RoboSub 2021: VantTec Technical Design Report VTec U-III

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***Abstract*—The RoboSub 2021 overall strategy, developments and improvements on existing systems, and final results are presented in this report. The strategy relied on the improvement of the vehicle design, in aspects such as stability, manufacturability and modularity, as were major flaws in the previous iteration. Also, the development of a perception system took a major role to further validate through simulations the Gate and Buoys challenges solutions proposed last year, as well as the development of a state estimation system in the case of a physical competition. A simulation environment was created for the former purpose, as the COVID-19 pandemic inhibited physical development. Furthermore, the electronics system achieved last year was deemed not robust enough, so a complete redesign is proposed. Finally, RTOS tasks running on an STM32 MCU were developed to manage sensor data. Simulation results showed the proposed systems capabilities, but further work is required to achieve complete robustness.**

***Index Terms*—RoboSub, Unmanned Underwater Vehicle, robotics, autonomy, GNC system, computer vision, perception, artificial intelligence.**

I. COMPETITION STRATEGY

More than a year has passed since COVID-19 pandemic started. The situation led to the establishment of health regulations by the government, which in turn inhibited team efforts into physical development. Graduation of senior team members and leaders led to changes in team management during the second half of 2020. The transition was difficult as the new leaders were still inexperienced, which in turn led to difficulties in the establishment of specific goals for the year. Thus, the team was not able to take full advantage of the available time, but served as a learning process for most team members. A major concern at the beginning of this year was the competition format as there was no certainty if a physical competition would take place. Also, Campus facilities had restricted access, so no entry to laboratories was guaranteed. These conditions led the team to consider physical and online scenarios when planning the strategy. During the second half of 2020 and first quarter of 2021, improvements on the design of the UUV were deemed as priorities in the case to prepare for a physical competition, as flaws in the stability of the vehicle, in the manufacturability, and in modularity were detected. With the update on the competition format, efforts shifted to the validation of the solutions proposed for the last competition through simulations. At the same time, work on the development of an state estimation system began, but for a number of reasons could not be completed. This did not propose a problem, as the system is not required for simulations. Improvements in the electronics and embedded systems are also addressed, although they remain in a theoretical proposal, as physical validation is still required.

A. Course Approach

This year, team efforts moved towards the development of new systems, the validation of the Gate and Buoys challenge solutions and improvements on flaws detected in the overall system presented last year.

Moreover, as COVID-19 restrictions limited the manufacture of VTec U-III UUV, a simulation environment was built to pave the way for further work, as it enables the development and testing of approaches based on simulated sensor readings, which is something the team lacked of.

Key advances have been achieved in the areas of perception and simulation environments that further validate the approaches. These advances, in conjunction with the aforementioned mechanical and electrical design changes, have the goal of increasing the robustness of the overall system.

Furthermore, as RoboSub 2021 tasks did not change at all, the Bins, Torpedo and Octagon missions were attempted in simulation, nevertheless additional work is needed to validate the solutions, since time limitations complicated the full development of the new perception system.

Path marker identification is essential to accomplish navigation through the Gate, Buoys and Bins missions. Thus, a reliable detection method was generated to ensure a correct following. So far the algorithm is only capable of recognizing the large path marker.

The strategy proposes that, by focusing on the development of a perception system, validated through simulations, higher confidence on the performance of challenge proposals for RoboSub 2021 can be achieved.

II. DESIGN CREATIVITY

A. Mechanics

The VTec U-III (Fig. 1) mechanical design is based on last year's model. The team identified areas of opportunity in the last design and established objectives considering the following aspects: stability, modularity, ease of manufacturing and future changes. The main objective is to provide maximum control and maneuverability to the submarine, while maintaining a sturdy and effective frame. Furthermore, its modular design enables the addition and movement of any component, as the ribs acts as anchor points for all components. Therefore, the UUV can be constantly improved for coming competitions, allowing further modification of components such as the pressure racks, thrusters or peripherals. Keeping in mind that the chassis will be maintained.

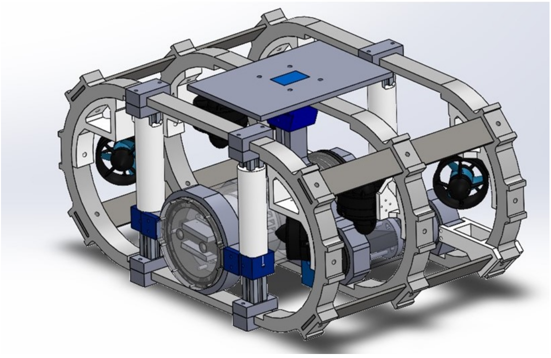

Fig. 1. Submarine design

1) Main Design: The design of the submarine structure is composed by 3 ribs, braced by 4 horizontal and 4 vertical columns that held up the three acrylic electronic enclosures, and the additional systems. The three pressured racks are positioned within the bottom of the frame to maintain the center of mass as low as possible, a flotation foam was placed on the top part of the submarine in order to make the center of flotation as high as possible. Since the 2 vertical thrusters can not provide stability in pitch, the separation of the center of mass and center of flotation allow the craft to have a restorative momentum when it tilts. The submarine counts with 6 thrusters to achieve movement in 4 degrees of freedom which are roll, pitch, heave and yaw. Based on previous competitions it was determined that the best motor configuration for our prototype is one inspired in the Blue Robotics BlueROV2, as it achieves excellent maneuverability and fits in with our current budget.

Nylamid was selected for the exterior frame of the vehicle, due to its lightweight and low corrosion rates which are ideal properties for the underwater operations the UUV will undertake. Moreover, Nylamid facilitates to manufacture the ribs in one single piece. Additionally, for the horizontal supports, stainless steel 316 is used, and for the vertical supports Bosch aluminum profiles were selected due to their impact resistance and durability.

2) Peripherals: Several peripheral systems were developed for the *Bins*, *Torpedoes* and *Octagon* challenges. Due to limitations in physical testing,

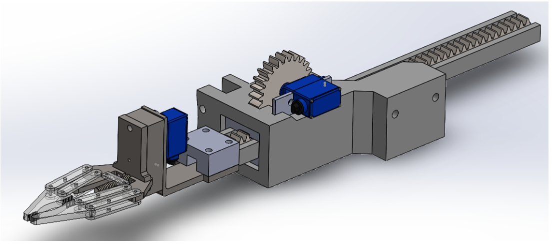

Fig. 2. Arm and Gripper design

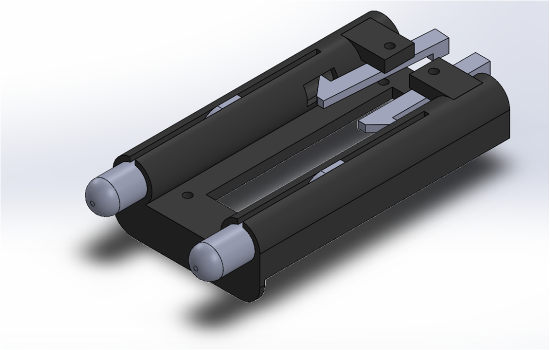

Fig. 3. Torpedo Launcher

the proposed designs still require validation with physical experiments, for serve as a base for future work.

a) Gripper: The gripper changed compared to last year's design. This iteration changed the orientation of the servomotor and the gear, and now allows to reduce the space of the gripper to fix the position where it will be located. Also this design allows to have a better grip of the objects, as the movement of the gear is linear, reducing the recoil when being used, and avoiding failures, such as the opening of the gripper during use, thus supporting greater load. This design also makes the gripper dismountable, allowing it to be placed in any part of the submarine's structure. (Fig. 2)

b) Torpedo: The torpedo launching system was also redesigned. A simpler system with a spring loaded shooter is proposed to replace the linear actuators of the last design. This mechanical shooter lowered the energy demand and had a smaller size compared to the actuator that was being used before. (Fig. 3).

The current design of the launcher (Fig. 4) allows for simultaneous or single shooting of the torpedoes using just one servo motor, and gives versatility by being able to change quickly to backup self propelled rubber band torpedoes in case of malfunctions.The way these torpedoes work is that the potential energy stored in a tensed rubber band can be converted to axial movement when released, being able to power a propeller on the back of the torpedo.

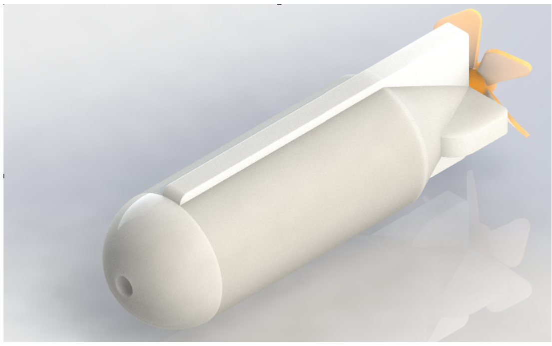

Fig. 4. Backup Rubber band torpedoes

Fig. 5. Marker Dropper.

c) Marker Dropper: The new marker dropper mechanism (Fig. 5) is composed by a crank slider, which releases the markers into the objectives. In order to fulfill such task, a 90 degree rotational motion is converted into a linear movement. Also, the marker dropper can be easily relocated inside the craft, thanks to a cylindrical enclosure that protects the mechanism from getting damaged.

B. Electronics

A major flaw was identified in the previous iteration of the electronic system, it's size. Most of the space inside the primary enclosure was taken by two Printed Circuit Boards (PCBs). The inefficient use of space made it difficult for extra functionality to be added to the UUV, as there was no space available inside the cylinder. With the redesigned electronics system, consolidating everything into a single, smaller PCB, space is freed up. Furthermore, power distribution was also implemented into this PCB, which means that there will be less space and weight taken up by wires. A render of the final design can be seen in Fig. 6.

Based on the team's experience competing in RoboBoat, it was decided that a focus on reliability had to be placed, as reducing the probability of failure and preventing any possible failures is of upmost importance. The new electronic system was designed considering the previously mentioned aspects. Each motor controller has its own current meter and fuse so, if a current measurement that is higher than what is normally expected is detected, the motor can be inspected for wear.

With an improved power distribution board, the amount of manual wiring is greatly reduced; which in turn, reduces the possibility of errors being introduced during this manual process. The risk of any accidental disconnections is also reduced by the use of robust, locking connectors. With both of these improvements, and the aforementioned measures taken, it is expected that downtime for maintenance will be greatly reduced. Additionally, this will prevent the creation of any leaks into the primary electronics system, as the hull will not have to be resealed constantly for maintenance.

In order to unify team efforts, a standardized electronics system was proposed, one that can be used in several projects, such as the team's UUV and USV. With this approach, a common codebase can be used, where only some small adaptations are needed depending on the situation.

The previous electronics system iteration was based on the on the team's RoboBoat competition entry. However, a critical design flaw was later identified: an underpowered MCU, an Arduino Nano. With the increased amount of motors, sensors and data processing that is needed to control the UUV, a faster MCU was implemented for the new design. With this increased performance overhead, more sensors and motors can be added if needed, without being limited by processing power.

With the new electronics design, the new PCB is placed in the central cylinder of the vehicle. Two LiPo batteries are used, each is placed in it's own secondary cylinder. One battery is used for the motors and the other for the Jetson and it's peripherals. The new compacted electronics design will future-proof the UUV, as there will be more space inside the hull for added functionality.

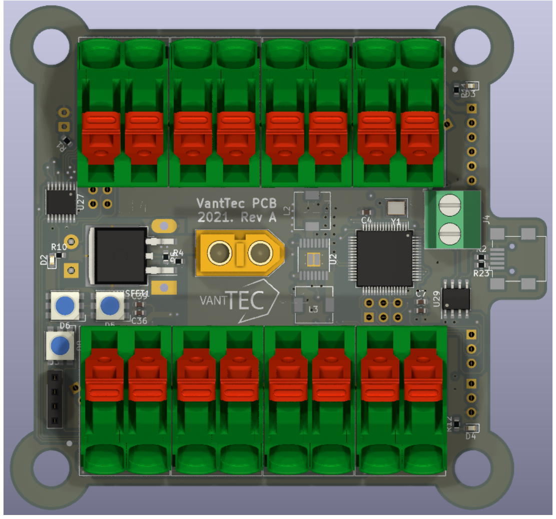

Fig. 6. New PCB Design.

C. Embedded Systems

Following the line of design thinking from the previous year competition, the STM32 microcontroller remains as the electric control unit (ECU) for the submarine motors. Also, the MCU is in charge of handling the information coming from the leak sensor, depth sensor and hydrophones. This year it was decided to change the STM32F103C8T6 model for the STM32F405RG model, as the latter provides better sampling precision and a larger number of programmable pins [10]. The change of models was made to ensure the possibility for further expansion in the number of peripherals the MCU needs to handle.

The micro-controller continues to run on a Real-Time Operating System (RTOS) to enable deterministic operation, task prioritization and a modular design [11]. In order to optimize the performance of the sensors, each one has its own task, where the data provided by them is interpreted and, if necessary, a response is given. Every task has its own sample time, as some of them require a certain amount of time for processing, but this also helps the scheduler to optimize the execution of each task,

Fig. 7. System Overview.

by providing a non conflicting sample time to each one.

The CAN Bus 2.0b (also known as ”Extended CAN”) continues to be used for data transfer between the MCU and the Jetson TX2 CPU, with each device acting as a node. The data frames, depicted in [12], enable package prioritization in concordance with the peripherals of interest. For example, the data packet from the data leak sensor is mission critical while the packets from the hydrophones or depth sensor can be dropped infrequently by the submarine without much trouble.

An overview of the embedded systems can be found in Fig. 7

D. Software Architecture

System improvements are worked on top of the software architecture (Fig. 8) proposed for the last competition [**?**]. The Robot Operating System (ROS) remains as the backbone of the software architecture, and has proven to be really useful as provides means to working with Gazebo, an essential tool for this competition.

In essence, a few number of ROS nodes where added to the architecture. A node per task was made, along with three nodes for online processing of the cameras: one for the frontal stereo camera point cloud, a second for the frontal image, and a third for the down-facing camera image for the path marker.

As only simulations are performed for this competition, only a few key nodes of the architecture are required. The control and guidance nodes for motion control and path-following, and the three nodes composing the perception system, along with the challenge node in turn or the master node.

Furthermore, additional nodes will be created for the integration of the sensor data, as the STM32 MCU is responsible for its processing and is not quite yet implemented with ROS.

E. Simulation Environment

The last competition strategy relied solely on the use of RViz to validate the challenge algorithms, which was deemed as an acceptable approach due to sudden changes caused by the pandemic. However, means of further validating the methods were still necessary, as physical tests were still not possible, and RViz does not provide infrastructure to simulate sensor data.

The previous factors led to the decision of developing a simulation environment with the next objectives in mind: to validate the past system approach; to prepare for this competition in the case of another online scenario; and to facilitate development for future competitions, for both RoboSub and RoboBoat, as physical testing can be difficult.

The first task in the development of the simulation environment was to find similar solutions proposed by the community. Simulators found in [1], [2], [3], [4], [5], [6] proposed attractive approaches, as some could simulate waves, buoyancy, water currents, wind, and a variety of different scenarios. However, some of them required the user to fill a complete description of the vehicle to work, which was a lengthy and tedious process as not all aspects of the model were known. In addition, the team was in no need to simulate waves or water and wind currents as the goal was to validate the correct functioning of the already developed algorithms with the improved systems.

The proposed Gazebo environment for RoboSub relies on the dynamic model of the UUV to simulate the vehicle state (position, velocity and orientation); a 3D model of the submarine; a frontal stereo camera [9]; a down-facing camera; a node to interface the UUV repository with Gazebo; a basic lake scenario obtained from [2]; and custom props for each challenge. These elements proved enough to simulate a stage (Fig. 9) for RoboSub competitions.

F. Control

The PID speed controllers for surge and sway degrees of freedom, and the PID position controllers for heave and yaw degrees of freedom remain in charge of the motion control of the vehicle. These

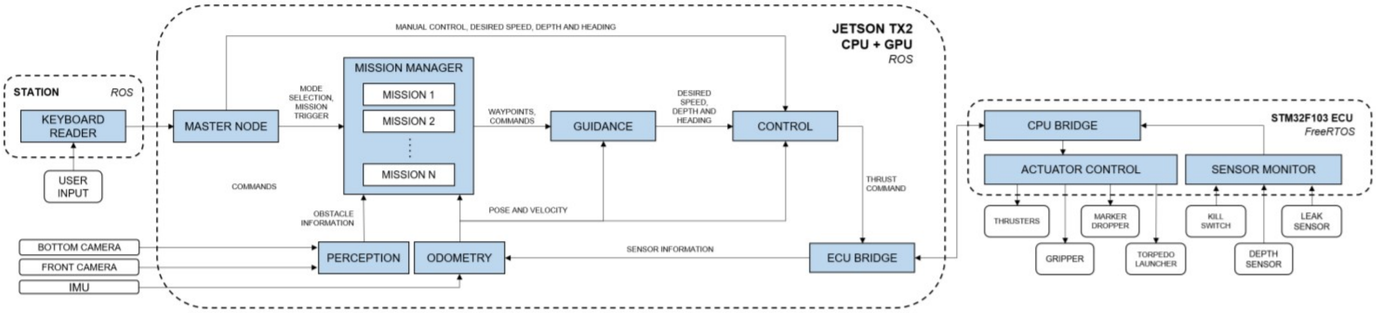

Fig. 8. Software architecture.

Fig. 9. Gazebo virtual environment

controllers proved to be enough to achieve enough maneuverability for some challenges, however, a more robust strategy regarding the development of an Adaptive Sliding Mode Controller (ASMC) is being designed for the future, as time was not enough to complete it for this year competition.

G. Guidance Law

The Line-of-Sight (LOS) implemented for last competition remains as the guidance law used for path-following control. However, the main problem with the method is that it does not take full advantage of the available thruster configuration of the UUV. For this reason, an adapted ASMC based guidance law [13] was developed for surge, sway, heave and yaw, but for time constraints was not fully implemented in the current system.

H. Perception

The perception system is composed of 2 sensors: a ZED mini stereo camera and a Raspberry Pi camera module. The stereo point cloud is used separately to calculate the distance, size, and orientation to obstacles. Meanwhile, the Raspberry Pi camera is used as down-facing camera. This year, upgrades have been implemented to the neural network, the point cloud system and the path marker detection method, with the goal of enhancing the UUV performance.

1) Path marker detection: The proposed detection approach consist on identifying the path marker with the image from the bottom camera. Firstly, an algorithm is in charge of reducing the environmental noise by applying several OpenCV filters. Then, the Canny edge detector along with the *findContours* function are utilized to encounter the number of borders that the marker has. Later, the function (minAreaRect) provides the marker rotation angle, which is used to create a waypoint in the same direction. It is necessary to notice that method only detects the larger marker. Moreover, the neural network is not employed, saving processing resources. Results can be seen in Fig. 10.

2) YOLO: The Convolutional Neural Network (CNN) Yolo Tiny v3 [8] was used as one of the object detection systems. Last year's approach for the CNN was trained on a synthetic dataset taken from pictures and videos from previous RoboSub editions. For this competition, a new dataset was created based on the simulation environment. That approach was chosen, first, as access to a pool was not possible to generate for a real dataset; second, there was no reason to develop a synthetic dataset with last year's approach, as no physical competition would take place; and third, it was easier for the new members to learn the appropriate process for

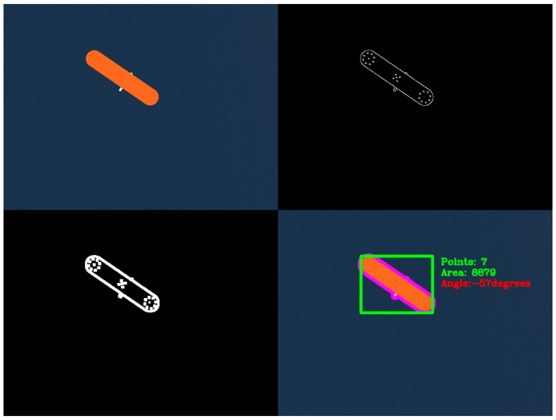

Fig. 10. Path Marker Detection

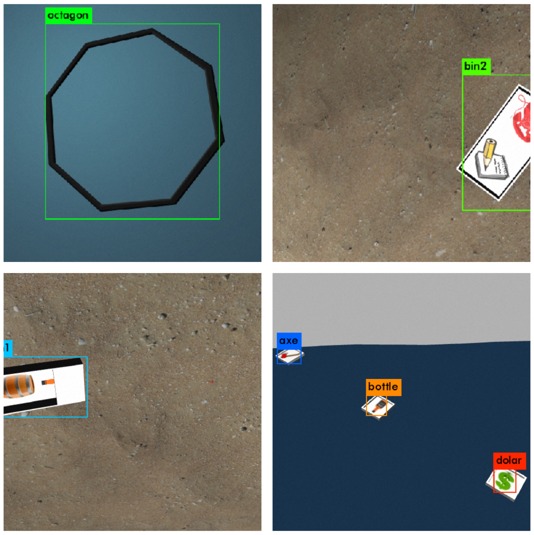

Fig. 11. YOLO: Object Detection

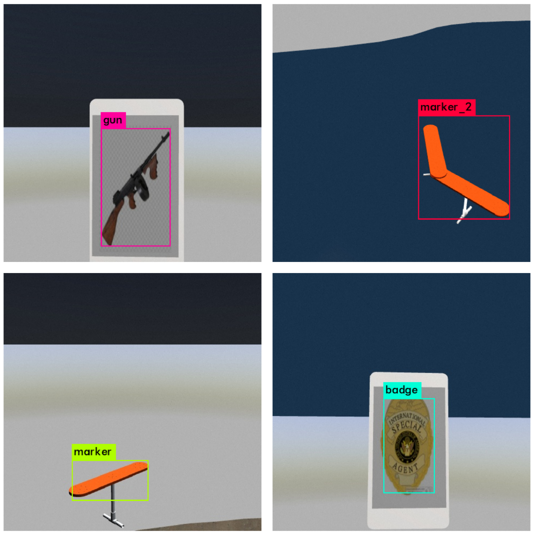

Fig. 12. YOLO: Object Detection 2

the next competition. To fulfill all the challenges of the competition 13 classes were chosen for training.

Data Augmentation was used to increase the size of the dataset, by using filters such as Gaussian blur and salt and pepper. After the augmentation, 1260 images were used for training, and 540 for testing. The training took 6 hours with NVIDIA GeForce RTX 2060 resulting in a 96.4% accuracy.

Fig. 11 and Fig.12 show correct identification for some of the competition props.

3) ZED Point clouds: The 3D object detection routine can be subdivided into three major steps. The first one is denominated as down-sampling, and as the name implies, it reduces the sample size, being the number of points, by averaging a centroid inside several voxels that subdivide the original 3D image. The second step is the point cloud segmentation, which relies on the Euclidean Clustering algorithm to find individual objects present in the point cloud. The last step is the maximum diagonal distance finder. The opposite corners of a segment are both the maximum and minimum points of the space occupied by an individual segment across the three axes. As the system currently only considers props for the first two challenges, the object with the maximum distance between these two points is likely to be the gate, identifying smaller objects as buoys.

III. EXPERIMENTAL RESULTS

In this section, evidence and validation of the proposed course approach is presented. The Gazebo simulation environment was used to test all of the challenges with the aforementioned perception system.

A Gazebo world that includes all the competition challenges was built to represent an scenario similar to the one present at the NIWC Pacific TRANSDEC facility in San Diego, CA (Fig. 9). The Gazebo world and its props was developed based on the '2021 Mission & Rules' document [7], and the RoboSub 2021 forum.

An aspect worth mentioning is that only the first and second challenge solutions include the input of the developed perception system. As mentioned

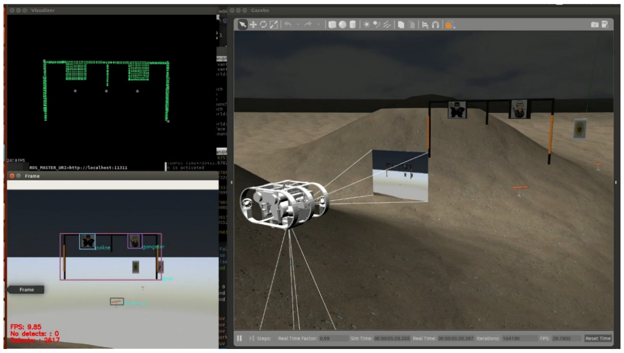

Fig. 13. Choose your Side Challenge

in the previous sections, the YOLO neural network was trained to identify classes for every challenge, but the point cloud processing only considered the gate and buoys as identifiable objects. This means that the Collecting and the Cash or Smash challenges still require validation with the perception system. Similarly, the Survive the Shootout challenge still requires further development, as the boards are identified as buoys, but the identified openings are not mapped to targets yet for the vehicle to shoot at.

A. Choose your Side

Fig. 13 represents the Choose your Side challenge of the competition. The scenario is composed by a black gate with images hanging at each side. The dimensions of the gate corresponds to the ones established in the competition rules. For the completion of the challenge, a search algorithm consisting on a sweep of 90 °in yaw for finding the gate followed by a translation in surge of 3 meters. This process is repeated until the gate is found, and the point cloud and image are processed. Then, the UUV will create three to pass the gate on the corresponding side. The first waypoint is located at the front of the gate, the second one behind the gate on the same side, and the last one is also at the back, but centered at the gate. The competition video showed the capability of the vehicle to correctly identify the gate, the position of each side, and the hanging images. The craft then proceeded to pass through the ”bootlegger” side.

B. Path Marker Following

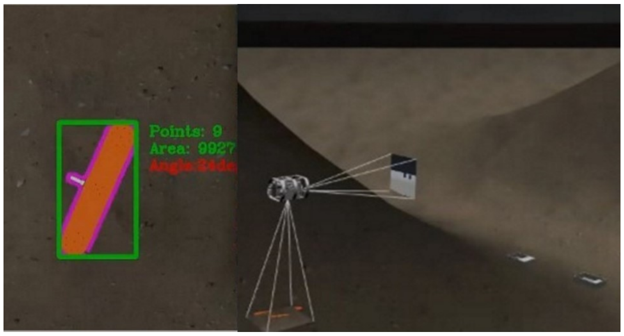

Fig. 14. Path Marker Following

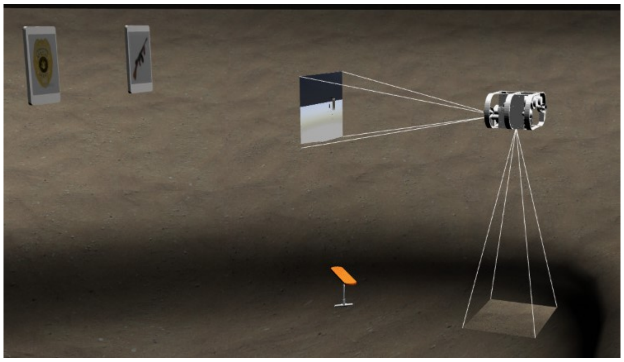

Fig. 15. Make the Grade Challenge

Fig. 14 represents a single straight path marker used to point to the next challenge to complete. In the simulations, the path markers are located between the Gate and Buoys, and the Buoys and Bins challenges. The competition videos show that the vehicle can move in the direction the marker suggests.

C. Make the Grade

The Make the Grade challenge is represented in Fig. 15. The props used for this challenge are two boards with images of a *Badge* for the G-man, and a *Tommy Gun* for the bootlegger. The Buoy challenge solution uses the same search algorithm as the first challenge. Once the appropriate buoy is chosen, the vehicle will move close enough to the buoy to touch and stay still. Then, the submarine will create waypoints to circumnavigate the obstacle and place itself behind the center of both buoys and search for another path marker pointing to the next challenge. The competition video shows the performance of the system when solving this task.

D. Collecting

Fig. 16 represents the Collecting Challenge of the competition. The scenario consists on two boards

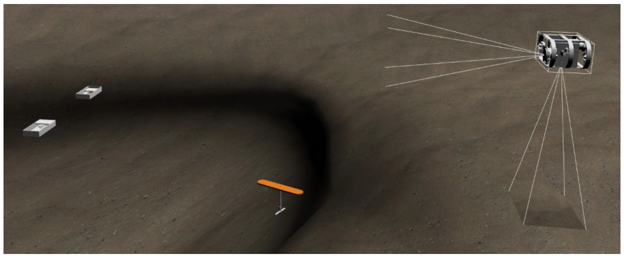

Fig. 16. Collecting Challenge

with images such as a *Barrel*, *Bottle*, *Paper* or *Phone*, with part of the opening covered. In the proposed solution, the vehicle will start the search algorithm until the bins are located with the stereo camera point cloud. The craft then will be placed in the center of the bins and will proceed to move to a waypoint above each bin. The down-facing camera image will then be analyzed with the YOLO neural network, and the system will determine if a marker should be dropped, if not it will then move the other bin. A solution was proposed, but did not consider inputs from the point cloud processing was not considered in the system development due to time constraints.

E. Survive The Shootout

The Survive the Shootout Challenge is represented in Fig. 17. The scenario is composed by two boards with images of a G-man and a Bootlegger each, and with two holes. The solution assumes input from the point cloud and YOLO neural network perception system. It is considered that the boards should be located and analyzed at the beginning of the challenge, only to select the board with an image different to the craft's role and proceed to shoot at it.

F. Octagon Challenge

Fig. 18 represents the Octagon Challenge of the competition. The props consists of three tables with the images of an *Axe*, *Dollar*, and *Bottle*, there is also an octagon figure with the dimensions established in the competition rules. In this case, the perception system was not fully operational, so it was tested as a proof of concept in the case of receiving the right vision inputs with point cloud and YOLO neural network. Assuming the submarine has identified the three tables, it would start by moving above the center table, then would descend to grab a bottle and move to the appropriate table to leave the bottle. Finally the robot will generate a waypoint to end the challenge a few meters ahead of the centered table.

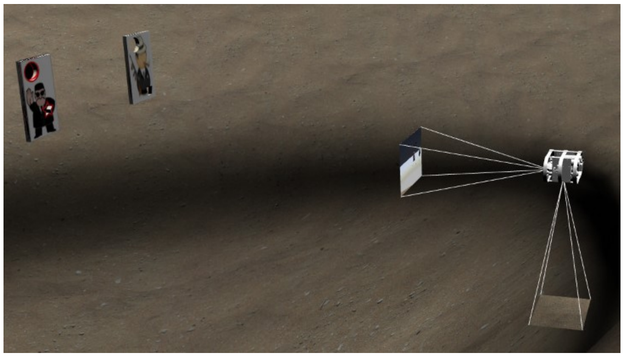

Fig. 17. Survive The Shootout Challenge

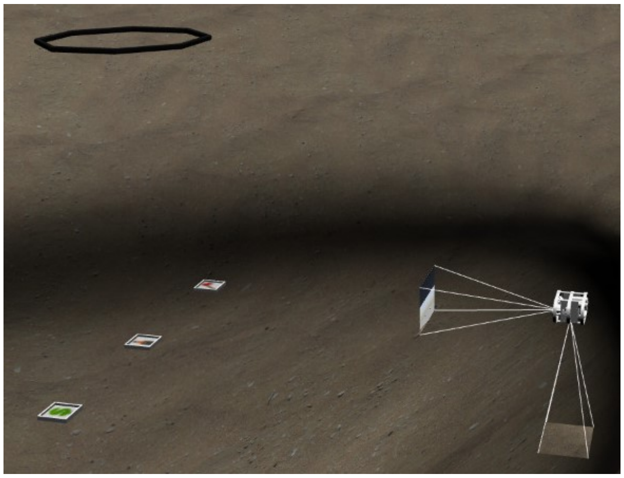

Fig. 18. Octagon Challenge

IV. CONCLUSIONS

A new strategy for RoboSub 2021 is presented. This strategy takes focus on the redesign of the UUV considering stability, manufacturability and modularity aspects. The electronics system was developed from scratch, as the previous iteration was not robust enough. A new perception system for object detection was developed, composed by a YOLO neural network for object identification, and point cloud processing for 3D detection. A path marker following method was developed. As the Covid-19 pandemic remained a latent threat for health well-being, simulations became the only means to validate the created algorithms. The simulation results show the capabilities of the overall systems to successfully complete the first and second challenges of the competition, including path marker following. For the rest of the challenges, solutions are proposed, but still require validation through an improvement of the perception system.

Finally, flaws were identified regarding the perception, control and guidance systems when working with the solutions for the challenges. The perception system needs improvements to correctly identify objects in the environment; a robust controller is under development to improve the response of the system for a real scenario; also, a new guidance law is under development, to replace the LOS in order to take advantage of the maneuverability the current thruster configuration offers.

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APPENDIX A: COMPONENT SPECIFICATIONS

See Table I.

APPENDIX B: OUTREACH ACTIVITIES

A. *Conexion Tec*

Conexion TEC is an event organized by Tecnologico de Monterrey's School of Science and Engineering which highlights the best engineering projects from each semester. VantTec participated with the technology developed for RoboBoat in both semesters.

https://www.facebook.com/conexiontec/

B. *El Camino del Ingeniero*

El Camino del Ingeniero is a conference that formed part of bigger movement called WOMXN UP, organized by the highschool robotics team FRC 6200 - XRams. Female team members of VantTec participated, sharing their trajectory in STEM, with the objective of empowering women and inviting them to seek STEM-related careers. https://www.facebook.com/xrams6200/

C. *Evolve*

Evolve is an event that supports the career decision-making process for students, organized by the Student Society of Mechatronic Engineers. Our president and RoboBoat project lead shared the team's trajectory and history, with a QA session at the end. https://www.instagram.com/saimt.mty/

D. *IMT FAQs*

An Ask Me Anything session with high school seniors and undecided major freshmen interested in pursuing Mechatronics Engineering studies to clarify doubts on higher education. https://www.instagram.com/saimt.mty/

TABLE I
COMPONENT SPECIFICATIONS

Component	Vendor	Model	Specifications	Quantity	Cost
Buoyancy Control	Blue Robotics	Buoyancy Foam	16in x 8in x 1in	1	35
Frame	Own design	VantTec 3.0	Nylamyd XL	1	130
Waterproof enclosure	Blue Robotics	6” series	11.75”	1	265
Waterproof enclosure	Blue Robotics	3” series	8.75”	2	204
ROV Tether	Blue Robotics	Fathom	35m	1	158
Plug	Blue Robotics	Leak proof plug	-	23	26
Penetrator	Blue Robotics	Leak proof plug	-	23	61
Thruster cable	Blue Robotics	Thruster Cable	-	6	20
Cable penetrator	Blue Robotics	M10 Cable Thruster	8mm	6	10
Thruster	Blue Robotics	T-200	-	6	1048
ESC Controller	Blue Robotics	Basic	-	6	150
High Level Control (ECU)	STMicroelectronics	STM32F405RG		1	20
Kill switch	Blue Robotics	Kill Switch	-	1	14
Battery	Blue Robotics	Lithium-ion Battery	14.8V - 18Ah	1	289
Battery	Zippy	Lithium-ion Battery	11.1V - 8Ah	1	220
Step down	Pololu	5V - 5A	-	1	15
CPU	NVIDIA	Jetson TX2	GPU and 8 GB memory	1	600
CPU Carrier	Connect Tech	Quasar	-	1	488
Internal Comms Network	-	-	CAN Bus 2.0b	-	-
External Comms Network	-	-	TCP/IP over Ethernet	-	-
Programming Language	-	-	C/C++/Python	-	-
IMU	VectorNav Technologies	VN-200	-	1	4000
Camera	Stereolabs	ZED Mini	1080p Resolution	1	450
Camera	Raspberry Pi	Camera Module V2	8 Mega Pixel Resolution	1	450
Hydrophone	Telodyne	RESON TC 4013	-	1	1200
Hydrophone	Aquarian	H1C	-	2	318
Depth/Pressure sensor	Blue Robotics	30 Bar	-	1	80
Leak sensor	Blue Robotics	Leak Sensor	-	1	26
Manipulator	Own Design	Own Design	3D Printed Gripper	1	5
Algorithms: Perception	-	-	Yolo Tiny V3 and 3D Computer Vision internal development	1	0
Algorithms: localization	-	-	-	0	0
Algorithms: autonomy	-	-	Line-Of-Sight Guidance and ASMC Guidance	1	0
Algorithms: autonomy	-	-	Non-Linear PID Motion Control	1	0
Open Source Software	-	-	OpenCV	1	0
Open Source Software	-	-	Point Cloud Library	1	0
Open Source Software	-	-	ROS Kinetic	1	0
Open Source Software	-	-	FreeRTOS CMSIS V1.0	1	0
Open Source Software	-	-	Eigen (C++ Library)	1	0
Team Size	-	-	-	31 members	0
HW:SW Expertise Ratio	-	-	-	9:12	0
Testing time: simulation	-	-	-	300h	0
Testing time: in water	-	-	-	0h	0