BOATNAME THE BRAVE

The Robotics Club at UCF

AUVSI and ONR's 4th International RoboBoat Competition

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Ross Kerley, Michael Podel, Kiran Bernard,
Travis Goldberg, Matthew Wimsatt, Paul Akin, Christopher Bunty
Brian Valentino, Matthew Znoj, Michael Scherer

Faculty Advisor: Daniel Barber

http://www.robotics.ucf.edu/surface

Abstract

Boatname the Brave, an autonomous surface vehicle (ASV), was developed by the robotics club at the University of Central Florida (UCF) for competition in AUVSI and ONR's 4th International Autonomous Surface Vehicle Competition. Using the knowledge and experience acquired in the previous three years, the Robotics Club has reengineered our ASV as a stronger, smarter, and more innovative vehicle. The mechanical, electrical, and software teams have overhauled last year's vehicle with improvements and advancements all around. With its propulsion system, water cannon, more accurate Global Positioning System (GPS), light detection and ranging (LIDAR) system, compass, dual cameras, and retuned software, Boatname the Brave has the advanced capability to excel and complete the missions set forth by this year's competition.

1. Introduction

The ASV Team of the Robotics Club at the University of Central Florida is proud to introduce the revamped Boatname the Brave. The vehicle has been developed for the 4th International RoboBoat Competition. This vehicle is the culmination of four consecutive years of research, testing and experience with autonomous surface vehicles.

Boatname the Brave was originally created for the 3rd International RoboBoat Competition in 2010, but numerous advancements have been incorporated for the 2011 competition. These advancements are distributed amongst mechanical, electrical, and software subsystems. Mechanical advancements include increased thrust and a rotatable center thruster for either lateral thrust or additional forward thrust. Electrical advancements include a compact system integration circuit board and a faster computer. Software advancements focused on sensor fusion between the LIDAR and computer vision.

2. Design Process

Many design elements were carried over from the 2010 competition on Boatname the Brave, but some areas required improvement. Changes to the platform followed the steps displayed in Figure 1. This process proved to produce effective modifications to the existing platform.

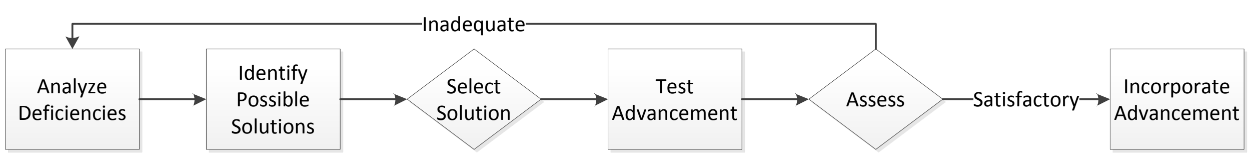

Figure 1: Design Process Flowchart

The 2011 RoboBoat rules were analyzed to identify critical requirements of the ASV. The requirements are a mix of qualitative and quantitative terms that an ASV must meet in order to complete the 2011 competition.

1. Travel through buoy pairs that are up to 100’ apart
2. Navigate a channel marked by 9-12” diameter red and green buoys
3. Collect a tennis ball from a landing zone up to 15” above the waterline
4. Shoot water at a picture of a burning ship, stopping when a red flag is rotated
5. Identify the picture and position of the hottest target amidst a group of four unique targets
6. Press a button behind a waterfall
7. Return to the starting position
8. Weigh less than 110lb to incur bonus points
9. Support a 3lb payload up to 7”x5”x4”

These requirements were analyzed to assess the need for ASV modifications. Some required additional hardware, and many required software modifications or additions. Requirements 1, 2, and 7 are satisfied by having a mobile ASV capable of heading control, buoy identification, and obstacle avoidance. Requirement 3 is satisfied by the addition of a mechanical system, explained in Section 3.5. Requirement 4 is satisfied by including a computer controlled water cannon that uses input from a camera to identify the target. Hot target identification, requirement 5, needs a non-contact thermal sensor, discussed in Section 4.4.5. Requirements 6, 8, and 9 are met by Boatname the Brave’s mechanical design.

2.1. Team Structure

The Robotics Club at UCF has structured the ASV team into three basic groups that operate cooperatively under one organizer, or team captain. The team captain’s role is to direct the leads and facilitate communication between team members. This structure is shown in Figure 2, below. ASV development required cooperation between the captain and leads to produce an effective vehicle based on combined knowledge and experience.

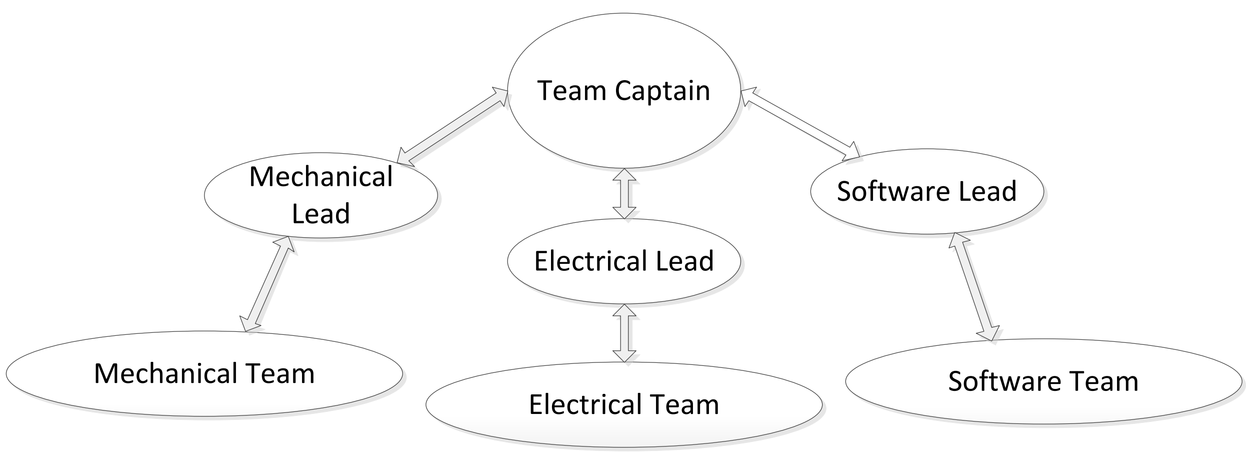

Figure 2: Team Structure

3. Mechanical Design

This year’s design incorporated new ideas into the 2010 platform to address deficiencies and the new challenges. Inadequate reliability, thrust, maneuverability and speed were a large concern after the 2010 competition. As a result, the propulsion system required significant upgrades this year.

3.1. Hulls and Frame

Boatname the Brave’s buoyancy comes from the two hulls that were created in-house. The height, 8 inches, and width, 6.5 inches, of the hulls were carefully designed to ensure that the frame would be 3” above the water when Boatname the Brave is fully outfitted. This height provides a cushion of space between electrical components to ensure that they are a safe distance from the water while allowing the LIDAR to be in the same plane as the channel buoys.

The frame is constructed of welded 1" square aluminum tubing. Aluminum was chosen for its light weight and non-magnetic properties. The square tubing allows sensors and other components such as the LIDAR, motor controller box, emergency stop switches and the retrieval arm to be easily mounted. A tower extends above the top-frame to support the camera, compass, GPS antenna and water cannon. An aluminum bumper on the bow protects the vehicle from obstacles and the shore. There are also eye bolts which are used to facilitate the thrust and weight test.

3.2. Propulsion

Boatname the Brave utilizes three CrustCrawler 400HFS brushless thrusters. One thruster is mounted to the inside of each pontoon. Mounting on the inside of the pontoons will reduce the ASV’s turning ability, but will greatly improve the reliability and protection of the thrusters. The third thruster is on a rotatable mount. This mount can alter the orientation of the thruster, either allowing the thruster to provide forward or lateral thrust. Lateral thrust increases the maneuverability of the boat and is useful when the ASV is lining up to complete a challenge. Each motor is capable of providing up to 15lb thrust. Therefore, all three motors can be used in forward orientation to provide up to 45lb thrust in the thrust test challenge.

3.3. Water Cannon

A water sprayer is required to extinguish the burning ship. This sprayer consists of an automobile windshield-wiper pump, flexible tubing, and an aluminum nozzle. The nozzle is mounted to a tilting servo and is capable of being controlled by the vehicle’s vision system. A firewire webcam is mounted with the nozzle so that Boatname the Brave knows exactly where the nozzle is aimed.

3.4. Waterproof Case

The waterproof electronics case is a modified Seahorse Hurricane SE-720 which rests horizontally between the two pontoons in the stern of the boat. It protects all of the electrical components including the computer, FPGA, custom PCB, motor controller, GPS, wireless bridge, and batteries from the elements. Splash proof connectors allow modular connection and removal of the peripherals. The FPGA, custom PCB, GPS, and a motor controller are mounted to an acrylic sheet in the lid of the case. A DC blower capable of 23 CFM actively cools the electronics.

3.5. Retrieval Arm

The Earth Treasure retrieval system incorporates a fiberglass pole, hook and loop fasteners, and a serial servo. The pole is oriented along the pontoons until the Earth Treasure platform is reached.

The arm is then computer controlled to sweep over the platform, snagging the ball with hook and loop fastener strips.

4. Electrical Design

The electrical systems have been redesigned for the 2011 ASV. They were redesigned to be more efficient, accurate, and easier to maintain. This system includes power management, an FPGA, computer, sensor integration, and a remote monitoring system.

4.1. Power Management

Power management was significantly upgraded this year to make use of a variety of power sources. Battery power comes from two isolated battery banks, one for motors and actuators and the other for logic, computing, and sensors. This arrangement minimizes electrical noise experienced by the sensors, and allows the ASV to continue computing if the motors deplete their battery bank prematurely. Both of these electrical power systems can accommodate 14-30V power sources. This allows a variety of batteries and power supplies to be used when testing and competing. A sophisticated shore power system has been incorporated to power the ASV whenever the power grid is accessible. This has been accomplished by installing an AC/DC converter inside the main electronics box. The broad input voltage range dictates that the voltage be regulated for different loads. High frequency switching power regulators have been selected and designed for broad input voltages and high efficiency.

4.2. Computer

Boatname the Brave is equipped with a new computer to allow faster processing of sensor data. It includes an industrial motherboard with a mobile i7 processor, 8GB RAM, 60GB SSD and a DC input power supply. This computer was selected for its high processing capability and low power consumption. A 5.0GHz 802.11n connection links Boatname the Brave to a development terminal during testing to monitor progress through the challenges and rapidly develop software.

4.3. FPGA

An FPGA was chosen for its utility and near limitless configurations. The FPGA links the computer to the main PCB using serial communication to the computer. The computer communicates with the FPGA to relay motor controller commands and to provide basic IO to the computer. The FPGA also receives incoming PWM signals from the R/C receiver and passes them through to the motor controllers when in R/C mode. The use of the FPGA allows incoming and outgoing signals to be rerouted in software without hardware changes as well as multiplexing the signals to allow control from either the computer or R/C. The FPGA also communicates with the battery monitoring system, discussed in Section 4.6, to provide the computer with that information. Since the thrusters are very powerful, the FPGA is utilized to hard-limit the thrust to protect the motors, batteries, and on-board sensors.

4.4. Sensors

To meet the requirements set forth in the 2011 RoboBoat rules, Boatname the Brave uses six different types of sensors. These sensors include a NovAtel OEM4-G2 GPS receiver, a

Microstrain 3DM-GX1 orientation sensor, a Unibrain Fire-I firewire camera, a Panasonic MiniDV camcorder, a Hokuyo UTM-30LX Laser rangefinder, and a long-range pyrometer.

4.4.1. Global Positioning System (GPS)

The NovAtel OEM4-G2 is a small and light-weight solution perfect for Boatname the Brave. The receiver is mounted in the electronics box with an external antenna located at the highest point of the vehicle. The GPS has a position accuracy of 1.2 meters and velocity accuracy of 0.03 meters per second. This GPS accepts a wide variety of voltages as well as provides an update rate of 20 Hz. Using this GPS receiver, Boatname the Brave has the ability to know its current position and velocity, assisting in navigation and path planning.

4.4.2. Compass

The Microstrain 3DM-GX1 Orientation Sensor has a 100Hz update rate combined with an accuracy of 0.20 degrees. It is easily mountable and requires only 50 milliamps from an 8V source. The sensor measures roll, pitch, and yaw accurately with 12 bit resolution, allowing Boatname the Brave to maintain a controlled heading.

4.4.3. Panasonic Camcorder

A Panasonic MiniDV camcorder serves as the main navigational camera. The computer processes the images from this device to make decisions about objects. For example, during the navigational challenge when the computer recognizes a red and green buoy, it will determine the best path to take between the buoys using the advanced vision system.

4.4.4. LIDAR

One of the most important sensors on Boatname the Brave is the Hokuyo LIDAR system. This compact and lightweight sensor boats 270 degrees scanning along with a 60Hz update rate that enables the computer to determine accurate distances of objects and obstacles. The position of this sensor has been adjusted due to difficulties in 2010. This year the Hokuyo is mounted inverted so that the sensor is on the bottom. This allows the sensor to be located closer to the water level to more reliably see objects low in the water, such as the navigation buoys.

4.4.5. Pyrometer

A serial interfaced pyrometer is used to measure the temperature of the four suspended targets. This sensor measures infrared emissions and returns a temperature value to the computer.

4.5. Remote Control

The FUTABA FASST 7C seven channel R/C Transmitter and Receiver is used to control Boatname the Brave in non-autonomous mode. This utilizes FASST, Futaba's Advanced Spread Spectrum Technology, to help with extended range and provide a high resistance to interference. The Remote control includes switches to select autonomous or remote control, and to activate the remote emergency stop system. This system allows manual control of the water cannon and different levels of hard-limiting to the thrusters. The use of this R/C controller along with the FPGA allows manipulation and rerouting of R/C signals as needed.

4.6. Monitoring System

An innovated monitoring system was developed and integrated into the electrical system to allow power monitoring of the ASV. The main PCB has an ATmega328P microcontroller which is used to collect, store, and transmit sensor data. These sensors include voltage, current, temperature inside the electronics case, temperature inside the motor controller box, and humidity. This data is displayed on the outside of the main box as well as transmitted over an XBee network to a remote display. The remote display also has the capability of stopping the ASV in case of an emergency. The main goal of this system is to allow for more testing of software without the worry of electrical or environmental concerns. In the past the electrical team has had to constantly measure batteries manually while on the water which became dangerous and wasted valuable time. Now it is simple to monitor the vitals and not worry about low batteries or dangerous environmental condition. This year the motor controllers are water cooled via another windshield wiper pump pushing water through the system. If the pump were to fail the remote monitor would recognize the issue and testing can be stopped until the issue is fixed.

5. Software System

Over time, an enormous base of software for all robotic vehicles made at the Robotics Club at UCF has been built-up within a completely open-source online repository called Zebulon. This repository contains code for everything from visualizations, sensor input, and embedded system interoperability. It has been extended with new code to implement a new architecture on Boatname the Brave that takes full advantage of SAE-JAUS in a manner which is clean and consistent with the standard. All code is commented using Doxygen formatting guidelines for automatic generation of code documentation, making the software clear and understandable for the development team and 3rd party developers.

5.1. Structure

Joint Architecture for Unmanned Systems (JAUS) compliance is a requirement for Boatname the Brave to support the JAUS Challenge and customer demands for open-standards. Pronounced "jaws", and maintained by the Society of Automotive Engineers (SAE), SAE-JAUS is a service-based architecture, defining re-usable capabilities broken down to the lowest level possible. This architecture heavily influenced Boatname the Brave's software design and implementation because of its well defined interfaces, facilitating independent development of system modules. Use of SAE-JAUS builds upon previous team experience and lessons learned for organizing software, and improved past solutions.

Boatname the Brave's software system is composed of two main programs, "Baseline" and "Surface." The Baseline program integrates all hardware and sensors, abstracting them via JAUS services. This program is standalone, and allows for any JAUS compliant program to subscribe to data streams or request control, which is how the Surface program performs autonomous navigation. This Surface program contains all of Boatname the Brave's intelligence, including vision processing, mapping and obstacle avoidance. These two programs work together in a master/slave relationship. Surface analyzes data from Baseline, makes decisions, and produces commands that are sent back to appropriate Baseline services to execute.

The programs use the open source JAUS++ library available on sourceforge.net for SAE-JAUS compliance. JAUS++ was selected for this project because of its strong documentation, support, friendly license, and proven compliance with SAE-JAUS at other AUVSI sponsored JAUS Challenges.

5.2. Mission System

Surface contains the artificial intelligence of the vehicle that is provided by a hierarchical state machine model which includes a major state for each mission of the competition and minor states for the execution of the mission. By using this model and C++ inheritance, each mission is self-contained and easily adjustable in the field. The state machine is created by instantiating the StateMachine class and works directly with instances GlobalInfo and GlobalCommand classes to get sensor data and to send action commands, respectively.

GlobalInfo receives sensor information through JAUS messages (sent from Baseline). It must decode the message and store the message so that it can be understood when the data is requested from the AI. GlobalCommand functions similarly but instead receives commands from the AI. It must encode the command into a JAUS message and then sends the message to Baseline where the command can be performed.

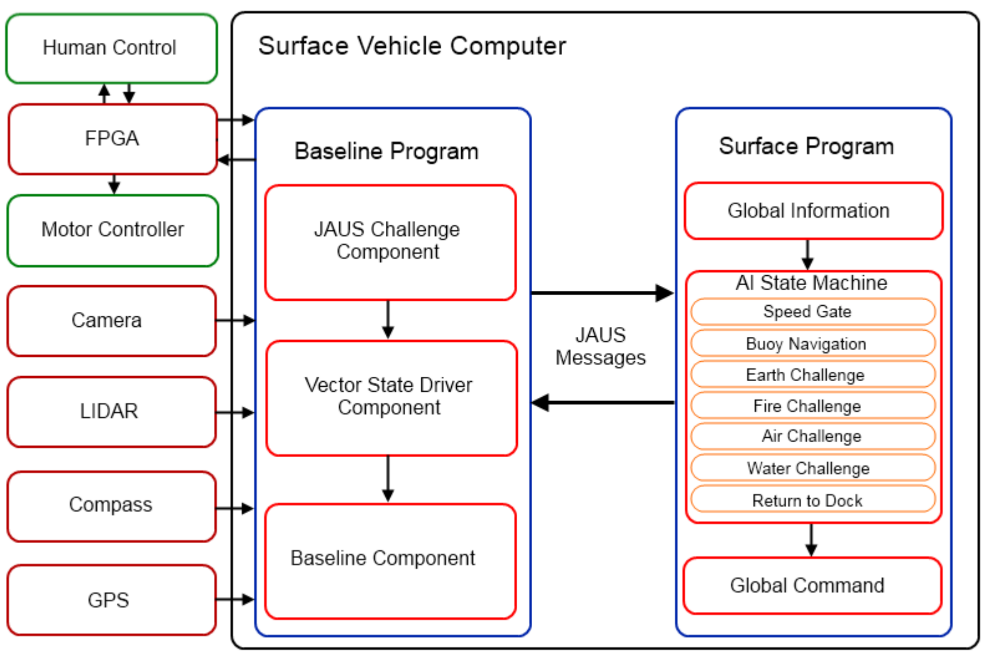

Figure 3: Software Flowchart

5.3. Vision

The key goal in the design of the vision system is having the ability to recognize objects, such as buoys and the burning ship, and calculate their location relative to the vehicle. The camera is located on the top, center of the vehicle.

The main purpose of the camera is to recognize objects of a specific color. With pixels of a particular color identified, image segmentation groups distinct clusters of pixels together to form a segment in the image. Since the buoys have distinctive colors, this classification works for identifying them during navigation. A fast line-scanning algorithm is used to group pixels into segments and calculate features such as an object size, centroid, and mean color. Only segments cohering to a particular size threshold are placed on the map. Using a projection algorithm, the location of the object in the LIDAR's field of view can be approximated, which allows the distance of that object to be calculated.

6. Safety

Safety is a key factor when working with any autonomous vehicle. Therefore, Boatname the Brave includes multiple systems to ensure that the vehicle and humans are always safe.

6.1. Emergency Stop

The emergency stop system is a hardware based system that is capable of disconnecting power from the drive motors and all other actuators. It is independent of all software so that the ASV can always be stopped in the case of an emergency. The system can be activated with momentary switches on the vehicle as well as from the remote control and remote monitor. The system can only be reset by pressing a button on the vehicle.

6.2. Thruster Protection

The CrustCrawler 400 HFS thrusters include safety shrouds around the propeller. This serves two purposes which include blocking a person accidentally damaging body parts as well as stopping foreign objects from damaging the propellers. Additional protection comes from mounting the thrusters on the inside of the pontoons. This minimizes the chance of any contact with the thrusters.

7. Vehicle Analysis

Multiple analyses have been conducted on Boatname the Brave to report the effectiveness of its design and budget.

7.1. Performance

Several qualities were taken into account when redesigning Boatname the Brave. These qualities affected the overall design and performance of the vehicle. Boatname the Brave's performance was measured after the construction phase to test the effectiveness of the design. The following table reports the specifications that are pertinent to Boatname the Brave's performance in the RoboBoat competition. Battery life is achieved by using two 6-Cell lithium-polymer batteries in parallel for logic and another two in parallel for motor power.

Item	Performance
Speed	3.0 m/s
Thrust	40 lb
Battery Life	3 hours of normal use
Waypoint Accuracy	1.0 m
Heading Accuracy	0.5 degree

7.2. Budget

The 2011 ASV budget includes support from outside sponsors and private club funds. Performance and cost will be reviewed after competition to determine the effectiveness of the budgetary allocation.

Item	Source	Approximate Value
Novatel GPS	Previous UAV	$1,500
Microstrain Compass	Retired Project	$1,500
Course	Previous ASV	$1,000
Batteries	Previous AUV	$1,000
DV Camera	Previous IGVC	$700
FPGA	Previous ASV	$150
Unibrain webcam	Retired Project	$100
Hokuyo LIDAR	Sponsorship	$5,500
Subtotal (Obtained Previously)		**$11,450**
ASV Computer	Sponsorship	$1,000
Crust Crawler Motors	Sponsorship	$2,000
Motor Controllers	Sponsorship	$850
PCB Components	Robotics Club	$500
Mechanical	Robotics Club	$500
ZigBee Pro 900Mhz	Robotics Club	$150
Electronics Case	Robotics Club	$100
Connectors	Robotics Club	$100
Subtotal (New Costs)		**$5,200**
Total Cost		**$16,650**

8. Conclusion

Boatname the Brave's platform has been re-engineered for optimal operation during the AUVSI RoboBoat 2011 competition. With its improvements, Boatname the Brave has advanced into a more viable and efficient platform with robust software and dependable hardware. The Robotics Club at UCF designed and built this vehicle to complete all missions set forth by the AUVSI and ONR's 4nd International ASVC event.