University of Puerto Rico, College of Engineering: Autonomous Underwater Vehicle - Proteus.

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***Abstract* — Proteus is the first autonomous underwater vehicle (AUV) designed, manufactured and developed in Puerto Rico and the Caribbean. The master minds behind this AUV are the members of RUMarino, a robotics association that help students develop in engineering through the development of robots at the University of Puerto Rico, Mayagüez Campus.**

Proteus consists of an acrylic cylindrical cabin guided by a precise navigation system, which consists of two implemented sensors, the Razor 9DOF IMU and the Bar 30 depth/pressure sensor. The vehicle is oriented with the help of its environment recognition components such as the sensors previously mentioned and both cameras aboard Proteus. Also, the vehicle counts with actuators, underwater thrusters (six T100 thrusters manufactured by Blue Robotics) that altogether with buoyancy foams maintain the vehicle in equilibrium, and help the vehicle move up, down and around in some degrees of freedom. Proteus will be competing for the first time in the 2017 RoboSub Competition to be held in San Diego California.

I. Introduction

Our planet consists of mostly water but nearly 95% of the oceans remain unexplored. As part of helping uncover the mysteries of our planet, Autonomous Underwater Vehicles (AUV) were created. To keep up with the times and be a part of history, the University of Puerto Rico in Mayaguez has been developing its own AUV with a team of students, which have been dubbed team RUMarino. The pioneer and multidisciplinary project provide students with a unique opportunity to work in science, technology, engineering and mathematics (STEM). Our members range across different areas of study: from engineering fields, such as Mechanical, Electrical, Computer, and Industrial up to business fields, such as Marketing and Human Resources.

The project focuses in the design of an autonomous underwater vehicle (AUV). After two years of hard work, understanding AUV's and how to develop one with limited resources, knowledge and funding, team RUMarino has developed a fully functional autonomous underwater vehicle, purpose built for successful completion of certain tasks in the Robosub competition, with robust and custom built low level digital controllers and custom vision algorithms to detect obstacles. Since this is the first AUV developed in Puerto Rico and the Caribbean, the project has captured the attention of everyone.

II. Design Strategy

Given the demand for a robotics group on campus, several students were given the task of creating the organization College Robotics for Manufacturing Engineers (CROME). From there came the projects Battle Bots, Vex and later was created Rumarino, the pioneers that took the challenge of creating the first AUV in Puerto Rico and the Caribbean, named Proteus.

Team RUMarino had no previous experience with any kind of autonomous vehicles, therefore it had a trial and error stage and research stage as well as a designing, manufacturing and a programing stage. Since the inception of the team, the majority of the time was spent on researching the best practices for AUV’s as well as developing a prototype to understand what worked and what did not.

During the 2016 fall semester, Proteus was broken down and each subsystem was designed, manufactured and tested for future integration with other parts to form our AUV. The team, at the beginning of this year, focused on a new design, which involves the implementation of a cylindrical pressure hull. The vessel gave the benefit to proceed with an unyielding and waterproof system to guarantee a more optimal and secure AUV, compared to the prototype that consisted of a pelican case as the hull, which gave problems with waterproofing and buoyancy. The outer structure was designed in NX to accommodate the cylindrical hull, as shown in Figure 1.

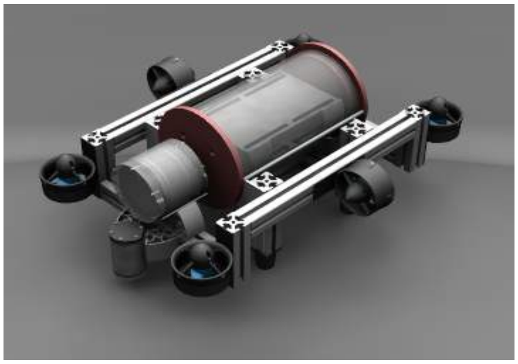

Figure 1. Nx CAD Rendering of Proteus

Keeping in mind accessible materials such as the aluminum extrusions and acrylic panels from the previous prototype. Both cameras are inside acrylic hulls on 3D printed mounts (Figure 2) that were integrated on the outer structure.

Figure 2. 3D Printed Mounts for Cameras

The design also takes into consideration the alignment of each thruster, which is important for a stable vehicle. As expected, the complexity of the team's first involvement with an AUV set a mindset to create an adjustable vehicle that is small, compact, and easy to assemble and refine.

Being this first time working with autonomous underwater vehicles for robosub, we had limited funding and we had to compromise advanced functionality to be able to have a vehicle that works and meets the requirements for the competition. Understanding our limitations in actuators and sensors for controllability, team RUMarino made a mechanically stable system where the center of buoyancy is above the center of mass so Proteus can correct any disturbances in pitch and roll movements in a passive manner. The important aspects for a stable underwater vehicle is its buoyancy. In order to obtain a 0.5% (or greater) buoyant sub, the team acquired buoyancy foams from Blue Robotics. The foams were mounted on the right and left side extrusions of the structure; this symmetry makes the vehicle balanced underwater, and counteracts unwanted rotations. For a more static look, black handmade cases made of a strong, but flexible plastic, were created to support the foams in place as showed in Figure 3.

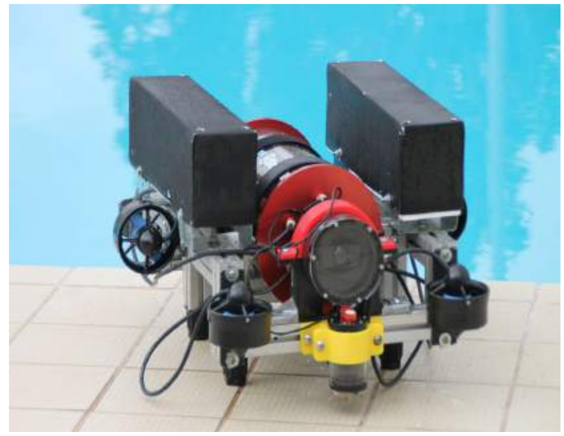

Figure 3. Custom Foam Encasings

The inside of the pressure hull was designed in NX to optimize the available space as much as possible, and for a more organized interior. The structure needs more refinements to accommodate even more electrical components, while improving comfort when assembling. A prototype, shown in Figure 4, was 3D printed with ABS material for the team's first competition.

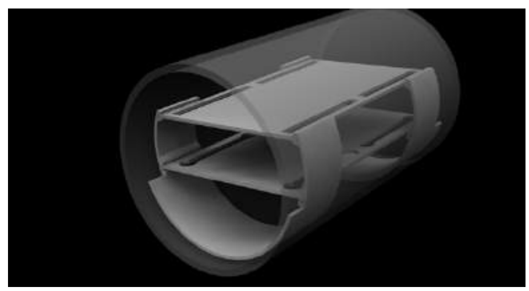

Figure 4. NX CAD Rendering

I. Mechanical System Design

Originally the project started as a PVC prototype that was later change to a pelican storm case. At first this was a waterproof case and with the different adjustments made to install cameras, sensors, actuators and other components it worked just fine. Proteus was an effective AUV that could move and perform all his actions in his degrees of freedom, but later the problems began. To be able to submerge efficiently it needed to have extra weight given by metal plates, this caused problems with the buoyancy, also there was a leaking problem that put in danger the whole project and made it difficult for the team to meet some competition requirements.

A. Structure

After some research, the team upgraded to the new and final design which is an acrylic cylindrical cabin, the next step was to find a way to organize the components, inside the cabin, for the weight to be balanced and not a requirement to use the metal plates. The design consists of a sliding slat that divides the space in two compartments.

This makes it easier to replace or work with the components without having to disassemble the rest of the components. All this is ensured by the outer cover which is a cylindrical cabin made in transparent acrylic sealed at its ends by two Aluminum lids. This aluminum plates have detailed perforations to include Blue Robotics penetrators, kill switch and Ethernet. This allows external components to be connected to the interior of the vehicle.

B. ACTUATORS

The thrusters used are 6 Blue Robotic T100 thrusters. These thrusters are UV resistant, have high strength and the core of the motor is sealed and protected with an epoxy coating. They use high-performance plastic bearings in place of steel bearings that rust in saltwater, everything that is not plastic is either aluminum or high quality stainless steel that does not corrode, also the thrusters can handle extreme pressures.

Fig thruster T100 with BlueESC

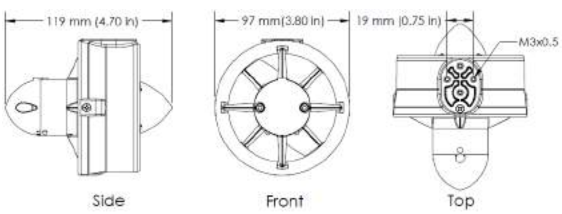

Figure 5. Thruster T100 without BlueESC

C. CHASSIS

The cabin is attached to an aluminum base. The actuators (6 Blue Robotics T100 thrusters) are in the aluminum base specifically so that Proteus can have horizontal, vertical or round movement. The two cameras are also on the frontal part of the aluminum base, one looking forward and one looking downward. With the help buoyancy foams located on both sides of the base, Proteus is steady and ready to go.

II. ELECTRICAL SYSTEM

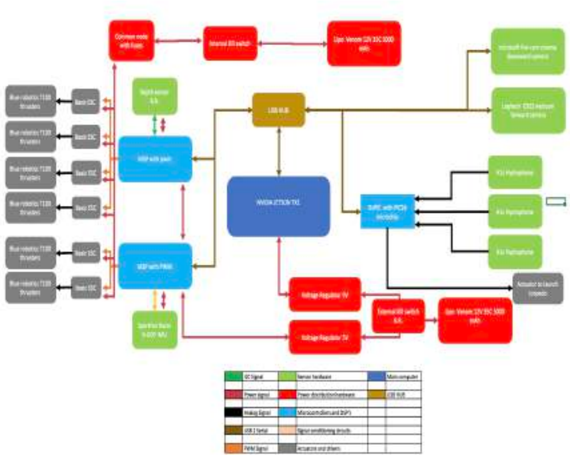

Figure 7. Connections of electrical system components

A. BATTERIES

To generate the necessary power around the AUV the selected batteries were Venom LiPo 35C 5000mah with 3 cells in series producing a voltage of 11.1V to power the electronics and a 6400mAh 11.1V LiPo to power the motors. For a higher safety measure, the LiPo will be stored in a fireproof bag made for the batteries. This is taking into consideration battery safety. By doing this, we avoid the situation where the electrical components get damaged.

Figure 7. Venom LiPo 3s 5000mah 35C

B. ONBOARD COMPUTER

The computer onboard Proteus for running all software packages and sensors consists of a NVidia Jetson TX1 with a quad-core ARM A57 CPU.

C. MODULAR COMMON NODE BOARD

To connect the six thrusters, we made a custom board with six XT60 connectors in parallel. This modular board contains fuses integrated in the board for safety with the connectors in parallel.

D. SENSORS

1. The Razor IMU 9 MOF 10736 this incorporates three sensors an ITG-3200 (three-axis gyroscope), ADXL345 (three-axis accelerometer) and HMC5883L (three-axis magnetometer), providing acceleration and orientation information

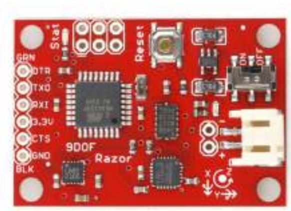

Figure 8. Razor 9DOF IMU

2. Two cameras, a Logitech c922 facing forward and a Microsoft LifeCam facing downward for vision processing and visual odometry.

3. Blue Robotics Bar30 sensor for measuring the depth of the vehicle as feedback to the depth controller.

Figure 9. Blue Robotics Bar 30 Sensor

4. The AUV needs to know where an underwater pingers are located to complete one of the task on the RoboSub competition. Precise location information is needed to make the AUV move to the pingers and submerge to the surface so the selected hydrophones to be mounted in the AUV are the H1a from Aquarian Audio Products. Two Aquarian Audio H1C hydrophones for acoustic signal processing.

Figure 10. The H1C Hydrophones.

V. Software System

A. Computing systems are at the core of all the moving parts of our submarine. The computing system constitutes the brain of the system, it's what we use to be able to determine what actions we are to take and when. For this we have developed our own software, this enriches the knowledge of our members and creates a strong foundation. However such a complex system shouldn't be put together all in one computer, since this would be a poor design for reasons we will explain. From a top down view of our system we could see that there are multiple layers of abstraction between the logical segment of the code, the mission logic, and the actuators. This provides us a way to work at different sections of the code, and the entire system, while still maintaining functionality of the system.

B. The system can be divided between our mission logic and mission execution. This is key in giving us an encapsulation so if one thing goes wrong the whole system has a way of recovering (this is still a work in progress). The mission logic is contained within the Jetson TX1 computer, this is our main computer, and through here all the decisions necessary for mission success take place. This computer also handles the cameras to process the computer vision aspects of the sub. All of the code that handles mission logic and cameras are based in Python for rapid development purposes.

C. We delegate the rest of the interactions to the surrounding world to two MSP430F5529 micro-controllers, this is what responds to the mission logic and is in charge of mission execution. Their low power requirements and ease of development make them perfect for interfacing with peripherals and act as the submarines extremities. They are directly responsible for the two controllers that manipulate the movement of the submarine through actuators.

VI. Vision

A. Proteus has 2 cameras, one facing forward, and one facing downward. The front camera is used in the majority of the mission tasks such as the buoy finding task and the gates localization. The downward camera is used solely to detect and to align with the path marker. The OpenCV open source library was used for the development of all the vision algorithms in Proteus. The vision processing code is written in Python. The team decided to use OpenCV with python because of the simplicity of the learning curve for the current and future members of the team.

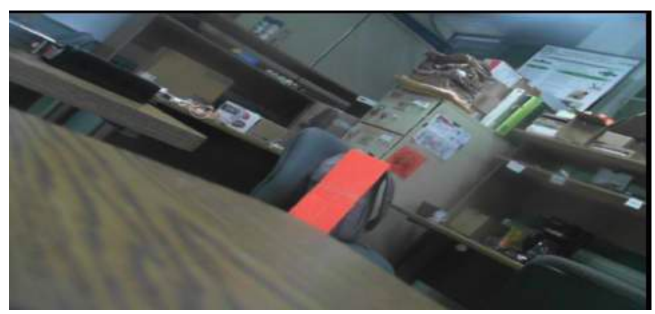

Figure 11. Original path picture

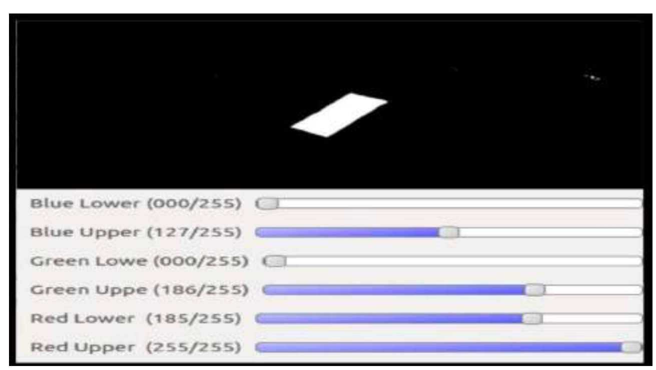

Figure 12. Color segmentation GUI

B. Combinations of image processing techniques were used to detect, track, and obtain meaningful information from the cameras data stream. A combination of filters and multi-stages algorithms were implemented to detect objects. To increase the accuracy of detection a parametric classification method was embedded in the detection algorithms. Early stages of our algorithms rely on color segmentation and structural analysis to validate that the expected object is detected. Once the object is detected the algorithm validates the detection using features extraction techniques. The machine vision algorithms possess the capability of calculating the distance of the target object from the vehicle. This is done using only one camera with an accuracy of 95% if the object is properly detected. This minimizes the cost and use of resources in the machine vision system of the vehicle. The uses of all the OpenCV functionalities were optimized in their use. This was achieved resizing the images coming from the cameras, changing the color spaces of the images to accelerate the processing of the images and using feature extraction only in a preselected area of the image and not in whole scene. This reduces the processing load in the computer and reduces the running time of the algorithms.

VII. Embedded Software

A. The embedded system abstracts the layer from the main system that talks to most of the hardware peripherals. This means that the main computer only sees an interface, it only communicates to it and are thus independent of each other. This makes it so if the mission logic goes wrong we can fail in a safer manner. Each micro-controller oversees its own control loop that sends signals to the motors. One oversees vertical depth using four motors and a depth sensor as a feedback sensor. The other one oversees the yaw of the system and it uses a 9 DOF IMU to take measurements about its surroundings.

B. The MSP430F5529 is a great platform to develop in, due to its great hardware features and documentation, at a low cost. To further the educational development, all the code for the hardware abstraction layer (Hal) were made by us for the controllers. This includes serial drivers, pwm drivers and sensor drivers. From this we could implement the controllers that were designed by the control team.

VIII. Experimental Results

After several months of unrelenting work and testing, all components are finally functioning perfectly. During the process the, IMU, suffered damages but thankfully all problems could be solved. Also, there were buoyancy problems at the beginning of the design that were solved by changing the cabin and using buoyancy foams. With all the components working perfectly, replicas of the objectives find in the official competition were created and one step at a time the work done by Proteus was improved.

IX. Acknowledgements

This achievement would not have been possible without the participation of the dedicated members of Rumarino, the help of teachers and instructors who gave us a hand during this adventure. Thanks also to the University of Puerto Rico, Mayagüez campus for providing the group a laboratory to work and for letting us use the pool to run the tests and simulations needed to achieve our goal. And finally, thanks to the sponsors who did not hesitate to give us their support.

Breakdown of sponsors

- Boeing
- Honeywell
- General Motors
- Universal Insurance
- Educational Services
- University of Puerto Rico Mayagüez Campus

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XI. Appendix—Outreach Activities

Given the fact that proteus is the only AUV in Puerto Rico and the Caribbean, it has been the center of attention around the island. It has been presented to the public in several educational fairs, open houses, an article for the newspaper ¨Metro¨, on local television in the program ¨Juntos en la mañana¨ and even Boeing company gave us the privilege of presenting Proteus at the conference "What's Next" hosted by The Atlantic. The talks and presentations about Proteus do not only capture the eye of the technology industry but also the high school students see it as a future goal, to create something amazing that could innovate the study of the ocean. There is nothing better than inspiring others.

High school STEM summer camp outreach