BRACU Duburi AUV Technical Design Report

Brac University (BRACU Duburi)

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***Abstract*—This year, BRACU released version 4.0. Duburi has significantly enhanced its functionality and modified its system architecture in response to the lessons learned from RoboSub 2022. The new AUV's construction, which promises to offer more underwater agility, is among the significant modifications. By eliminating extra space, the new design reduces weight and is more hydrodynamic than the previous one. Additionally, Duburi now has a Vectornav VN200 INS in place of its previous magnetic field-dependent IMU, which supplied inaccurate data in the event of any magnetic interference. This INS calculates its heading using data from the gyroscope and accelerometer. Due to Duburi's focus on modular hardware and software this year, ROS (Robot Operating System) now powers Duburi. A hot-swappable system and cleaner, better organized wiring are additional features of the newly created rover, which also includes quick maintenance options. The design, as a whole, effectively and quickly corrects all of the preceding flaws.**

I. Competition Goals

A. Oh for crying out loud

Dropping from the dock, the AUV will dive to a depth of 10 ft which is ensured using Bar30 Sensor. The Bar30 sensor achieves this by utilising the fundamental property of fluids. The formula used for this purpose is:

$$depth\ d = \frac{p}{\rho * g}$$

After reaching the determined depth the AUV rotates 60 degrees clockwise using the help of the Vectornav VN200 which provides the AUV with fused heading data achieved through the sensor's built in accelerometer and gyroscope, which also improves upon the previous years flaw caused due to use of magnetometer based IMU. before embarking upon the gate-detection task, "Destination".

B. Destination

This task is approached in two stages. Firstly, as the AUV advances towards the gate, the entire gate is detected as whole and the AUV is kept in line with the gate using visual homing method that is achieved by aligning the camera center with the gate's center point. Once a certain proximity threshold is achieved, the second stage begins. In this stage, the chosen destination sign (Abydos or Earth) is detected and identified on the gate. The unidentified side is still kept in the ML Algorithm as a negative data set in order to ensure that the AUV will not approach that particular side of the gate. On the second stage operation the AUV than approaches the desired side of the gate keeping the AUV center aligned.

C. Start Dialing

Once done with the gate-detection task, the AUV will rotate to a predetermined angle,clockwise and advance forwards to find the buoys of the "Start Dialing" task. Initially, the whole buoy is detected and once it gets a proper detection a tracker is maintained so that the rover always keeps the object as its point of interest. When the AUV is at a sufficient proximity to the buoy, it will then change the tracker on to the chosen destination sign (Abydos or Earth) using the visual homing method which works via aligning the center point of the camera with the center point of the bounding box. Then the AUV will proceed accordingly pushing onto the correct sign.

D. Goa'uld Attack

Upon completion of Start Dialing, the AUV will rotate to a predetermined angle, anticlockwise and proceed forwards until it finds the panel of the "Goa'uld Attack", torpedo launching task. Once the panels are detected, the AUV will position itself by stabilizing and aligning its center with the target and launch torpedo for the first open gate, and then it will go dive downwards until it detects the next opening which is closed Iris on the challenge. Once a confident detection is achieved the AUV will hold its depth and will attempt the torpedo launch for the second opening.

E. Location

The AUV after completion of Goa'uld Attack moves towards Location.Once the camera detects the bins for the task "Location" the rover initiates the bottom mounted cameras.The bottom mounted cameras detect the bins and align accordingly using visual homing method.The rover then aligns itself Using the grabber, the AUV will grab the lid and remove it. Then the correct bin is identified based on the previously chosen destination sign and the marker is dropped in the selected bin with the aid of front and bottom camera feeds.

F. Engaging Chevrons

Using computer vision, the AUV approaches the location of the task "Engaging Chevrons". Once the location is identified, the AUV approaches the determined location and stabilizes above the DHD. Using the bottom camera, chevrons are detected. Once identified, the chevrons are picked by the grabber one by one, and then we proceed to detect the chosen destination sign. Upon identifying the correct signs, the chevrons are placed one by one on the signs. If the AUV fails to complete the task within a predetermined amount of attempts, the AUV will then abort the task and will resurface with the thruster's upward thrust.

II. Design Strategy

A. Mechanical Subsystem

Our experiences from SAUVC and Robosub have led the mechanical team to reassess and improve several aspects of our mechanical design, namely the construction and size of the hull, material and buoyancy tuning. Moreover, our design complements our focus on modularity and easy repair/replacement of components in an efficient time frame.

1) Material

The body of the hull is built with Marine 5083 grade aluminum. Because of its low density, high strength-to-weight ratio, resistance to corrosion, and good thermal conductivity, this specific aluminum was chosen. The top enclosure along with the front and bottom camera openings are sealed with acrylic windows having brass frames. Although this gave the AUV an upper edge in terms of weight there was a significant rise in manufacturing cost. Furthermore working with aluminium in particular required expert involvement in terms of welding which also increased production time.

2) Hull Design

a) AUV Shape

In terms of this years design Duburi has now went ahead with a octagonal shape compared to the previous year's hexagonal shape. The design choice was made keeping previous year's findings in mind. The flat surface in a pentagon shaped design in previous years AUV led to increased drag when it tried to go in reverse which greatly reduced the AUV's efficiency and put excessive yet unnecessary load on the rover to reach the same level of competence compared to this year's design. This year the hydrodynamic hexagonal shape allowed equal flow over the AUV's surface reducing turbulance. It also massively reduced the drag caused when operating in reverse. Although to keep the rover hydrodynamic in this year's design the outer support structure used to mount thrusters was removed hence resulting in the thrusters being more prone to physical damage in an event of collision.

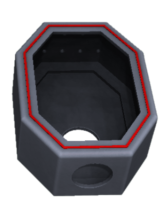

Fig. 1: Duburi 4.0 Hull

b) Hull volume

This year the AUV has less volume compared to the prior designs. A larger system allowed more freedom in terms of component placement, maximum component dimension and most importantly made the AUV more accepting to change. But this year we had to compromise the internal space. The benefits outweighed the drawbacks for this design choice. As the space was mostly redundant for our current compact system.The increased volume meant more material used adding extra weight which resulted in penalties in RoboSub 2022. Furthermore the large structure meant the AUV faced difficulties in performing extreme maneuvers.

c) Weight Distribution

With the new design of our AUV we have kept weight distribution into consideration.Hence we have shifted major weights at the back of the AUV. In this scenario this causes the rover to have a slight upward pitch due to the weight in the back. The weight is balanced when the manipulator is mounted in the front. This compensates for the additional weight in the back and shifts the center of mass in the middle of the AUV.

Fig. 2: Duburi 4.0

d) Grabber

We have upgraded to a custom-made grabber with a two-finger design, incorporating a specialized linear actuator for enhanced stability and grip. The grabber's body is constructed from aluminum, with rubber tips on the fingers for improved traction. To ensure a secure hold, two fingers are positioned on one side and one on the other, creating an interlocking mechanism during gripping. Additionally, we have integrated a Sharp sensor to determine the object's proximity and confirm if it remains securely held, enabling us to achieve precise and reliable grasping. In the event of a failed attempt, the sensor promptly detects the error.

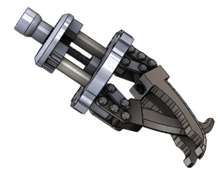

Fig. 3: Duburi 4.0 Grabber

e) Torpedo

Duburi uses an elastic force induced propulsion system for its torpedo. The mechanism works by holding back two torpedoes using elastic bands which store the energy for propulsion. When the rover needs to launch the torpedo a servo is used as a trigger. The servo moves in one certain direction releasing the torpedo. Furthermore when one torpedo is launched the mechanism prepares for the next launch and the servo moves to another direction hence completing two launches with the mechanism. The major drawback with this design approach is that it only holds two torpedos. Another drawback it being less accurate compared to independent onboard propulsion based systems.

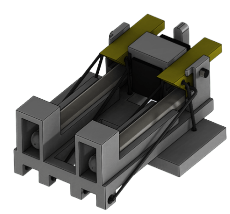

Fig. 4: Duburi 4.0 Torpedo Launcher

f) Dropper

The previous years dropper used a servo based release mechanism to drop balls. This had a major drawback where the release mechanism could get jammed. Hence this year's system uses a solenoid based release mechanism which ensures a smoother ball drop. This also allows the design to have lesser moving components and reduced design complexity. A drawback could be magnetic interference to the system caused by the magnetic field.

g) Propulsion System

The propulsion system for this year stays the same with 8 thruster configuration powered by 4 BlueRobotics T100 and 4 BlueRobotics T200 thrusters although the major change lies with the propulsion system placement. This year the thrusters are directly mounted on the AUV hull. The upper mounted thrusters are mounted at a 45 degree angle to ensure that the resultant force is optimal. The bottom mounted thrusters are mounted parallel to the hull allowing menuvers such as roll or pitch.

h) 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.

B. Electronic Subsystem

1) Battery pack

This year Duburi does not come only with off the shelf lithium polymer batteries. We have built a new and robust lithium ion battery that has a greater energy density. Furthermore it can also be expanded to increase capacity if required. Furthermore the system also provides power at a lower cost per mAh of capacity. Building the battery pack in house allows us to customise the output voltage as well as capacity. Although the advantages are there but we are still reliant on Lithium Polymer batteries because of their high current rating

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) Microcontroller

Previously Duburi relied on 8bit ATMega2560 microcontroller for its control unit. Which had major drawbacks such as high latency,slow processing and most importantly lacked real time engagement required for optimal performance. This year the issue is solved by relying on 32 bit STM32 based system Pixhawk further integrated with Vectornav VN200 INS,ensuring greater performance and reliability with real time communication.The faster processing speed has massively increased the AUV's overall performance. But this also has increased code level complexity as this requires major system migration.

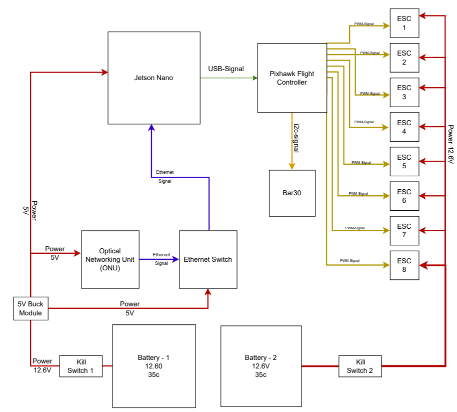

Fig. 5: Power Flow Diagram

C. Software Subsystem

1) ROS Implementation

This year one of the major goals for the team was to ensure modular code that could be modified on the go. Hence Duburi system now runs on ROS Noetic. The reason for choosing ROS Noetic over newer distributions was due to widely available system integrations.As ROS Noetic is an older distribution it has major bugs already resolved whereas the newer versions can have bugs that may become the difference between winning or loosing. The current system runs on Rospy. The backup system also communicates with the main computer using ROS Serial,solving the issues where after extended period of use some amount of data can be lost. This is solved by constant acknowledgements of data.

2) *Computer Vision System*

a) *Image Enhancement*

While testing our vision system what we face on a daily basis is the lack of clear waters. Most test facilities at our convenience have unclear water which does not allow the vision system to work efficiently. Hence we have further included image enhancement algorithms that forms a proper image while avoiding our shortcomings.

b) *Model Training*

We have split our dataset into three portion where 70% of the data is used as training dataset, 20% for testing and finally 10% as validation dataset. We utilised the Pytorch SSD MobileNet v2 using the Jetson Inference framework. We took a transfer learning approach to leverage the knowledge from large scale datasets and while allowing us to ensure specific object detection according to our requirements. Furthermore we added Stochastic Gradient Descent(SGD) as our optimisation algorithm.

3) *Sensor Fusion*

Previously as our IMU, we used MPU6050 that was prone to deviation caused by magnetic interference. Hence now we have fused the Vectornav VN200 INS with Pixhawk which allows precision data and avoids any sort of deviation caused by magnets. The sensor fusion was done by passing the INS value to the Pixhawk to allow the system to use more reliable source of heading data.This goal was achieved by using the Mavlink protocol in python using pymavlink.

III. Testing Strategy

A. *Computer Vision Unit Test*

In our previous system, we had optimised our system to provide us with real time detection at a smooth rate. But previously although the detection were really accurate but in some situations the detection may loose the object and provide vague detections. The previous system could provide 22 Frames per Second at max. Duburi team with continuous effort has established ground breaking landmark for its computer vision system by reaching a staggering 45 Frames Per Second in terms of detection. This was a breakthrough for the team. The graph below depicts the frames per second over a time frame of 50 seconds.

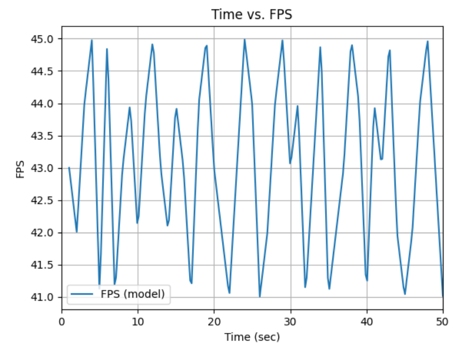

Fig. 6: FPS vs time graph

B. *Pressure and Depth*

Duburi is tested for pressure and depth tolerance rigorously. We have tested our AUV in underwater depth up to 10 meters. Although the AUV can tolerate much deeper depths, the scenario is yet to be explored. Furthermore the AUV has been pressure tested by vacuuming the inner air. We have achieved up to 400mm hg. Although this does not ensure full vacuum and is about half times the atmospheric pressure. This allows the team to test and check for any potential leaks in the system by observing vacuum pressure change.

C. *Visual Homing Approach*

In our AUV we have applied a new approach where we have implemented visual homing which figures out the detection center, then calculates the offset. Then using a calculative approach we fix the AUV's position to align with center of the computer vision detection. The AUV constantly holds the center position by keeping the center of the detection as the point of interest.

D. *Sensor Fusion*

We have currently implemented sensor fusion. The main goal is to overcome the magnetic interference barrier to receive accurate and uninterrupted heading data. This is done by taking the sensor data from Vectornav VN200's gyroscope, accelerometer and magnetometer. Then the data is fused and Kalman Filter is applied on the received data to received an Attitude Heading Reference System (AHRS) value. This ensures fluid data that is free from irrelevant values.

E. Grabber Testing

We have a new and optimised grabber system. Which went through rigorous testing from grab testing to strength testing. The waterproofing test was done by operating the arm over a period of 6 hours. The AUV was able to operate even after excessive stress. Furthermore the grabber was tested to hold a weight of 2.5 Kg. Which could be pushed further but due to limited resource was kept at threshold.

F. Simulation Environment

We have built a new and robust unity based technical testing environment. This allows the user to interpret and test codes prior to real world testing. The environment consists of completely rendered version of the competition ground and props. This allows us to estimate probable bugs prior to water testing. This allows the team to follow an Extreme Programming approach to development.

Fig. 7: Task Detection in Simulation Environment

G. Thrust to power ratio

According to the current draw data provided by BlueRobotics the Thrusters draw around 20.36A at 14v power supply and 16.91A in terms of a 12 volt power supply at full throttle. Currently the AUV is operated at less than 25% throttle which draws around 0.5A at 12V and 0.7A at 14v.

H. Comparative Study of processing unit

We have used an array of processing units which include microprocessor based single board computers such as Jetson Nano,Raspberry Pi and microcontrollers such as ATMega2560 and STM32 based Pixhawk. During our development process what we have observed is as a secondary computer STM32 based Pixhawk works more efficiently compared to Arduino. This is due to the shift from an 8 bit processing unit to 32 bit processing unit STM32. Furthermore the Raspberry Pi has also been tested as the secondary computer, which could perform multi threaded codes allowing more load to be put onto the computer which could not be achieved by the microcontrollers. As the main board the Jetson Nano is used. The board can perform high level computations required for image processing tasks. The optimised linux based Jetpack OS works flawlessly keeping our predetermined tasks in check.

ACKNOWLEDGMENT

The remarkable journey and progress of Bracu Duburi is significantly attributed to the unwavering dedication and brilliance of the individuals who have played a pivotal role in its triumph. We sincerely acknowledge their hard work and commitment in elevating Bracu Duburi to a global platform. We are immensely grateful for the support we have received from Brac University, encompassing financial assistance, emotional guidance, and valuable resources. Our honorable advisor, Dr. MD. Khalilur Rhaman, has been a guiding light throughout our journey, providing direction during challenging times. We extend our deepest gratitude to Sadia Hamid Kazi, Chairperson of the CSE department, for being a constant pillar of support. Our heartfelt thanks also go to Professor Syed Mahfuzul Aziz, Pro Vice-Chancellor, and Dr. David Dowland, Registrar, for their unwavering encouragement. Lastly, we cannot imagine our team without the indispensable presence of our co-advisor, Sayantan Roy Arko, and our other co-advisors, Adnan Sabbir, Mohammad Saurav, and Nayem Hossain Saikat. We are sincerely grateful to them all.

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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	T100 Thrusters	T100 Thruster	Purchased	$ 1600	2019
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 Nano	Nvidia Jetson Nano	Purchased	$ 175	2019
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)	-	-	-	-	-	-
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