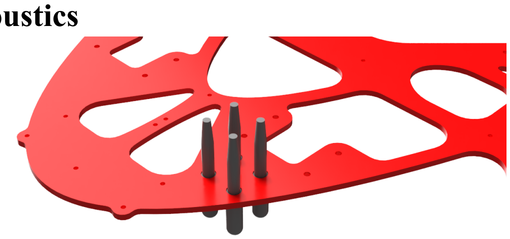

Fig 2.7 Hydrophones Placement

The hydrophones have been closely placed in a square array to avoid spatial aliasing. A custom PCB consisting of an amplification unit and a bandpass filter is used for signal conditioning before sending the signal to the DAQ.We have used the NI9223 DAQ as our analog input module for data acquisition .The signal will then be used to find the direction of arrival using the MUSIC (Multiple Signal Classification) algorithm on the single board computer.

C. SOFTWARE DEPARTMENT

1. Computer Vision Algorithms

To complete the Robosub challenges, we made sure that the vision algorithms put in place were efficient, feasible in the real environment and yet were highly accurate. We differentiated the props from the surrounding environment on the basis of their colour and then after putting a filter on the basis of area, extracted out the contours of our target. Further on, bounding rectangles helped us to navigate the bot as needed accordingly. In order to navigate in between two tasks, we implied certain algorithms to navigate along the path marker. The path marker prop was divided into two subcategories - 1) The semi circle ends, 2) The linear edges. Detection of both these subcategories were handled differently. The technique implied was Hough transform which can be used to detect any shape, if you can represent that shape in mathematical form. Assuming the intersection point as a vertex and the centres of the semicircular ends as other two vertices , an isosceles triangle was constructed. The slopes of the detected lines were used to find the internal angles of this triangle and then by using this along with the distance between the two centres, through simple trigonometric relations, we could find the coordinates of the intersection point which helped us to draw a line along the entirety of the path so as to easily navigate.

Figure 2.8 Detection of path marker and calculating the angle

2. Detecting the Targets

This year's iteration brought new innovations in computer vision and deep learning algorithms, the most significant one being SRGAN. Super-Resolution Generative Adversarial Network (SRGAN) architecture allows us to artificially enhance image resolution with minimal computations. Utilising this technique, we were able to enhance our camera feed by up to 4x its current pixel space, allowing better execution of other CV algorithms. We have also utilised state-of-the-art object detection algorithms such as YOLO-V5 and fasterRCNN to detect and classify different tasks corresponding to G-man and Bootlegger.

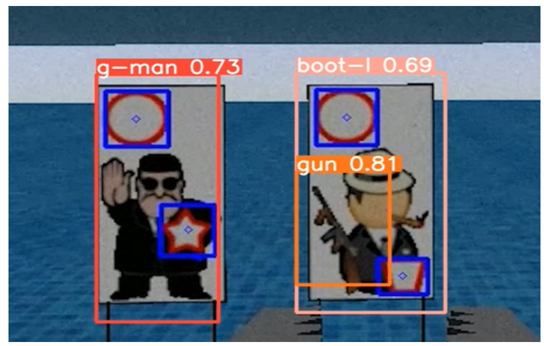

Figure 2.9 Identifying and classifying the targets in torpedo task

3. Simulations

Simulations are an essential tool to determine the effectiveness of our vehicle before testing it in a physical environment. For simulating the vehicle, we used the UUV package in Gazebo simulator. Adding different types of noise to the environment helped improve accuracy of the simulation.

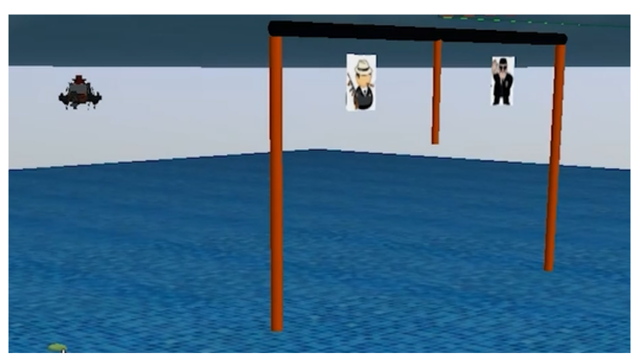

Figure 2.10 Gazebo scene setup for the gate task

4. Mission Planner

We used SMACH as a tool for our mission planner. SMACH gives a full introspection into the state machines, state transitions, and data flow. SMACH is a library for task-level execution and coordination, and provides several types of "state containers". The mission planner helps to make decisions based on the input given by the camera feed filtered by the vision algorithm and plan its journey accordingly based on the hierarchical state-provided.

III. EXPERIMENTAL RESULTS

As we participated as an online participant, we tested the working, control, accuracy and efficiency of our bot using the Gazebo simulation environment. These simulations proved to be immensely useful in providing some insights that we would take care of during the production of our future bots. We have implemented Computer Vision as well as Machine Learning algorithms using OpenCV and YOLOv5. The use of both these technologies proved a very significant improvement from our last year's bot.

So, in order to compete with a near equal level to in person teams, we needed to simulate our bot, its environment and its working in as realistic environment as possible. The simulations needed to be built in a robust manner along with incorporating some real life features like criss cross design at the bottom of the pool, random waves, dirty water and random noise. These features also made it possible for us to predict the accuracy and success levels of various tasks that our bot can perform.

1) For the gate task along with style, success rate would be near to 99%,
2) As we have performed the path marker and buoy tasks in physical mode as well created their simulations, their accuracy level would be 100%,
3) As we have incorporated model training in YOLOv5 as an improvement to last year's feature matching algorithm for object detection, it has increased the accuracy levels of buoy and torpedo tasks by an approximate of 15% each, making the success rate of buoy task to be 95%, shooting the torpedo at the bigger opening to be 85% and shooting the torpedo at the smaller opening to be 85%.
4) Significant improvement in the design of the gripper with respect to the thickening of its fingers and addition of groves at the tips, made it easier to lift the bottles, moreover the incorporation of Machine Learning technologies for detection of correct tables increased the octagon task's accuracy level to 65%.

The water tight hulls used in AUV already possess IP-68 rating and were tested for any manufacturing defects. Holes were drilled in the lower half of the hull using 10mm drill bits and were fitted with potted cable penetrators by BlueRobotics. Nitrile rubber O-rings were placed in the penetrators' grooves because of their ability to expand under differential pressure and completely fill the grooves. The hull was then completely closed from top and held underwater for long durations to check for any leakage. Since we are participating as an online contestant, the gripper was simulated to hold objects and task specific props of varying dimensions. Then the gripper was simulated under varying loading conditions such as static, dynamic and impact loading to optimise the weight to strength ratio.

IV. ACKNOWLEDGEMENTS

DTU AUV would like to thank and express gratitude towards everyone who has come together and helped us to make the project a huge success. We'd like to express our sincerest thanks to our faculty advisor Dr Ajeet Kumar and his guidance on the design considerations. Moreover, the team wouldn't have been able to function without its cold sponsors who generously funded us and helped us acquire all the resources that were required during the many stages of the project. Finally, we would like to thank the knowledgeable and resourceful network of DTU AUV alumni who made themselves available for advising and sharing their valuable experiences and helping us circumvent multiple roadblocks that one faces while designing a vehicle.

V. REFERENCES

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APPENDIX A: COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year Of Purchase
Buoyancy Control	NA	NA	NA	NA	NA	NA
Frame	In House	Plane truss structure 3D printed attachments	4mm Aluminium 6061 T6 sheets 3D Printed ABS	Custom	$150 $81.20	2020
Waterproof Housing	Hammond Hammond Polycase	1554YA2GYSL 1554C2GYCL AN-07F-01	IP68 rated, Polycarbonate IP68 rated, Polycarbonate IP68 rated, Aluminium	Purchased (Modified)	$108 $27 $33.69	2020
Waterproof Connectors	Blue robotics	Potted Cable penetrator	Quantity: 20,M-10 thread, 6mm cable	Purchased	$100	2019
Thrusters	Blue robotics	T200	Quantity: 8,Operating Voltage:7-20V, Full Throttle Current(@20V):32A	Purchased	$1432	2019
Motor Control	Blue Robotics	ESC for T200	Quantity:8,7-26 volts (2-6S)	Purchased	$216	2019
High-Level Control	Arduino	Mega 2560	6-20V,54 digital I/0 pins,16 analog pins, Clock speed:16MHz	Purchased	$24.30	2019
Actuators	Hitec	Servo HS5646WP	IP67, Torque:11.3-12.9 Kg-cm^2/s^2	Sponsored	Sponsored	2019
Battery	Tattu	Tattu 14.8V 25C 4S 10000mAh Lipo Battery Pack	14.8V 25C 4S 10000mAh	Purchased	$350	2019
Converter	Traco	THM 60 – 2411WI	Output Voltage:5.1, Current:12A	Purchased	$158	2021
Regulator	Robu	LM2596S	Quantity:2,Input Voltage:3-40V,Output Voltage:1.5-35V(Adjustable)	Purchased	$1.60	2020
CPU	Nvidia	Jetson Nano	Quad-core ARM Cortex-A57 MPCore processor	Purchased	$300	2020
Internal Comm Network	N/A	N/A	N/A	N/A	N/A	N/A

External Comm Interface	N/A	N/A	N/A	N/A	N/A	N/A
Inertial Measurement Unit (IMU)	Bosch	BNO055	9 Axis, supply voltage:2.4-3.6V, Range:125-2000 deg/s	Purchased	$10.70	2019
Manipulator	In House Developed	Gripper Dropper Torpedo Launcher	3D Printed ABS	Custom	$24.33 $13.10 $15.73	2020
Algorithms: vision	N/A	OpenCV, YOLOv3	Underwater Single Image Dehazing, YOLO Object Detection, Distance Estimation using triangulation, ORB	Custom	N/A	N/A
Algorithms: acoustics	N/A	TDOA	Hyperbolic positioning	Custom	N/A	N/A
Algorithms: localization and mapping	N/A	OpenCV	Localisation using vision algorithms	Custom	N/A	N/A
Algorithms: autonomy	N/A	Smach	Finite State Machines	Custom	N/A	N/A
Vision	Logitech	C930E	Full 1080p HD video at 30 frames per second	Purchased	$ 130	2019
Acoustics	Teledyne	Reson TC-4013	Quantity:3,1 Hz-180KHz ,depth:700m	Purchased	$538x4	2020
Algorithms: vision	N/A	OpenCV, YOLOv3	Underwater Single Image Dehazing, YOLO Object Detection, Distance Estimation using triangulation, ORB	Custom	N/A	N/A
Algorithms: acoustics	N/A	TDOA	MUSIC	Custom	N/A	N/A
Algorithms: localization and mapping	N/A	OpenCV	Localisation using vision algorithms	Custom	N/A	N/A
Algorithms: autonomy	N/A	Smach	Finite State Machines	Custom	N/A	N/A
Open-source software	OpenCV, YOLOv3, Robot Operating System, Smach, Gazebo, Python, C++					