BRACU DUBURI: The First Autonomous Underwater Vehicle Of Bangladesh

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***Abstract*— BRACU Duburi the first Autonomous Underwater Vehicle(AUV) from Bangladesh is competing for the first time in the RoboSub competition this year.We are an underwater robotics team from Bangladesh consisting of undergraduate students from BRAC University,in collaboration with The Robotics Club of BRAC University.With our past experience from Singapore Autonomous Underwater Vehicle Challenge we are determined to take part in this years RoboSub. With RoboSub and it's missions in mind we have now developed a new strategy and have upgraded our AUV from it's predecessor with new electronic, software and mechanical designs. The AUV can perform precise maneuvers with the help of a new and robust vision system and custom PID control. The design of BRACU Duburi was centered on the idea of *"Using least resource possible to get the best outcome"* due to scarcity and difficulty sourcing components.**

I. Competition Strategy

A. Introduction Overview

BRACU Duburi's grand strategy for RoboSub 2022 is to target performing the most basic tasks first with a simple design; only after perfecting the basics have we then introduced more functionality (and complexity) to our designs to make it capable for performing the more advanced tasks of the RoboSub course.

B. Team Organization

Duburi is subdivided into several specialized teams (i.e. subteams), each of which is responsible for designing, developing, and testing one of Duburi's subsystems. At the helm is Duburi's Computer Vision subteam. It is tasked with selecting, training, and testing Duburi's Machine Learning Algorithms required for detecting objects underwater, which is an integral part of Duburi's autonomous functioning. Follow by the control subteam,they develop the microcontroller code needed to operate Duburi's propulsion system and end effectors to carry out the course tasks. On the hardware end, the Electrical Electronic subteam is responsible for selecting Duburi's components and sensors and designing and implementing Duburi's PCB in accordance with Duburi's control system. The mechanical subteam is responsible for designing building Duburi's main hull and the mechanisms required for performing the tasks such as the marker dropper and torpedo launcher. With support from the 3D Modeling Simulation subteam by creating all of Duburi's 3D models using a combination of SolidWorks, Fusion 360, and Blender. They also have the secondary function of developing the simulated environment in Unity. Finally, all the subteams are managed by Duburi's Operations subteam, who are responsible for pitching to sponsors, facilitating communication between the teams, performing outreach activities, and hiring recruits.

II. Task Training Strategy

A. With Moxy

Heading mode is activated by one of two switches. Activation of these switches is detected by digital pins of the microcontroller. An activated switch is considered HIGH, whilst an unactivated one is considered LOW. The microcontroller detects which of the two switches is HIGH, and this tells the microcontroller which mode is to operate in. Based on the mode selected, the AUV either rotates 90 degrees and 180 degrees before entering the gate-detection task. This yawing motion is implemented using Duburi's IMU's gyroscope and magnetic compass.

B. Choose Your Side

It is a two stage operation. First stage, the entire gate is detected as whole.Once a certain proximity threshold is achieved, it enters the second stage.In this stage, detects and identifies the gate according to the side selected in the previous task. The other side's gate is not identified, but is kept in the ML Algorithm as a negative set. This ensures that the AUV will not approach that gate.

C. Path

The path is detected by the camera mounted underneath the body. The camera frame is divided into four quadrants with a center point which aligns to the center point of the bounding box.In case of position shift the camera detects the error via visual homing technique and then takes relative decisions based on that.

D. Make the Grade(Buoy)

The process happens in two separate stages,starting with a whole buoy detection as a first stage measure.When the AUV gets closer to the buoy it locks on to the predetermined choice from the toss using the visual homing method which works via aligning the center point of the camera with the center point of the bounding box and the AUV follows accordingly

E. Collecting (bins)

The AUV will detect the box using the bottom mounted cameras.With the help of manipulators the AUV will grab the cover and remove it.The AUV will then follow the predetermined path and drop the marker in the selected box with help from both the camera feeds.

F. Survive the shootout(Torpedos)

The AUV detects the board with the previously set choice using mounted cameras then aligns near the smaller hole preparing to launch the torpedo. The launcher has a latch that holds the torpedo and when triggered drops and activates the torpedo. The torpedo is self propelled by DC motors with the help of a 3.5v lithium ion battery that is concealed within the torpedo.

G. Cash or Smash(Octagon)

We have used a passive sonar system with an array of hydrophones to determine the source of the pinger. With the pinger location determined the AUV moves to the determined location then with the help of the cameras detects the bottle and picks it up using the mounted manipulator. Then it takes a turn towards the table with the appropriate picture based on the selection and drops the bottle on the table. After that it comes back inside the octagon and resurfaces with the thruster pointing upwards.

III. Creative Design

A. Hydrodynamics and Mechanical Subsystem

Our mechanical team carefully deliberated over several aspects of the Duburi's hull, namely its material, shape, construction, and buoyancy, and made decisions that would achieve this goal in the most effective manner possible. Furthermore, our experience in SAUVC taught us the importance of modularity and being able to easily access and repair or replace components as quickly as possible. This requirement is also taken into consideration in our design.

1) Materials: With that in mind, we have chosen Marine 5083 grade aluminum as the chief material of Duburi's hull. Marine aluminum is chosen for its low density, resistance to corrosion, high thermal conductivity, and high strength-to-weight ratio. A small bit of acrylic is also used for the windows and the internal frame.

2) Hull-Design: Our hull design consists of only three primary elements: a water-proof enclosure, an internal acrylic frame, and an external aluminum. All the electrical components of Duburi are screwed on the internal frame, and the frame itself is just bolted on the enclosure. This makes it very easy to remove it from the enclosure and replace components. For the same reason, instead of attaching our thrusters directly to the exterior of the enclosure, we have bolted on an external frame on top of it to which our thrusters are attached. We can very quickly and easily replace the thrusters whilst keeping the risk of damage to them or the hull to minimum due to this external frame. A torpedo launcher, grabbing mechanism, and marker dropper are also attached to the outside of the hull as secondary elements to perform the competition tasks.

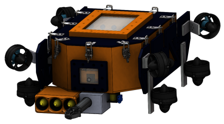

Fig. 1: 3D View of the Hull design.

3) Enclosure: The enclosure is a metallic rectangular body with a curved end. The front-edge was curved prior to construction to make the overall shape more hydrodynamic. Since we have constructed the enclosure out of a solid block of aluminum, the only points through water that can leak through to the interior are points where the remaining hull-components are attached to the hull. This makes water-proofing the hull quite trivial as we only need to seal the gaps in our screw-holes with epoxy resin and hardener. Alongside simplifying water-proofing, cooling our electrical system is also made far easier by this "metal-block" approach. Since aluminum is an excellent conductor, we have designed the internal frame in such a way that the greatest heat generating electrical components, such as the SBC and ESCs, are kept in direct contact with metal walls of the enclosure to dissipate the heat. Because of the low density of aluminum, the thinness of the enclosure walls, and the spaciousness of the interior, Duburi's hull has a very low density overall. Thus, no additional measures are required to ensure that Duburi meets the buoyancy requirements as per the RoboSub 2022 Handbook.

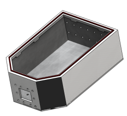

Fig. 2: 3D View of the Hull design.

B. Propulsion System

1) Thrusters: Our propulsion system consists of eight Blue Robotics T100 thrusters and ESCs. The thrusters are purpose built to run underwater and being waterproof can be operated in great depths.

2) Locomotion: Duburi's propulsion system is capable of achieving six degrees of freedom in movement: heave, surge, sway, yaw, roll, and pitch. However, our mechanical team prioritizes performing the first four as consistently as possible as only these are required to perform all six tasks of competition. The latter two will be implemented prior partaking in the Autonomy Challenges of RoboSub 2022.

To minimize the complexity of Duburi's propulsion mechanism the eight thrusters were split in two sets of four. One set is used to perform heaving motion only, and they are attached symmetrically about the bottom four corners of the external frame. Similarly, the other set of thrusters is used to achieve the remaining three degrees of motion, and they are symmetrically placed on the top of the frame at a 45-degree angle (relative to Duburi's length).

The four bottom-facing thrusters maneuvers the AUV in the vertical direction. One benefit of this approach is that any two thrusters can be replaced in case of malfunction, as two of these bottom-thrusters are redundant. Roll and Pitch can be achieved by making use of all eight thrusters together, but it is yet to be implemented.

C. Electronic Subsystem

Our electrical team considered several designs for the electrical and electronic architecture for Duburi, and after consideration settled on the one that utilizes the least number of components whilst delivering sufficient functionality and satisfactory levels of reliability.

1) Core System Architecture Internal Communication: Following the approach laid out above, our Electronic Subsystem is based primarily on two core components: the microcontroller (Arduino Mega) and a Single-Board Computer (Jetson Nano). These are the central nodes to which all other components, including the ESCs, sensors, and cameras are connected. The operation of these components is controlled and monitored by the microcontroller and Single-Board Computer (SBC).

The SBC functions as the brain of Duburi. It runs the AUV's Machine-Learning Algorithms and is thus responsible for Duburi's computer vision. For this, the SBC receives visual data from Duburi's two HD cameras - one of which is placed

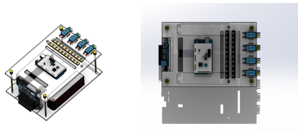

Fig. 3: 3D model of Duburi internal Circuits

in front of the hull and the other beneath it - via USB connection. Based on the Duburi's present mode of operation and the objects that it detects by this vision. Consequently, the SBC sends a command via serial connection to the microcontroller using the UART communication protocol and PySerial to either stay on the current mode of operation or go into the next one. Depending on the task assigned by the SBC, the microcontroller powers and accepts input from Duburi's sensors, all of which are connected to it. Then, based on this sensor input, the microcontroller manipulates the Duburi's end-effectors - which includes its thrusters, marker dropper, torpedo launcher, and grabber - to accomplish the task.

2) Sensor Selection: The final aspect of Duburi's "central nervous system" are the sensors. The electronic team has taken a minimalist approach to sensor selection. In other words, Duburi collects only the data that is essential for its operation and the completion of the competition tasks to keep the design simple and save resources. Thus, only three sensor modules are utilized in Duburi (apart from its camera). These modules are:

Depth Sensor (Bar30): Used to measure altitude and control heave

Accelerometer Gyroscope (MPU5060): Used to estimate the current position of Duburi and implement PID control of its movement.

Magnetic Compass: Used to detect Duburi's heading and make necessary adjustments.

3) Software: Our new version of the AUV has new approaches to different aspects of the software Subsystem. The subsystem can be divided into three sections which are Vision, simulation and control.

4) Vision: With the help of our new machine vision approach we have achieved better efficiency compared to our past systems. The new models were mainly implemented to conquer the previous barriers. By testing multiple aspects we have set our mind towards a new system which can now run more efficiently than its default state as major performance improvements were made by customizing the model.

5) Simulation: As for the simulation system we have developed a testing environment with the help of Unreal game engine and apply our theories before we actually implement it in the real AUV. This helps simulate different scenarios without harming the AUV. Apart from that we are currently developing a new system where we can directly implement arduino code to work on the AUV simulation.

6) Control Unit: In our new control unit system we have used a custom PID controller which helps to achieve precise maneuvers underwater. Apart from that the PID controller is tuned precisely to achieve the best possible outcome. Furthermore the control system has been designed to work in sync with the computer vision system and help the AUV navigate.

IV. Experimental Result

A. *Mechanical*

The main challenges for the mechanical design that was seen in the past was mainly due to the smaller design which lacked space and due to that there were other problems that were a direct result of congestion inside the AUV. The main problems we faced due to the space was that no new component could be used. Furthermore this also caused a problem in dissipating heat from the computational units. Due to that the frame rates dropped drastically hindering the overall performance of the AUV.

The newer design addresses the past issues and is a drastic improvement. To address the previous generation's lack of space the new design is way larger in size and can now hold equipment that were not possible in the past which were needed for the newer detection and grabbing mechanisms. Apart from that this year we have implemented a quick release latch mechanism that makes a waterproof seal and is currently tested at 9 feet depth and with the current results it is expected to reach a theoretical depth of 25 meters. We have now attached the heatsink with the AUV's chassis to dissipate the heat away and distribute it to keep the computational unit in working order.

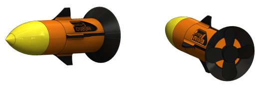

Fig. 4: 3D model of torpedo design.

Moreover we have designed a manipulator and torpedo launch mechanism from the ground up using locally sourced materials with the help of reverse engineering.

The newer design at first had similar water leakage issues and to combat that a new type of soft silicone gasket was used to ensure a waterproof seal. Apart from that minor imperfections in the mechanical structure were later on corrected. Yet we still use absorbent pads so that which can absorb 428.51 gram of water per pad to keep electronic systems safe. Also as a further fail safe mechanism there are leak sensors inside which detect leakage and have an external led indicator to notify it's leakage state.

B. *Software*

In the past the initiation times were sluggish and the frame rates were really low. This resulted in poor use of resources. The past models required huge amounts of training data to reach usable accuracy. The new version addresses the issues faced in the past and it is done through three different phases which are:

1) Dataset collection and labeling: We collected training data from locally available resources and labeled them. The testing environment was replicated according to the competition standards. We now use model pruning techniques that require less datasets and also take less time to train.

2) Training stage: The training stage in the past used different models such as tensorflow and Yolo V5 which did not suffice the demands of the AUV. Now we have improved and can now operate at an optimal level. We have used Jetson inference method using SSD and also we are using Jetson inference for the vision system as well.

The improvement can be seen on the table below:

Name	Model	FPS
Yolo V5	Darknet	10
Tensorflow	SSD	7
Jetson Inference	SSD	27

C. *Electrical system*

keeping system failure in mind we have incorporated a hot swappable system.The sensors are directly mounted on the pcb. Apart from this the new PCB also incorporates different fail safe mechanisms to avoid total system failure.

In the case of sensors the AUV has come a long way. For depth sensing we reverse engineered a BMP280 air pressure sensor to work underwater to work as a water pressure sensor. This year we acquired a BAR30 sensor that can measure water pressure that can measure water pressure up to 30 bars.

Apart from that the new stacked design provides ease of access to all the components and the batteries can now be easily swapped instantly. The power system is more efficient as there's very less power loss as we have removed all unnecessary wiring. We have used insulators to avoid any sort of electrical interference.

V. Acknowledgement

Bracu Duburi would not have been able to be in its current state without the contribution of many hardworking and brilliant individuals. We acknowledge their contribution and dedication towards bringing Bracu Duburi to the global platform. We really appreciate the support Brac University has provided us, be it financial,mental or even with resources. A special thanks to our honorable advisor Dr. MD. Khalilur Rhaman who has guided us since the beginning of our journey and has been the lighthouse to our lost ships in times of distress. Utmost gratitude towards our Chairperson of the CSE department Sadia Hamid Kazi ma'am for being our constant source of support. We would also like to thank our vice chancellor Professor Vincent Chang and Registrar Dr. David Dawland for the support and constant encouragement. Last but not the least the person without whom we can not imagine the team and we are grateful to our co-advisor Sayantan Roy Arko along with our other co-advisors Adnan Sabbir,Mohammad Saurav and Soyeb Ahmed. [1][2]

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Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
Buoyancy Control	Designed In-House	-	-	Custom	$0	2022
Frame	Designed In-House	Custom marine grade aluminium Wire cut	-	Custom	$118	2022
Waterproof Housing	Designed In-House	Custom marine grade aluminium blending and argon welding	-	Custom	$263	2022
Waterproof Connectors	Blue Robotics	Cable Penetrator	-	Purchased	$80	2022
Thrusters	Blue Robotics	T100	Power :55 HP, Torque : 59 Ibs-fit	Purchased	$1200	2019
Motor Control	Blue Robotics	Basic ESC		Purchased	$288	2022
High Level Control	Arduino	Ardunio Mega 2560	ATmega2560 16 MHZ	Purchased	$10	2019
Actuators	Designed In-House	-	-	Custom	$0	2022
Propellers	Blue Robotics	-	-	Purchased	$0	2022
Battery	Wild Scorpion	11.1 v LiPo Battery	3 cell and 5500mah x 2	Purchased	$90	2020
Converter	Blue Robotics	5V 6A Power Supply	Input : 7V-26V, Output : 5V 6A	Purchased	$25	2022
Regulator	-	-	-	-	-	-
CPU	Nvidia	Jetson Nano	4 Cores, Maxwell with 128 CUDA cores	Purchased	$99	2019
Internal Comm Network	Ardunino	Ardunino Serial Communication	Serail communication Using UART protocol	Purchased	$0	2019
External Comm Interface	TP-Link	Optical Fiber		Purchased	$16	2022
Compass	Speedy Tech	GY-88	HMC5883L 3-axis magnetometer	Purchased	$14.20	2019
Inertial Measurement Unit (IMU)	Speedy Tech	GY-88	MPU6050 3-axis gyroscope BMP085 barometer - thermometer I2C interface	Purchased	$0	2019
Doppler Velocity Log (DVL)	Blue Robotics	Bar30	300m Depth/ Pressure Sensor	Purchased	$85	2022
Manipulator	Designed In-House	-	-	Custom	$0	2022
Algorithms	Nvidia	Darknet	Jetson Inference	-	-	-
Vision	Nvidia	Darknet	Jetson Inference	-	-	-
Acoustics	Designed In-House	-	Filtering in frequency and time domain	-	-	-
Localization and Mapping	Designed In-House	-	Custom Designed underwater Lidar	-	-	-
Autonomy	-	-	-	-	-	-
Open-Source Software	-	-	Custom Designed underwater Lidar	-	-	-