V-BASS – 3rd Generation

Vision-Based Autonomous Surface Ship at Florida Atlantic University

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Abstract:

Florida Atlantic University's Third Generation Vision-Based Autonomous Surface Ship (V-BASS) has been successfully optimized to compete in this year's 7th Annual International RoboBoat Competition. While keeping with the previous generation's modular design for efficiency and reliability, this generation of V-BASS boasts a reengineered electrical system, modified superstructure and new integrated sensors. Layered software architecture for platform control, a high-level state scheduler for mission management, adaptive control capabilities using computer vision and a unique interactive simulator to assist with mission planning all contribute to making V-BASS the optimal vehicle for the challenges in this year's competition.

Figure 1: the acclaimed V-BASS platform

I. Introduction

Advances with Autonomous Surface Vehicles (ASV) are highly regarded and sought after in research and industry. The effective processing and execution of tasks by a vehicle in unpredictable environments is a pressing topic of interest; it inspires professionals and comprises the motivation for groups of dedicated students to compete in such an event as the 7th Annual International RoboBoat Competition.

By presenting teams with a distinct set of mission requirements and a strict time limit, the International RoboBoat Competition promotes a real-world setting that challenges the rapid development of a robust and advanced ASV platform. Objectives for the competition include the ability to demonstrate the vehicle's propulsion strength and speed, its agility to navigate a buoy field, locate and engage objects of interest, and identify and locate objects, sounds and light signals both above and below the surface upon which the vehicle navigates.

Waypoint navigation alone will not compensate for a constantly changing environment, which makes V-BASS's vision-based navigation system ideal for an ASV platform.

FAU's Third generation V-BASS (Vision-Based Autonomous Surface Ship) is an ASV with the ability to autonomously adapt to a variety of obstacles. It is the result of a collaboration of a multi-disciplinary group of dedicated engineering students from the Ocean and Mechanical, Electrical, Computer Engineering and Computer Science departments and the wealth of experience at FAU for developing systems for the maritime industry.

II. Design Overview

The V-BASS platform is a catamaran by design with two outboard brushed DC motors for propulsion. Maneuvering employs differential thrust, while electrical power is provided by lithium polymer (Li-Po) batteries. The platform employs various sensors and auxiliary systems to include a LIDAR, two Logitech webcams (one facing forward and one downward) and a unique hydrophone array.

III. Hulls and Superstructure

With a dual hull configuration and wide beam to ensure transverse stability while completing mission tasks, the catamaran platform is ideal for the third generation V-BASS. Repurposed hulls from the second generation of V-BASS were revitalized with structural maintenance, a new paint job and modified superstructure, making this platform both reliable and cost effective.

The superstructure consists of 1 inch square beams that are mounted to the deck via four (4) metal brackets. The electronics box rests on the superstructure and is supported by four aluminum corner brackets.

IV. Propulsion System

V-BASS's propulsion system consists of two (2) Seabotix outboard thrusters that are mounted to the hulls with specialized motor mounts that were designed and fabricated in-house. With a maximum rpm of 6000, the thrusters supply robustness, power and reliability to the platform while maximum maneuverability is achieved through differential thrust.

Differential thrust is achieved by differing the amount or direction of thrust produced by each motor. The motors are controlled with Roboteq SDC1130 motor controllers, and are connected to the propeller shafts via custom couplings.

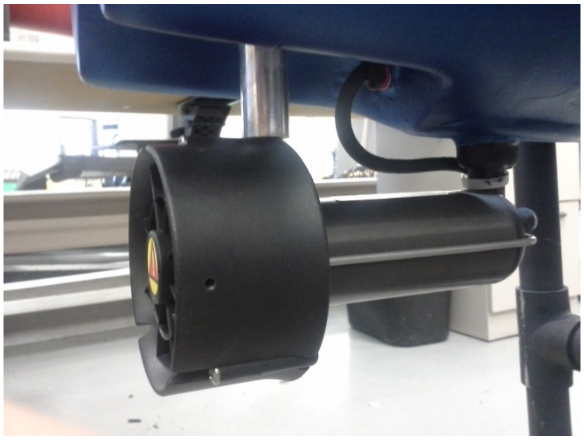


Figure 2: Seabotix outboard thruster

V. Electronic System

The electronic system's core for V-BASS boasts a TS-7800 single-board computer with ARM9 architecture that is connected to a motherboard (fabricated in-house) and a BeagleBone microcontroller for high-level commands.

Essentially a breakout board, the motherboard allows the subsystem access to the necessary ports on the TS-7800 SBC. On-card devices on the motherboard include: an R/C Master/Slave Control Switch (toggles autonomous mode into manual mode), the Pololu Maestro Mini (generates PWM signals), power monitoring and regulating systems (including three analog buffers), a connector for the digital compass, on-board status LED's, two (2) water leak detection sensors, an H-bridge motor controller, and house-keeping inputs for R/C and RF activity. Motivation for implementing the BeagleBone for this generation of V-BASS involved its being more cost effective than a TS-7800 while performing with the same Linux system.

Other modifications to V-BASS include a battery charger, which provides the option to charge the batteries without removing them from the vehicle, and an added adapter (from a 10 pin to a 16 pin) that allows the motor controller configuration and the batteries to communicate to the electrical box.

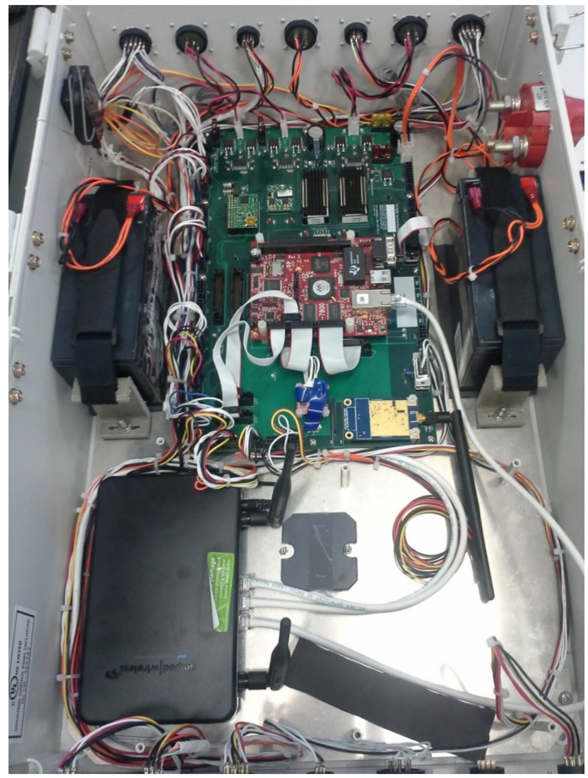


Figure 3: inside V-BASS's electrical box

VI. Hydrophone Array

The hydrophone array was designed in-house. The system is mounted underneath the vehicle's electrical box with the hydrophones positioned along the inner hulls of the vehicle.

VII. Layered Software Architecture

The V-BASS system implements "layered control" architecture to simplify its design complexity by providing a modular control of each subsystem. It uses a Lightweight Communication and Marshaling (LCM) interface with UDP protocol, which reduces latency as commands are processed. This configuration allows multiple processes to run simultaneously and at different rates as necessary.

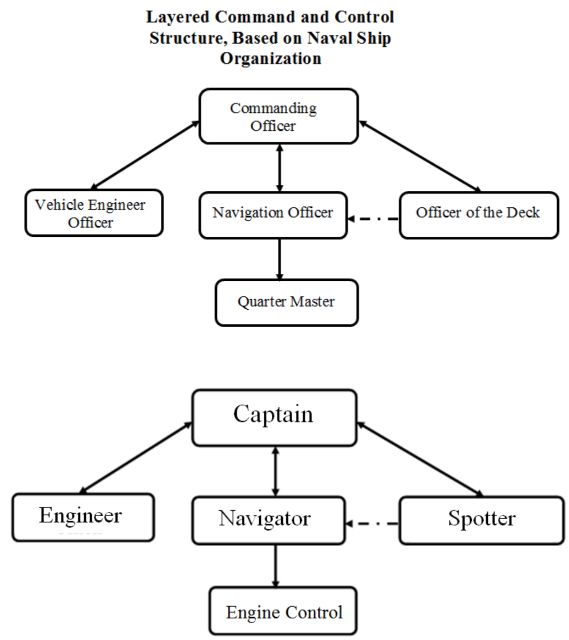
At its core is the TS-7800 single board computer with ARM9 architecture, made by Technologic Systems. It uses a Linux Kernel 2.6 with a full DEBIAN distribution operating system. To process all high-level commands, V-BASS is also equipped with a BeagleBone processor, which functions conjointly with the TS-7800 to execute mission tasks.

Navigation, data filtering and logging, house-keeping functions and communication are all controlled by middle-layer programs and generated by high-level commands. The middle-layer programs double as control-ware, which collaborate with device drivers to control motors and sensors on the platform.

A high-level mission scheduler prioritizes each mission task by dividing each mission into a set of objectives, each of which involve the completion of a number of tasks. To manage these processes, several programs must run independently and are linked together using the Lightweight Communication Software (LCM). A watchdog timer on the motherboard monitors the time spent on each task to assist the platform with completing all missions in the allotted time frame.

VIII. Mission Command Structure

V-BASS's command and control structure is derived from the distribution of responsibilities on a naval vessel. A separate nomenclature was adopted to identify each responsibility within the system.



Captain

The Captain is responsible for the mission and system management. It intercepts data from the Spotter and refers to the state of the vehicle before making "decisions" to proceed with each task.

Spotter

The Spotter receives data from the vision systems (and OpenCV), hydrophones and other external components at a particular rate. This information is relayed to the "Captain" for the decision-making process.

Navigator

This component is responsible for all GPS and Navigation data and waypoints, which are used by the Captain along with data from the Spotter. When a desired heading and transit speed is determined, the navigator translates all waypoints to geographical waypoints which use a North East Down reference frame.

Engineer

Responsible for all low level processes relating to the vessel, the engineer monitors the vehicle's status. If a failure were to occur on the vehicle, the engineer will determine whether or not it can be fixed and relays this knowledge to the captain to infer how to proceed.

IX. Vision System

The vehicle's vision system is comprised of two Logitech webcams: one of which is mounted on the superstructure facing forward, while the other faces downward and is positioned below the vehicle's waterline, and a LIDAR system.

Two Plexiglass panels supported by angled aluminum constitute a splashguard for the forward facing webcam. The downward facing webcam is mounted by one of the hulls via the superstructure and housed in a waterproof casing. The casing consists of milled Plexiglass that is sealed with an O-ring and an aluminum plate. Both the splashguard and the waterproof casing were fabricated in-house.

One major revision to the second generation's vision system involves a state-of-the-art LIDAR system. Using a single forward facing camera for the vision poses major limitations to the platform, since it impedes the system's ability to easily determine distance to an object. Integrating the LIDAR system involves calibrating it with the camera's frame of view to accurately determine distance. Once implemented, the LIDAR will eliminate the need for a camera-based distance algorithm that utilizes the number of pixels on a screen, thus relieving much of this challenge.

The vision system also employs an Open Computer Vision (OpenCV) library to apply multi or single-channel filters to better find contours (outlines) or edgemaps of a desired object. The use of OpenCV optimizes the xy positions for the centers of each buoy during missions.

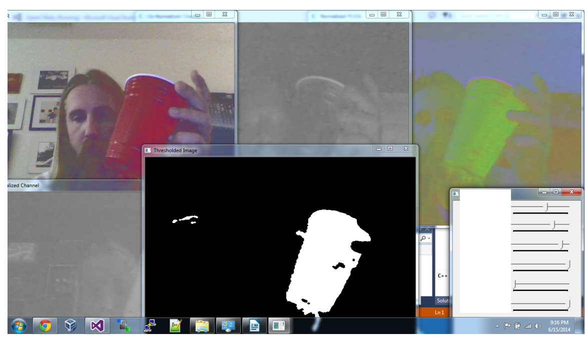


Figure 4: using OpenCV to manipulate color spaces

X. Navigation System

The platform's state machine controls the vehicle's navigation for each mission. Each objective presents unique navigation directives, which can be satisfied by GPS waypoint and compass heading control or (most commonly) the vehicle's vision system. Expected feedback for the navigation system includes buoy color inputs from the vision system, speed over ground from the GPS and the vehicle's orientation (yaw).

Waypoint Navigation

Using the provided GPS coordinates for each mission location, a lookup table was programmed into a high-level mission configuration file to be accessed by the Navigator component of V-BASS's system architecture. The vehicle's destination and source of navigation is computed by the Navigator while real-time processed vision information is provided by the Spotter in the case of a required obstacle avoidance maneuver.

Vision Navigation

For vision navigation, the vision system (two Logitech webcams) acts as a sensor whose data is interpreted by the Spotter function. The Spotter will provide a desired heading for the vehicle according to its current and upcoming tasks, which are delegated by an independently running control loop. The Spotter's output is published to a specified channel on LCM. This output is received by the Captain function, who calls the Navigator function to filter and convert the desired heading into an actual bearing.

XI. Control System

Through the use of differential thrust, a moment about the vehicle causes it to turn while steering. This quality of differential steering allows the vehicle to possess a smaller turning radius and the ability to steer without a forward speed.

VBASS utilizes heading and speed controllers to maintain a desired heading and vehicle position. The controllers must be tuned as a couple to compensate for the coupling effect of differential steering.

Two separate proportional control laws allow the motor heading controllers to govern the vehicle's direction. With a yaw of North-East-Down convention, the port controller would exhibit a positive slope while the starboard controller has a negative slope [1].

The boat's forward speed is expressed as a percentage of maximum motor power. This percentage is used to set a bias value (to bias the proportional control law) to a desired steady-state speed for the vehicle. A speed controller shifts this bias value as it assists the vehicle in reaching a desired steady-state speed.

XII. OpenGL Simulation

When code is modified for V-BASS, we require an alternative way to test it with the platform that allows for frequent and easy development. OpenGL is an open-source graphics language which allows us to display both common sensor values for the platform (to include the boat's position, compass reading, speed, objects in view, etc.), and a 3D visualization of the course.

The framework for the simulation is a strong Model-View-Controller, where "Model" is the physical course, "View" is OpenGL's 3D representation of the Model, and "Controller" implements inputs from the keyboard and handles file input, output and basic messaging. LCM allows OpenGL simulation to become integrated with the vehicle's high-level code.

For this year's competition, OpenGL allowed us to implement a new command structure for buoy field navigation. Using simulation, we were able to develop V-BASS's behavior before integrating it with the motors, computer vision and other sensors.

XIII. Mission Tasks

Mission management for each task is accomplished with high-level command and communicated through the LCM.

V-BASS's watchdog timer monitors the allotted time for the vehicle to complete each objective, which consists of a series of tasks. For this year's competition the vehicles are allotted twenty minutes to complete a total of four mission tasks, excluding the "Speed Gate".

Speed Gate

The objective of this mission is to navigate through a starting gate and speed through a successive "Speed Gate" in as little time as possible. This is accomplished via dead-reckoning since vision navigation would likely hinder the vehicle's ability for speed by attempting to perfect the vehicle's desired heading. V-BASS's hydrodynamic hulls provide directional stability that is optimized as the vehicle's speed increases, thus reducing the need of a vision system to stay on track.

1. Buoy Channel/Obstacle Avoidance

Whereas last year's challenge presented a channel of buoys for the obstacle avoidance mission, this year's mission introduces a buoy field. This mission involves successfully navigating through the field without hitting any "obstacles", meanwhile entering and exiting through the correct gates.

To dominate this task, V-BASS will communicate with the "Spotter" to determine a perpendicular line to the plane of the entrance gate. The vehicle will exit through the center of the entrance gate, collect a specific heading and continue in the direction of that heading until an object is recognized as an obstruction. This is determined based on the bisecting angle for the field of view of the forward camera. In the instance of an obstacle, the vehicle will evade by moving a computed distance to the left or right of the object, and will attempt to regain its preferred heading after the detour. This obstacle avoidance process continues until it crosses a GPS threshold, at which point V-BASS will stop and scan for the exit gate. Once the exit gate is identified, the vehicle will head towards the exit gate while commencing with obstacle avoidance.

2. Automated Docking

Given the GPS coordinates for the dock, the goal of this challenge is for V-BASS to dock in the correct space (with the corresponding symbol for its run).

The goal of this mission is for V-BASS to dock at a floating dock in a spot corresponding to the correct symbol for its run.

This is accomplished through the vehicle's vision navigation system, which will identify the correct symbol and determine a bearing for the vehicle to travel. When the dock is at a specific range within the camera vision, the vehicle will identify the bottom of the dock and determine its distance via a distance finding algorithm. Upon determining its distance to the dock, V-BASS will execute a short burst forward until a button on the bow is pressed, indicative of having reached the dock. At this point the vehicle will reverse, stop, and navigate towards the coordinates for its next challenge.

3. Acoustic Beacon Positioning

Given the GPS coordinates of a field of buoys, V-BASS must identify the buoy with an active pinger and relay its position and color. To complete this mission, the vehicle will utilize its vision navigation system and hydrophone array. The vehicle will first navigate to the location and heading of the buoy field with all buoys in their unique positions, then use its hydrophone array to determine the heading of the pinger's sound and travel towards it. The vehicle will stop next to the buoy, identify and relay its color and position and then proceed to pick a new desired heading towards the next mission.

4. Underwater Light Identification

For this mission task, V-BASS must activate and report a sequence of lights that are submerged at a given location. The vehicle will initialize the mission by traveling to the desired location and using the downward facing camera to locate a solid white light. It will hover over the light and send a message of its location, then read the light pattern using its vision system. The light sequence will be communicated and the boat will complete the mission by returning to the dock.

XIV. Conclusion

This year's goal has been to improve the V-BASS 2nd Generation platform while maintaining its reliable and effective modular design. To achieve this goal, the team has donated many hours to V-BASS to make this platform our most reliable and high performance vehicle to date.

XV. Acknowledgments

Advances for this year's platform would not have been achieved without the dedication and practice by individuals from a plethora of engineering disciplines and interests.

Contributions by past members of the V-BASS team were vital to this year's developments: Mario Miranda and Ivan Bertaska.

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Special thanks to Dr. Karl Von Ellenrieder for presenting our team with the Roboboat challenge.

XVI. References

[1] Bertaska, I. et al., 2013. "Experimental Evaluation of Approach Behavior for Autonomous Surface Vehicles". In Proc. *ASME Dynamic Systems and Control Conference, 2013.*