# Yellowfinn II: Autonomous Underwater Vehicle

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***Abstract* - Embry-Riddle Aeronautical University (ERAU) is entering the Yellowfinn II Autonomous Underwater Vehicle (AUV) into the 2018 AUVSI Foundation Robosub Competition. The goal of this iteration was to refine on the design initially used in the prior competiton cycle. In this goal the major focus was on building robust capabilities at a sensor and software level to allow for easier adjustment to the changes the competition is going through. This aligns itself with the design philosphy: "autonomy happens", where the vehicle is designed with robust individual capabilities and the tasks for the competiton simply fall out as basic state machines that leverage these capabilities.**

## I. Competition Strategy

There were two governing factors that shaped the design process and decisions made are that of the changes to many of the competition tasks as well as the availability of team members to work on the project. The team was comprised of three members, all of whom graduated or were on internships over the summer and as such, were unable to continue the project. This resulted in the team presented here.

This iteration of Robosub had one of the most fundamental changes to the tasks required of the teams. As such, the team wanted to avoid a trap that many teams fall into, that being not realizing the resources required to complete all tasks and over committing themselves. The strategy selected on would be to focus on a few tasks and to be able to do the consistently. The tasks selected to focus on were primarily navigation and controls focused tasks, that being the gate, dice, and acoustic pinger. Given the team available, these tasks can be achieved by the refinement of a few systems, and did not mandate the integration of addition hardware such as a manipulator.

It must be acknowledged that this strategy will likely not result in the winning of the competition based on the vehicle capabilities demonstrated by other teams in past years, however winning is not the primary intention of this platform. The tasks selected and the approach to those tasks is designed to focus on areas of learning suited to the students as well as providing a place for the team to grow from moving forward.

## II. Design Creativity

The major focus of this year was on refining the software subsystem to create a more robust and capable processing system. This focus was achieved in two ways, in a rework of the vision subsystem and an integration of the imaging sonar into our sensing suite.

The vision rework was focused on two areas, improving the accuracy of the neural network model employed and the performance overall. To achieve this, the subsystem was reworked into an architecture where both Jetson's could communicate with both the forward and downward facing cameras. Based on the current task, processing power can be routed between the using both cameras or doubling the framerate of a single device. This allowed for a more computationally heavy, but accurate model to be employed as many of the tasks require only one of the two cameras. [1]

The other major sensing rework was the inclusion of the imaging sonar. This allowed two different capabilities of the vehicle to be improved through fusion with other sensors. The initial use case used the sonar was improving the distance estimations of camera classifications. This allowed for simple path planning to be used in our tasking, yielding more repeatable task operation. The next sonar fusion ties in with the localization system. This builds on an Extended Kalman Filter built last year to estimate the vehicles location. The sonar provides a measurement less susceptible to drift or error than the IMU or DVL.

The final area of design of note was the newly designed hydrophone array for 3-dimensional pinger localization. The team leveraged a knowledgebase built up from the Maritime RobotX Challenge. [2] The array utilized and underlying mathematics were derived and tested by the sub team however. Appendix A contains the derivations for the time difference of arrival localization algorithm used.

## III. Experimental Results

Initial testing of the camera system leveraged the database of images the team has been building up over the years as well as images provided by other teams of their construction of course elements. Testing of the vehicle using the vision system took place in the university pool. Even though some of the new course elements were not constructed by the team, system behaviors were tested using similar objects. For instance, the older style of buoy was arranged in a manner similar to the dice and the sub was tasked with hitting all of one color. This allowed for a better understanding of the system to be discovered as well as giving insight into the behaviors needed to be able to complete the tasks in San Diego.

Testing of the sonar integration was one of the least tested components of the system. This in part stemmed from the available testing facilities. The university pool is much smaller than the Transdec or open water, yielding an environment not indicative of the where the algorithm would be used. One major focus of this year will be building an aggressive log of all sensors synchronized together, allowing for algorithms to be validated during the academic year.

Acoustic navigation testing was designed to be done as a multi-step process. Initial testing involved a simulation of signal returns to prove the algorithm. Testing then focused on the array alone locating the sound source. At the time of writing, this process is ongoing and the integration of the array onto the vehicle is ongoing. Testing of that system will begin after integration is complete.

## Acknowledgements

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## References

[1] Goring, Robert, "Feasibility of Neural Networks for Maritime Visual Detection on a Mobile Platform" (2017). *Dissertations and Theses*. 331. https://commons.erau.edu/edt/331

[2] Cronin, Stephen, "Application of Neural Networks to Acoustic Localization" (2017). *Dissertations and Theses*. 324. https://commons.erau.edu/edt/324

## APPENDIX A: ACOUSTICS DERIVATIONS

Hydrophones at 4 locations:

$$h_0 = (0,0,0)$$

$$h_1 = (\alpha, \beta, \gamma)$$

$$h_2 = (\delta, \varepsilon, \zeta)$$

$$h_3 = (\eta, \theta, \iota)$$

Assuming the source is much farther that the hydrophone spacing, the overall distance to the hydrophones from the source at (x,y,z) is:

$$D = \sqrt{x^2 + y^2 + z^2}$$

Looking at the phase difference of arrival, we can compute the distance offset the signal hit the hydrophones 1, 2 and 3 from the reference, 0.

$$\Delta d_1 = \frac{(\Phi_0 - \Phi_1)}{2\pi}\lambda$$

$$\Delta d_2 = \frac{(\Phi_0 - \Phi_2)}{2\pi}\lambda$$

$$\Delta d_3 = \frac{(\Phi_0 - \Phi_3)}{2\pi}\lambda$$

These deltas can also be represented as the difference of the vector from the reference distance D and the actual distance to hydrophones 1, 2 and 3.

$$\Delta d_1 = D - d_1 = \sqrt{x^2 + y^2 + z^2} - \sqrt{(x-\alpha)^2 + (y-\beta)^2 + (z-\gamma)^2}$$

$$\Delta d_2 = D - d_2 = \sqrt{x^2 + y^2 + z^2} - \sqrt{(x-\delta)^2 + (y-\varepsilon)^2 + (z-\zeta)^2}$$

$$\Delta d_3 = D - d_3 = \sqrt{x^2 + y^2 + z^2} - \sqrt{(x-\eta)^2 + (y-\theta)^2 + (z-\iota)^2}$$

Squaring D and $d_n$:

$$D^2 - {d_1}^2 = x^2 + y^2 + z^2 - (x-\alpha)^2 + (y-\beta)^2 + (z-\gamma)^2$$

$$D^2 - {d_1}^2 = x^2 + y^2 + z^2 - [x^2 - 2x\alpha + \alpha^2 + y^2 - 2y\beta + \beta^2 + z^2 - 2z\gamma + \gamma^2]$$

$$D^2 - {d_1}^2 = 2x\alpha - \alpha^2 + 2y\beta - \beta^2 + 2z\gamma - \gamma^2$$

$$(D - d_1)(D + d_1) = 2x\alpha - \alpha^2 + 2y\beta - \beta^2 + 2z\gamma - \gamma^2$$

$$D - d_1 = \frac{2x\alpha - \alpha^2 + 2y\beta - \beta^2 + 2z\gamma - \gamma^2}{D + d_1}$$

Substituting in $\Delta d_1 = D - d_1$:

$$\Delta d_1 = \frac{2x\alpha - \alpha^2 + 2y\beta - \beta^2 + 2z\gamma - \gamma^2}{D + d_1}$$

Converting the denominator:

$$\Delta d_1 = \frac{2x\alpha - \alpha^2 + 2y\beta - \beta^2 + 2z\gamma - \gamma^2}{2D - \Delta d_1}$$

Rearranging:

$$2D\Delta d_1 - \Delta {d_1}^2 = 2x\alpha - \alpha^2 + 2y\beta - \beta^2 + 2z\gamma - \gamma^2$$

$$2\sqrt{x^2 + y^2 + z^2}\Delta d_1 - \Delta {d_1}^2 = 2x\alpha - \alpha^2 + 2y\beta - \beta^2 + 2z\gamma - \gamma^2$$

$$\alpha^2 + \beta^2 + \gamma^2 - \Delta {d_1}^2 = 2x\alpha + 2y\beta + 2z\gamma - 2\sqrt{x^2 + y^2 + z^2}\Delta d_1$$

Solving for the other two hydrophones:

$$\delta^2 + \varepsilon^2 + \zeta^2 - \Delta {d_2}^2 = 2x\delta + 2y\varepsilon + 2z\,\zeta - 2\sqrt{x^2 + y^2 + z^2}\Delta d_2$$

$$\eta^2 + \theta^2 + \iota^2 - \Delta {d_3}^2 = 2x\eta + 2y\theta + 2z\,\iota - 2\sqrt{x^2 + y^2 + z^2}\Delta d_3$$

At this point, we have 3 equations and 3 unknowns, (x,y,z). A numerical approximation technique can be used to solve for these three.

## APPENDIX B: COMPONENT SPECIFICATIONS

| Component | Vendor | Model/Type | Specs | Cost |
|---|---|---|---|---|
| Buoyancy Control | Bluerobotics | Subsea Foam | | ~ $300 |
| Frame | Custom | | | |
| Waterproof Housing | Custom | | | |
| Waterproof Connectors | Blue Robotics | Pass Through | | |
| Thrusters | Blue Robotics | T200 | | $169 each |
| Compass/IMU | VectorNav Technologies | VN-100 | | $1200 (Donated) |
| DVL | Nortek | DVL 1000 | | $18000 (on loan from research lab) |
| Cameras | Point Grey | Blackfly GigE | | $250 each |
| Hydrophones | Teledyne Reson | TC4013 | | $1200 each |
| Sonar | Teledyne | Blueview 900 | | $65000 (on loan from research lab) |
| Team Size | 3 Members Semester | | | |
| HW/SW | 35/65 | | | |
| Testing in Water | 20 Hrs. | | | |

## Appendix C: Outreach Activities

This year, Team Yellowfinn, working through RAER, was involved in a number of large scale outreach activities both on and off campus. At Embry-Riddle, the team hosted several outreach events. In the summer of 2017, ERAU and RAER hosted a robotics summer camp for high school students. Here, 24 students spent a week learning how to build and then program their robots to perform a variety of autonomous tasks ranging from dead reckoning through courses to using computer vision to line follow and acquire specifically colored balls.

At the end of the Fall 2017semester, the team hosted nearly 50 fourth to eighth grade students from Old Kings Elementary School and Milwee Middle School as they learned skills that could be used in their own seaperch platforms. At this event, the students learned about buoyancy and soldering through activities that taught them how to apply these skills.

Another local outreach opportunity that some members of the team took advantage of was mentoring for a local FIRST Robotics Competition (FRC) team, team 2152 SMASH. This team consists of more than 50 students from Spruce Creek High School and University High School. As mentors, the two students were responsible for mentoring the of the mechanical and electrical subsystems. They also taught the students about the engineering and design processes.

The team's outreach efforts also took them out as far as St. Petersburg, FL for one of our largest events of the year. At John Hopkins Middle School, the team ran a two-day long event that the middle school teachers called "STEM Day". During these two days, the team interacted with over 175 sixth and seventh graders as they guided the students through various interactive learning activities such as boat building, resource collection, 3-D printing, and glider building. These activities taught the students valuable lessons in buoyancy, remote operations, additive manufacturing, and aerodynamics.

Through these several varied outreach activities, the team feels that it has meaningfully impacted students of all ages, engaging and encouraging them to participate and pursue education in STEM field.