Floating Point IV Autonomous Surface Vehicle

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***Abstract*- This journal paper describes the plan, design and construction of Floating Point IV, an autonomous surface vehicle. The ASV is designed by the RoboBoat team from Robotics Association at Embry- Riddle (RAER), to compete in the 9th international RoboBoat competition hosted by AUVSI. The ASV has a tri-hull modular design with a custom deployment design for an autonomous submarine. It also includes an array of sophisticated sensors, including Lidar, GPS and hydrophones to complete the required tasks. The software has been updated and revised for better autonomous obstacle avoidance, path planning and vision processing. The ASV now includes an Autonomous Underwater Vehicle (AUV) for 2016, which is capable of launching from the ASV and performing interoperability missions.**

I. Introduction

Floating Point IV is an autonomous surface vehicle (ASV) specifically designed to compete in International RoboBoat competition. It is an update, both in terms of software and hardware, from the previous ASV. It is proudly presented by the RoboBoat team of the Robotics Association at Embry-Riddle (RAER). The purpose of the ASV is to successfully complete all the challenges of the competition. The challenges include speed gate, obstacle avoidance, docking, and interoperability. The ASV was redesigned to be faster, smarter, and to include the deployment system for the 2016 interoperability challenge: an autonomous underwater vehicle (AUV). Both the ASV and the AUV host an array of sophisticated sensors. These include Velodyne LiDAR, Hemisphere GPS, Teledyne hydrophones, and Sparton IMU. It also includes a powerful on-board processing unit with a custom made PCB, along with its own communications system. The deployment system is custom designed and constructed to innovatively and effectively deploy the AUV. The whole system is designed to be efficient, powerfully capable, and easily upgradable.

Figure 1: Floating Point IV

II. RoboBoat Challenges

Floating Point IV is designed and built to compete in the 2016 International RoboBoat competition hosted by AUVSI. The ASV and AUV is designed specifically to take on the various tasks of the competition. These include:

1. Speed gate: The ASV has to drive through a set of start and speed gates as fast as possible.

2. Obstacle Avoidance: The ASV has to enter the obstacle course through an entrance gate, avoid obstacles (buoys), and exit through the exit gate.

3. Automated Docking: The ASV has to recognize preassigned shapes and colors to execute a docking sequence in autonomous mode.

4. Interoperability Challenge: The ASV has to launch, recover, and communicate with an AUV. The AUV has to report the characters shown on a LCD screen underwater.

5. Pinger Challenge: The ASV has to identify active pingers placed underneath certain buoys, and circle them.

6. Return to dock: The ASV has to navigate back to its starting point.

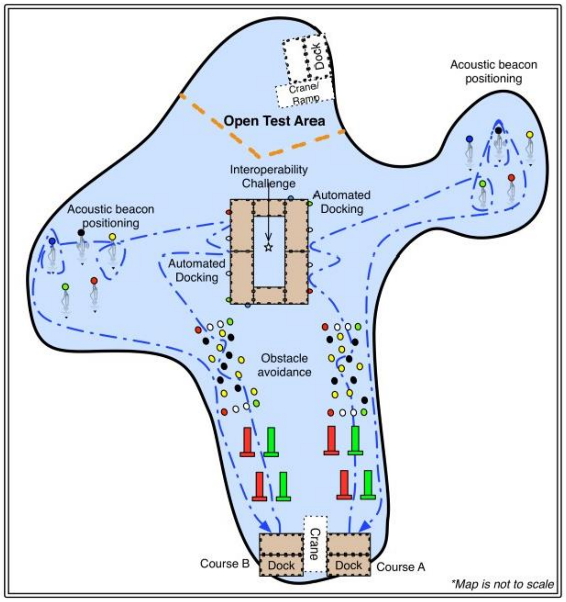

Figure 2: Competition Layout [1]

III. Vehicle Design

A. Design Strategy and Considerations

Simplicity, effectiveness, and upgradability were the core design ideas that the Floating Point team followed. The external and internal components are assembled in such a way that they can be removed and replaced independent of each other. The motors are mounted on a motor mount external to the frame of the boat, and can be modified to accommodate any future upgrades. The deployment system is entirely modular, and can be removed easily to put another system in place. The ASV has an internal chamber that houses the electronic and computing components, and can be easily accessed to remove and replace any component. The AUV also has accessible components which can be switched and upgraded easily when required.

Likewise, the software is designed to be modular, for effective debugging and increased stability. The software architecture consists of a set of independent modules running as separate processes. They are tested extensively before being compiled into the main computer on the ASV, which ensures a fast, reliable and effective run. If needed, each module can be debugged separately to ensure faster and more effective debugging.

The team believes that aesthetics is an important part of a design. Therefore, the project is built to be streamlined and professional looking. Every panel and component is machined and inspected before being implemented in the main design, which ensures a professional grade appearance.

B. Hull Design

Floating Point IV features the same tri-hull design as its predecessor, Floating Point III. It is lightweight yet robust, while allowing the vehicle to cruise at faster speeds than the previous versions. The material used is wood, which is then coated with fiberglass to ensure strength and rigidity. The end result is a lightweight, strong and waterproof structure. It has two mounting points on the top for external sensors, such as GPS and Lidar. The streamlined design allows the AUV to be very fast and stable in the water.

The rear deck is built to allow the installation of different attachments. Floating Point III used a landing pad and a quadcopter, while Floating Point IV uses an AUV and a deployment structure. The modular design enables changes to be made without affecting or damaging the main structure of the AUV.

C. Deployment Design

In order to properly prepare the boat for competition regulations, the group needed to build and design a deployment system for the AUV. The group chose the spool and pulley system, because it was reusable, lightweight, and required minimal alterations to the boat's structure in order to deploy the submarine.

The deployment process first began by determining which process would work best: leaving the boat attached to the back of the boat or creating a system that would lift it and place it in the water. After the group weighed the pros and cons of each system they came to the final decision of developing a system which would pick the sub up and place it in the water.

The final deployment system, shown in Figure 3, is created to be lightweight, efficient and innovative. It consists of a linear actuator, slide rails, truss and a servo motor. When the linear actuator is powered it extends and pushes the truss forward while the sub is simultaneously being pulled up. When the linear actuator is fully extended, the servo rotates to lower the sub in the water. For retrieval, the servo rotates in the other direction until it picks the sub up, which is regulated using a Hall Effect sensor as a limit switch. Finally, the linear actuator comes back to the original position and drops the AUV in its holding spot.

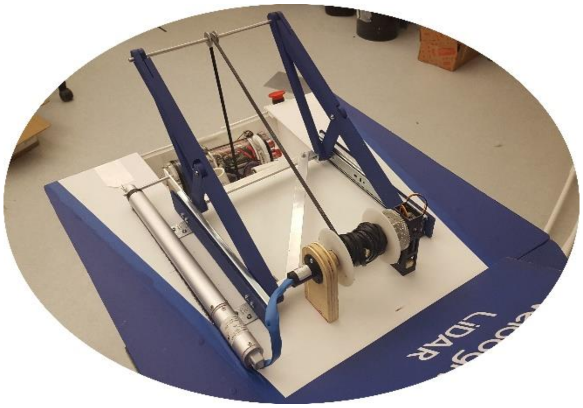

Figure 3: Deployment System with AUV

III. Vehicle Hardware

A. Propulsion

Propulsion was one of the major concerns of the team while designing Floating Point IV. Due to the addition of an AUV and its deployment system, the ASV required more power than the previous version. A powerful ASV would mean more direct points in the Thrust measurement and Speed Gate challenges, while shaving off lap time for the entire run. Therefore, the team decided to opt for the Blue Robotics T200 thrusters with external ESC's.

Figure 4: Blue Robotics T200 Thruster [2]

The thrusters use brushless motors, and is made of high strength, UV resistant polycarbonate injection molded plastic. The internal components use plastic, aluminum or high quality stainless steel, which prevents it from corroding. It has a maximum forward thrust of 11.2lbf as shown in figure 3, which gives the AUV a maximum speed of around 4-5 knots, which is approximately 30% faster than the previous ASV. Moving left and right is done using torque vectoring. One thruster provides forward thrust and the other reverses to provide a torque which turns the AUV left or right. It has a very small turning radius, which allows for maneuvering in tight spots.

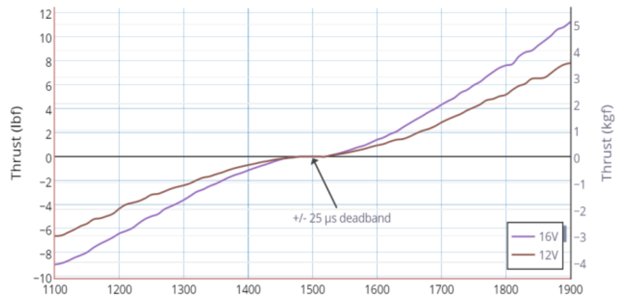

Figure 5: Thrust vs. PWM input [2]

B. Sensor Array, Computing, and Communications

Floating Point IV consists of cutting edge sensors that allow the AUV to complete the required tasks for competition. This includes a Velodyne VLP-16 laser range finder, Hemisphere GPS, Teledyne Hydrophones, Sparton IMU and Cameras. Processing is done onboard using a custom ASUS motherboard with an Intel Core i7 processor, while power is provided to different components using a custom made PCB.

Figure 6: Velodyne LiDAR and Hemisphere GPS units [3,4]

The LiDAR spins 360 degrees 10 times each second, while capturing over 350,000 data points ranging from 15 degrees above and below horizontal. This allows a virtual map of the environment around the AUV, which is then 'read' by the software to detect potential obstacles around it. The GPS and the Sparton IMU allows for precision navigation and maneuverability. The Teledyne Hydrophones can detect ultrasonic sound waves underwater, which allows the AUV to complete the Pinger Search challenge. The camera is used to take video input, which is then processed on board using the vision processing software to recognize the shapes and color for the docking task.

Communication with the ground station and judges is done using a pair of Ubiquiti Rocket multi-antenna with diversity. The radio communicates at 5.8 GHz for one-way communication with the ground station instead of 2.4 GHz to avoid any interruptions. The system also includes an independent long range RC system, which allows the ASV to be controlled manually at any time.

Safe operation of the ASV was crucial for the design and development of the Floating Point project. The ASV includes both remote and local E-stop systems. The ASV has a commercially available E-stop button which immediately cuts power to the thrusters when pressed. The remote E-stop switch is on the RC controller, which bypasses all software systems and cuts power to the thrusters when engaged. Switching to manual operation mode also bypasses the software and allows the user to control the ASV.

IV. Vehicle Software

Floating Point IV utilizes individual independent modules of software that only listen to certain type of data, and then tag outgoing data for consumption by other modules. There are separate modules for environment mapping, obstacle avoidance, path planning and navigation. All the modules can be controlled via the Objective Tracker, which is used to indicate the order of the tasks Floating Point performs during competition. Each software module is compiled as an independent executable and run on the onboard computer, which allows for the reset of individual modules without impacting the performance of the other standalone modules.

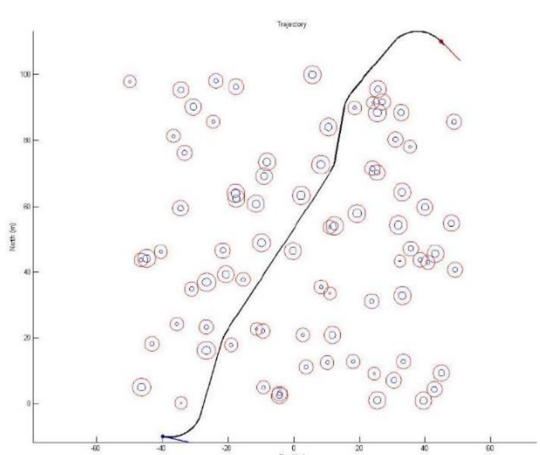

Figure 8: Obstacle avoidance and path planning simulation

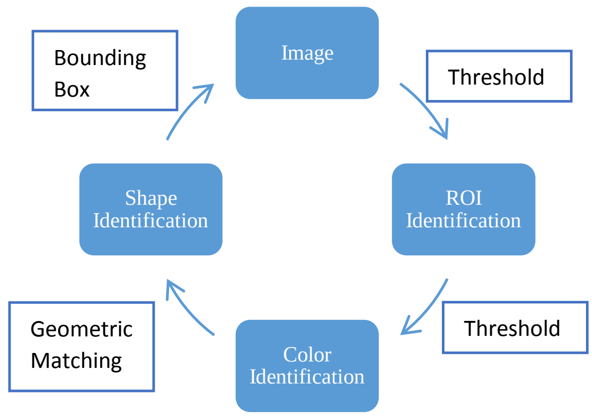

Figure 7: Vision Processing Algorithm

Floating Point creates a persistent map of its surroundings using the data points provided by the LiDAR. It is done by the Mapper module which creates an object for any obstacle it detects. The Path Planner module uses state information from the Mapper Module (global data), and the vehicle state (local data) to compute the shortest distance and time path to the required point while avoiding any obstacle.

The objective tracker keeps track of the tasks the ASV performs, and automatically triggers a transition of tasks based on the object it identifies. For example, after starting the speed gate, it searches for the finish gate, locates it, and after driving through it, triggers a transition to the next task.

Floating Point IV incorporates a sophisticated and efficient algorithm for image processing, which is used for both Docking and interoperability challenge.

Image acquisition is used to take the camera feed, then thresholding is applied to detect the white background to isolate the region of interest (ROI). This allows the subsequent processing to be faster since the image size and complexity has been significantly reduced. Further thresholding is applied (defined by the user, depending on the color assigned by the judges) to detect the correct colored shape.

Finally, Geometric Matching is performed on the isolated shapes to match the correct shape as assigned by the judges. A bounding box is then applied to the original image, and the ASV shoots a heading towards the centroid of the bounding box for docking. The process is tested to be accurate 90% of the time, and since the program repeatedly performs the same functions, an average is taken to finalize the location of the desired dock while eliminating incorrect detection.

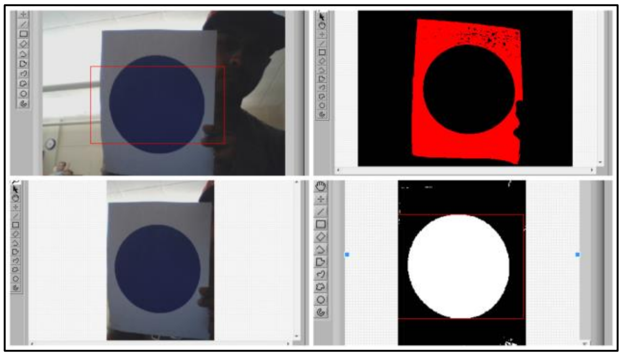

Figure 10: Recognizing a Blue Circle using Vision Processing

V. Autonomous Underwater Vehicle (AUV)

The AUV was designed with cost and functionality being the most important factors. It is equipped with four thrusters with two for going in the z-direction and two for going in the x-y direction. The thrusters consist of small brushless motors which are cheap and easy to replace. The propellers were then selected for the motors with the size and shaft diameter in consideration. To power the thrusters, a 3 cell lithium polymer was selected due to its high energy density and weight. The battery is also important for powering not only the thrusters, but also for every other component in the AUV such as the onboard computer and the electronic speed controllers.

The Raspberry Pi is used for controlling the PWM board which in turn controls the electronic speed controller. It also acts as an interface between the computers onboard the main vessel by sending a heartbeat and the pictures it has taken for the required tasks. The hull of the AUV is made from 0.25-inch-thick acrylic which will provide structural strength as well as waterproofing for the vehicle. The ASV has O-rings and silicon glue to waterproof the seals. The sensors onboard the AUV include a camera, a depth sensor and an inertial measurement unit.

Once the AUV is deployed, it descends to a suitable depth (around 1 meter) using feedback from Bar30 pressure sensors manufactured by Blue Robotics. Afterwards, it uses the raspberry Pi IR camera module to search for a light source (LED panels) to navigate towards it. Using vision processing on the AUV, it recognizes the LED panel and takes a photo of it. The photo is then transferred over Ethernet to the ASV for better recognition of the hexadecimal alphabets displayed on the LED panel.

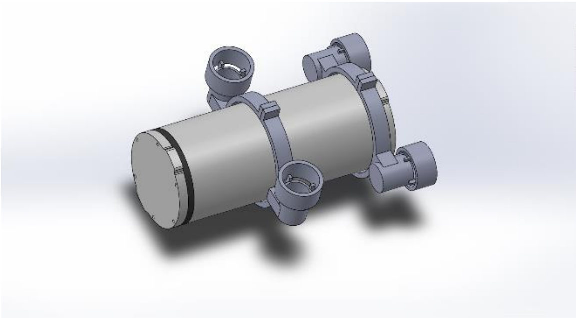

Figure 9: AUV CAD model

The AUV can successfully be deployed and retrieved from the ASV 95% of the time, which was shown during testing. In the case of a power failure, the AUV is made to be naturally buoyant so that it surfaces on the water. The AUV can reliably travel at depths of 2-3 meters, and take a photo of the digital screen for processing. The photo is taken using a raspberry pi camera module, which is then sent through the Ethernet cable to the ASV. The ASV then receives the photo and processes the image using the on board vision processing to determine the characters.

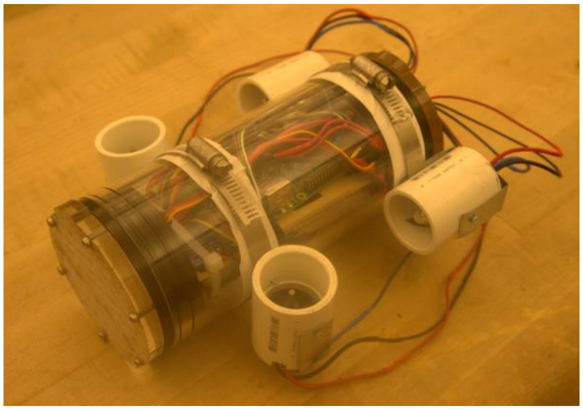

Figure 11: Final AUV

VI. Conclusion

Floating Point IV, presented by the Robotics Association at Embry- Riddle, has an improved hardware and software system to successfully complete the challenges of the 2016 RoboBoat competition. Through research and testing, the team has shown successful operation of the ASV and AUV, and all related sub-systems.

VII. References

[1] Final RoboBoat Tasks and Rules, AUVSI RoboBoat

[2] Blue Robotics, http://www.bluerobotics.com

[3] Velodyne, http://velodynelidar.com

[4] Hemisphere, https://hemispheregnss.com