UPRM Roboboat Team: RUM-BA 2.0

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The UPRM Roboboat Team goes into detail about the design and manufacturing process of RUMBA 2.0, the enhanced vehicle prepared for the competition being held on Summer 2020. As a second year returning team, a variety of improvements were done to the ASV taking into consideration last year competition. These include fixing the hull to reduce lift forces, changing the top surface of the vehicle to reduce weight, and the incorporation of simulations to test the vehicles coding. Same as last year, the ASV will rely on the recreation of objects detected in a virtual mapping generated by the LIDAR alongside ultrasonic sensors. The base communication system is designed using ROS, and the embedded system consists of a Beagle Bone Blue controller that has Ardupilot connected to a TX2 for decisions and commands. Due to external variables, the team decided to complete three out of the six tasks and perfect them to achieve the greatest amount of points possible.

Keywords—AI, ASV, ROS, LIDAR, Ardupilot.

I. COMPETITION STRATEGY

On last year's competition, the team encounter several hurdles and technical difficulties during the competition week. The vehicle was in turn, not able to complete any of the tasks or have as much in-water test time as expected. Upon returning, extensive troubleshooting was done to identify and correct the bugs. After considering all that took place and given that the ASV did not perform as expected, the competition strategy for this year is going to be the same from the previous year. At the beginning of the school year, the team redesigned and worked to complete four of the six tasks, those being mandatory navigation channel, speed gate, obstacle field, and object delivery. Our last focus was the object delivery given that it requires drone deployment. Considering that full autonomy was not achieved, the competition strategy will be based on setting up the position and orientation of the ASV manually and then starting the corresponding task mission when the desired location is reached. After further evaluation, considering the time restraints, and not being able to perform drone testing, the team decided to focus on three tasks out of the six. This leaves the object delivery task and gives the team more time to perfect it for next year's competition.

For this year's competition, the target is to complete the three tasked mentioned above flawlessly and acquire the most points possible for each.

A. *Mandatory Navigation Channel*

Since this is a mandatory task, the team plans to complete it at the beginning of the run. RUM-BA 2.0 will determine the position of the buoys, that will be the starting point, using the Lidar and the camera. The ASV will go from one waypoint to the other using YOLO to detect the next gateway buoys and Stereo Depth in combination with the LIDAR to confirm midpoint positioning to pass through them. In case it gets near a buoy that is out of its Field of View (FOV), the ultrasonic sensors will help in the redirecting of the vehicle, avoiding the object.

B. *Speed Gate*

Like the Mandatory Navigation Channel, using the camera and the LIDAR, RUM-BA 2.0 will determine the position of the starting gateway. After going through, the vehicle will use 75% of the thrust to reach the blue buoy as fast as possible without losing vision of it. Then it will go around it and come back to the starting waypoint.

C. *Obstacle Field*

For this task, RUM-BA 2.0 will rely on the virtual map, generated using data from the camera and the LIDAR, and the ultrasonic sensors, positioned in five locations around the vehicle. This combination performs obstacle avoidance considering all the buoys detected and allows safe navigation through the empty paths of the course.

II. DESIGN CREATIVITY

As mentioned before, the ASV went through a redesign and troubleshooting to improve precision and performance. The ASV kept part of its flat hull made of PVC sheets because of its low density and high strength. A flat hull gives the boat more stability in small lakes with calm waters. Last year, RUMBA 2.0 had intermittent connection to the base which caused the ASV to stop its course. For this year's competition, the adaptation of a ubiquiti antenna to our FrSky transmitter/receiver that is set to a Turnigy 9X RC controller was another interesting solution to extend the range of our radio communication. The team kept the dual lens camera that is capable of Stereo Depth to simplify the position of objects. Another one is the use of Ultrasonic sensors for avoidance of objects out of the generated map, and field of vision, of the LIDAR and camera. Finally, the recreation of the objects detected in a virtual map is very useful to have at hand reliable data that can be reused throughout all the competition days, when stored.

A. *Vehicle Design*

The team kept the flat hull vehicle because of its simplicity and stability, using PVC sheets. The flat hull is used mostly on calm waters for planning [1], which is the expected behavior of the competition pond. Last year's ASV had a problem with the bow rising when cruising through the course. This became an issue since the camera would lose visibility. To correct this issue and improve control and stability, long half-moon PVC pieces were added and shaped with all-purpose putty filler. Through test and simulation, it was clear that it reduced water drag resistance and lift force (Appendix A, Figure 3). This allows the bow of the vehicle to not rise when accelerating through the course. Another design change was done on the top surface of the vehicle. The goal was to become the lightest vehicle in the competition by reducing material used and creating room for the drone (Appendix A, Figure 5). A minimalistic approach was taken.

Last year, all the components inside the vehicle were placed on top of a platform. This was added to raise all the components off the bottom surface to prevent damage if water entered the ASV. It proved to serve its purpose because the components did not become submerged or in contact with water, preventing a short circuit (Appendix A, Figure 6). RUMBA 2.0 keeps the component platform even though some modifications were made, the first being a reduction of voltage regulators and cables to reduce clutter. The components will have 3D printed holders to be able to move and organize such so that they are secured in place. This will allow easy movement and replacement of the electrical components found inside the boat to avoid agglomeration of team members working on the vehicle at the same time. Another design specification kept from last year ASV was the 3-inch thrust extension that kept the T200 thrusters submerged deeper into the water to avoid them taking in air, which can cause the thrusters to malfunction.

B. Electrical

The electrical subsystem is composed of all the electrical connections inside the boat. The principal connections are for the three batteries that are used for the full functioning of the boat. The batteries are connected in parallel which supply a total of 30 Amps (10 Amps each) and 14.8 Volts. They are located at the front part of the platform for the safety of the components if any water gets inside the boat and to keep the center of mass. The batteries are connected to a switch for the protection of any malfunction before connecting them to the components. Voltage regulators were administered before the components to protect them from receiving excess power. There are three distinctive voltage regulators which are used to maintain the components close to their operating voltage. Failure to do so could cause damage to the electrical components. Compared to last year's ASV, the amount of voltage regulators was reduced to prevent overheating inside the boat and increase efficiency by reducing the amount of power losses. From this point, all the power through all the boat to microprocessors, ultrasonic, thrusters, and the light tower.

C. System

One of the main strategies in the design was to be able to modularize and divide the subsystem in such a way that the development and testing is not dependent on other subsystems. Considering our experience in last year competition, and the communication difficulties between the vehicle and the base, it was determined to start with a redesign of the full network. A ubiquiti antenna was added to optimize connection and the final design of the network can be seen on Appendix A, Figure 7. Once the network was defined, the team proceeded to optimize the subsystems even further. ROS (Robotic Operating System) was kept as the foundation of the vehicle since it still follows the initial conditions of modularity that is being considered in the design. The main software subsystem is composed of perception, actions, and Artificial Intelligence (AI), and will be further explained

1. Perception

A separated module was created to a conglomerate of all the data received from the different sensors to create a cleaner representation of the world. By separating this component, that is normally in conjunction with the AI, it can be tested separated from such. In other words, the dependency of our main AI algorithm from requiring real data for testing was eliminated. Instead of collecting or creating all the data from the sensors to test the AI subsystem, the team simply created the outputs of this module which are very easy to validate.

2. Actions

Another subsystem extracted from the regular AI module is the actions. Deliverables were made into a list of the necessary actions that the system needs to perform to complete all the tasks and created an API around it to be called by the AI system. By being their own module, the need of the AI having a physical system to test was eliminated and it became easier to debug.

3. AI

The AI module is essentially a group of decision trees. Each decision tree represents the different decision and actions to be taken during a task. These trees are then put into a queue depending on which task it to be performed first, giving us flexibility on how we want to approach the competition. In other words, the AI system listens to the perception subsystem to decide and it calls the Action subsystem to make the actions.

D. Vision

The vision system consists of a dual camera that is used to apply a SLAM with Stereo Depth to generate point cloud data from the visible surroundings. A clustering algorithm, HDBScan, is then used to identify object due to a high point density in a specific location. These detected objects are passed to the mapper with the corresponding location to position them in a virtual map appropriately. A similar object detector is performed with the LIDAR sensor where it uses the distance and servo positions to obtain a point cloud. HDBScan is also applied to this point cloud to properly identify objects that are later passed to and it only needs clustering because it already identifies the point.

E. Embedded

The embedded system consists of a Beagle Bone Blue controller that has Ardupilot installed to be capable of autonomously move the boat to the different positions required. A TX2 is connected to it to take all the decisions necessary and to then give the correct commands to the Beagle Bone Blue to acquire the correct positions. An Arduino is connected to the Beagle Bone Blue and to all the ultrasonic sensors to implement a layer of object avoidance. An Arduino Nano is connected to the TX2 to add the LIDAR functionality with the servos to the system. Also connected to the Beagle Bone Blue there is the GPS to know the positions of the boat and the radio receiver to receive manual inputs from a radio controller.

III. EXPERIMENTAL RESULTS

After modifications were done to the hull and overall design of the vehicle, the weight was reduced by 40% which is more than expected. Computational Fluid Dynamics (CFD) analysis was performed to evaluate the overall drag and lift forces being exerted on the hull. Such analysis shows a reduction in both forces and overall better performance.

The team was not able to being the Spring semester until the last week of January due to the earthquakes of large magnitude in the island. In early March, Puerto Rico begun a stay at home order with curfew that obligated everyone to remain home due to the COVID-19 pandemic. Given these time restrictions, the in-water tests performed were limited and mostly for critical functions.

Only connection and control testing were able to be performed physically (both successfully). The team was on the process to start testing more complex behaviors when the access to physical testing at our university's pool was lost. Even though we were presented with many challenges, simulated test was performed with the use of ROS and Unity. The reason for Unity instead of using already available simulated testing software (gazebo) is that the user interface was made in Unity, making implementation simulation for testing was relatively easy with the nature of ROS. Additionally, most of the team members are using Virtual Environments to be able to use ROS, which are not ideal for performing simulated test, but since Unity runs on their native OS, the computing issue was solved. The initial results from the simulated test were promising although due to issues out of the team's control, a successful simulated task run have not been able to be completed. YOLOv3 is still the main object recognition software used with the NVIDIA TX2 board which can run such. To train it for the real competition objects, data from the forums and last year competition was collected to then perform data augmentation techniques to train a model that would recognize these objects. These models were tested successfully (Appendix A, Figure 8).

ACKNOWLEDGMENT

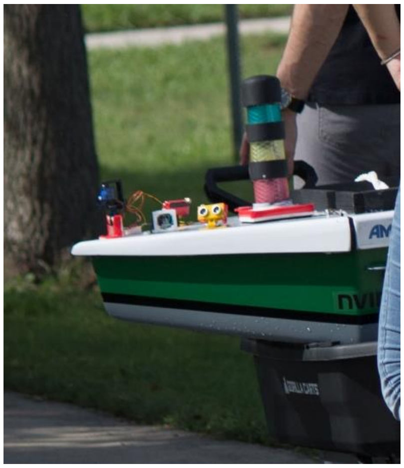
The UPRM Roboboat Team was founded under the Association of Females in Mechanical Engineering. The team thanks this organization for giving the tools needed to establish the organization and for their effort to promote gender equality within engineering. Another thanks to the professor advisor, Dr. Ivan Baiges, which has continuously supported the team through the adversity since the team was founded in University of Puerto Rico at Mayaguez.

The UPRM Roboboat Team is extremely thankful of the UPRM Alumni that have given their trust and support through sponsorships from the companies where they currently work at. These companies include Lockheed Martin, General Motors, Boeing, NVIDIA, AMGEN, Procter & Gamble, SolidWorks, Mathworks and Blue Robotics. The Engineering Faculty and the University of Puerto Rico at Mayaguez have given the team a place within campus to work on the project, and that is appreciated too. With their financial support, the organization was able to work for a second year of competition. They have given the tools needed to overcome adversity and set higher standards. Every milestone achieved, is because they helped get there. In addition, special thanks to the university community and the team's families for supporting not only the individual team members, but the whole team. Thank you to RoboNation and Roboboat for helping create a community that has transformed into a family.

REFERENCES

[1] "Boat Pennsylvania Course." *Hull Types and How They Operate | | Boat Ed.com™*, www.boat-ed.com/pennsylvania/studyGuide/Hull-Types-and-How-They-Operate/101039_101039011/.

Appendix A: Relevant Images from the Design and Analysis



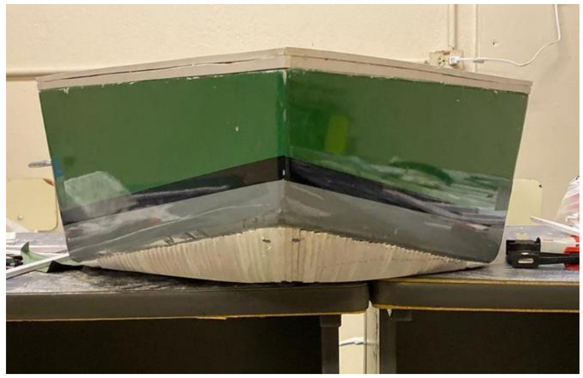
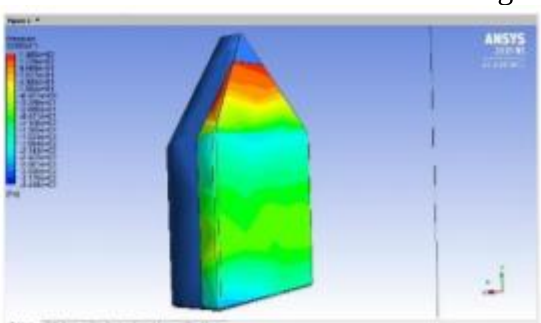


Figure 1 and 2: Comparison of last year flat bow from RUMBA and the rounded bow in the design of RUMBA 2.0.



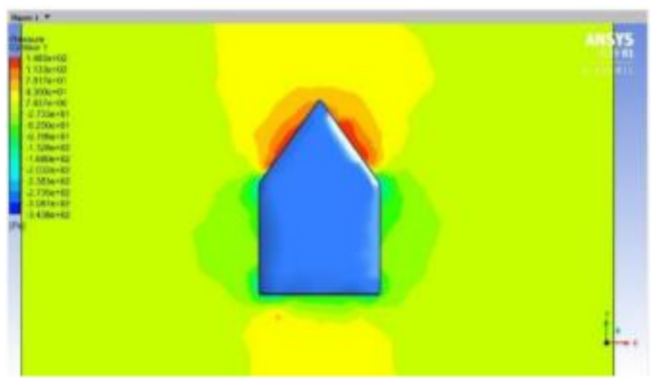


Figure 3 and 4: CFD analysis done on RUMBA 2.0 hull.

Figure 5: Top hull minimalistic design.

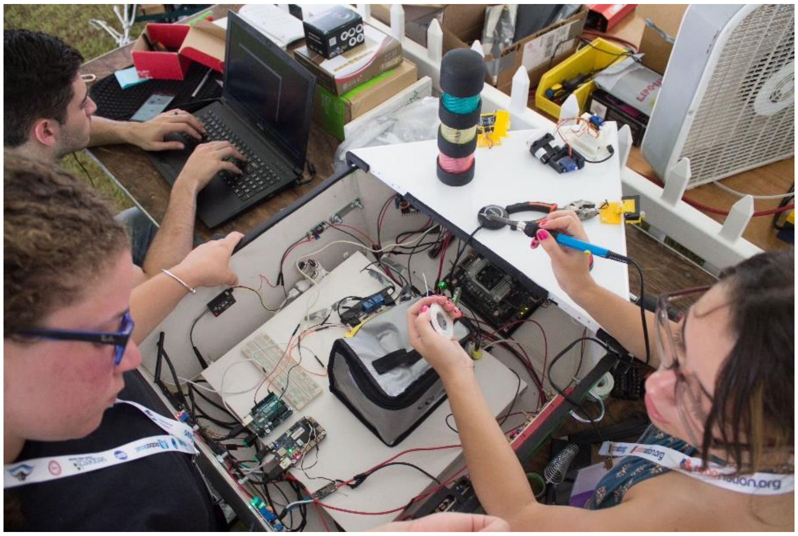


Figure 6: 2019 Competition interior platform design of ASV.

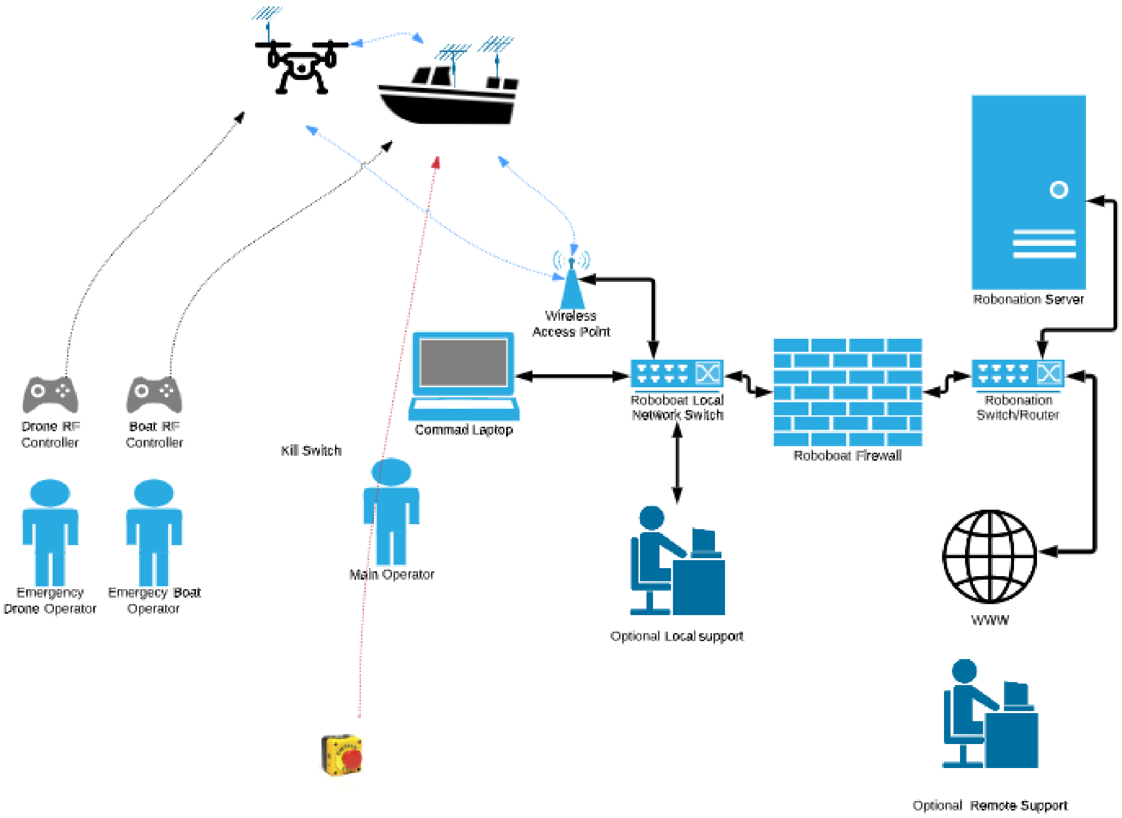


Figure 7: Network design diagram for the RUMBA 2.0.

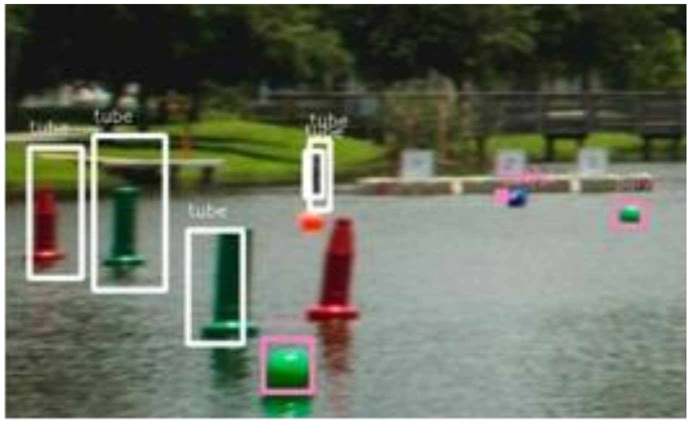


Figure 8: Object identification using YOLOv3.

Appendix B: Component Specification

Component	Vendor	Model/Type	Specs	Cost (if new)
Hardware				
PVC sheet	Home Depot	Modified	4’x8’	$89
14.8 V, 10 Ah Batteries	Hobbyking	Turnigy Graphene	Capacity: 10000mAh Voltage: 4SIP/4 Cell/ 14.8 V Discharge: 15C Constant/30C Burst Weight: 936 g (including wire, plug and case) Dimensions: 168x69x40 mm Balance Plug: JST-XH Discharge Plug: XT90	$100 each
Jetson TX2	Nvidia	TX2		$600
Thrusters	Blue Robotics	T200	**Maximum Forward Thrust @ 16V:** 5.1 kgf / 11.2 lbf **Maximum Reverse Thrust @ 16V:** 4.1 kgf / 9.0 lbf **Maximum Forward Thrust @ 12V:** 3.55 kgf / 7.8 lbf **Maximum Reverse Thrust @ 12V:** 3.0 kgf / 6.6 lbf **Rotational Speed:** 300-3800 rev/min	$169 each
Ultrasonic	Amazon	HC-SR04	Working Voltage: DC 5V Working Current: 15mA Working Frequency: 40Hz Max Range: 4m Min Range: 2cm	$9.78

			Measuring Angle: 15 degree Trigger Input Signal: 10µS TTL pulse Echo Output Signal Input TTL lever signal and the range in proportion Dimension 45 * 20 * 15mm	
Voltage Regulators	Amazon	eBoot	Input: DC 3 V to 40 V (input voltage must be 1.5 V higher than the output voltage, no boost) Output: DC 1.5 V to 35 V voltage is continuously adjustable, maximum output current is 3 A	$10.95
Voltage Regulator for TX2	Amazon	Solu		$9.59
Voltage Regulator for Beaglebone Blue	Amazon	DROK		$9.00
Beaglebone Blue	Beagleboard	Beaglebone	AM335x 1GHz ARM® Cortex-A8 processor 512MB DDR3 RAM 4GB 8-bit eMMC flash storage Integrated power management 2×32-bit 200-MHz programmable real-time units (PRUs) NEON floating-point accelerator ARM Cortex-M3 USB2 client for power & communications, USB2 host	$82
GPS	FPVDrone	Ublox M8N	Ublox Neo-M8N module • Industry leading –167 dBm navigation sensitivity • Navigation update rate up to 10 Hz • Cold starts: 26s • LNA MAX2659ELT+	$27.89

			• 25 x 25 x 4 mm ceramic patch antenna • Rechargeable 3V lithium backup battery • Low noise 3.3V regulator • Power and fix indicator LEDs • Protective case • 30cm Pixhawk2.4 compatible 6-pin and APM compatible 5-pin 2 types cable included • Diameter 60mm total size, 32 grams with case.	
Camera	SVPRO	SV-960P2CAM-V90	1.3MegaPixels, Max. Resolution 2560(H)X960(V) Sensor 1/3-inch OV9750 Pixel Size 4860µm x 3660 µm Resolution & frame MJPEG: 2560X960@ 60fps/2560X720@60fps /1280X480@60fps /640X240@60fps Sensitivity 3.7V/lux-sec@550nm Mini illumination 0. 1lux Shutter Type Electronic rolling shutter / Frame exposure Connecting Port type USB2.0 High Speed Free Drive Protocol USB Video Class（UVC） Support OTG Protocol USB2.0 OTG AEC Support, AEB Support Adjustable parameters Brightness, Contrast, Saturation, Hue, Sharpness, Gamma, Gain, White balance, Backlight Contrast, Exposure	$81.99

			Lens Parameter: M9 Lens HOV 90-degree, optional M12 no distortion lens, wide angle 180degree lens USB Interface Micro USB Operating Voltage DC5V/Operating Current 160mA~220mA Working temperature -10～70℃/ Storage temperature -20～85℃ Board size /Weight 80X16.5mm, about 30g Cable Standard 1M	
LIDAR	Sparkfun	LIDAR Lite V3	Range: 0-40m Laser Emitter Accuracy: +/- 2.5cm at distances greater than 1m Power: 4.75--5V DC; 6V Max Current Consumption: 105mA idle; 130mA continuous Rep Rate: 1--500Hz Laser Wavelength/Peak Power: 905nm/1.3 watts Beam Divergence: 8m Radian Optical Aperture: 12.5mm Interface: I2C or PWM 20 x 48 x 40 mm (0.8 x 1.9 x 1.6 inches)	$130
Team				
Team Members	Undergrads	Electrical, Mechanical, Computer, Software, and Industrial Engineering	25	N/A

Appendix C: Outreach Activities

Since the team was founded, in 2017, we have participated in various outreach activities. As a team that encourages gender equality, we prioritize educational activities for all levels, where we focus on the importance of inclusion. In 2018, we participated in various outreach events. In the following section, we go into detail of the events taken place from May 2019 to May 2020.

In May 2019, the team participated in the Mechanical Engineering Half-Day Program for girls aged ten to seventeen. The members of our team became group proctors and were tasked with discussing how women have endless opportunities within STEM. Our team also had an exhibition with our boat floating on a small pool where some girls were able to remote control it and see how it worked. Next to the pool, we had a table with a computer where our Software Members prepared a game that simulated the competition and the girls could play. On October 2019, the team had an exhibition table in the UPRM Open House. Students from all ages came to our table and our team members spoke to them about how our team was multidisciplinary and that there was a role for everyone. We invited some senior students to give us their information so we could mentor them when they came to the university in August 2020.

Figure 9: University of Puerto Rico-Mayagüez Open House Exhibition

The team partnered with the American Society for Engineering Education on November 2019 to participate in their Engineering Fun Day half day program where they spoke to high school students about how to get involved in special projects like ours and how enriching the experience is.

Come around February 2020, our team partnered with a local charity organization called "Fundación CAP Puerto Rico." This non-profit organization has the purpose to help families of children with pediatric cancer not leave the island and receive treatment in the Pediatric Hospital of the Puerto Rico Medical Center, close to their families. Our team sold the organization's branded merchandise and all proceeds received were donated to Fundación CAP.

Figure 10: CAP Foundation Fundraising Event

Other events were scheduled for the months of March, April, and May but due to COVID-19, the events were cancelled. Future projections for our team include developing strategies to connect with more students virtually. Our team looks forward to developing strategies to connect with more students virtually in the coming months. When in-person activities resume, our team will contact schools from the Eastern side of Puerto Rico so we can expose twelfth grade students to STEM and special projects like ours. This will ensure that students feel empowered and inspired but most importantly, educated in topics like gender equality, special projects, different engineering and business branches, opportunities in the university and professional development.