Autonomous Robotic Boat Platform

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Executive Summary

The objective of Team OBSCENE (on board self-governed computer engaging in nautical events) is to design, build, and test a flexible and robust ASV (autonomous surface vehicle) that can be further developed to contend in the 8th annual international RoboBoat Competition, which is sponsored by the AUVSI (Association for Unmanned Vehicle Systems International) Foundation and co-sponsored by the ONR (Office of Naval Research). The ASV must meet all constraints set by the AUVSI Foundation and the Bradley University Department of ECE (Electrical and Computer Engineering). Winning the competition is the ultimate goal of the RoboBoat project.

This project benefits the Bradley University ECE Department, as well as the students directly participating. The AUVSI RoboBoat competition is entering its 8th year of existence, and in that time it has established itself as an important and prestigious opportunity for universities and their students. Participation in such an event signifies that the university is academically sound and its students are technically proficient. Approval of this project is the first step towards earning such a reputation for Bradley University.

Due to the currently unreleased rules for the 2015 RoboBoat competition, the four student design team proposes that a flexible and robust platform be developed and delivered in accordance with the deadlines set forth by the ECE Department. Because of the late release of rules, the timeline needed to design a competition-ready autonomous boat extends past the deadlines established by Bradley University senior project requirements. Therefore, the design delivered to the department in April 2015 will not be in a state to compete in the RoboBoat competition, but rather it will be a well-designed and dependable foundation, which can then be given the features and functionality necessary to compete in the AUVSI competition. The proposed boat will carry out several key functions including the ability to be manually controlled from a remote location, identify and avoid obstacles autonomously, travel to a given global positioning system (GPS) coordinate autonomously, and power its motors for a minimum of 30 minutes.

The design team identifies these features as being common to all successful boat designs and, due to historic trends, having a high likelihood of being necessary in the upcoming competition. For these reasons, the final design has the functionalities described above. The successful implementation of these features indicates that the boat is on schedule and, with additional development, will be ready for competition in the early summer.

The RoboBoat team proposes that a design meeting the above requirements be implemented within a budget of $1,500. This design includes a boat frame, and two to four motors. Once the 2015 AUVSI competition rules are officially released a boat frame and motor type will be decided. Until that time the design team does not have enough information to make well-informed boat frame and motor design choices. A single camera provides visual feedback to an x86 mini-ITX motherboard, which executes the image processing as well as high level controls of the boat. GPS and compass sensors enable the boat to travel autonomously. An 8-channel remote control (RC) unit makes remote, manual control of the boat possible. Microcontrollers interface with the GPS and compass sensors, and decode RC signals and send them to the boat's motors. A wireless adapter allows remote access of the main processor (x86 mini-ITX motherboard) and thereby increases the productivity of the team's debugging and testing time.

Abstract

An autonomous robotic boat platform is proposed as the design team's senior capstone project. The team's desire is to compete in the 2015 RoboBoat international competition. The boat platform is designed to meet competition requirements and constraints and Bradley University's budget constraints. The RoboBoat competition constraints, requirements, and missions are used to develop the subsystems of the boat platform. These subsystems include boat frame, motor configuration, and central processor. Once the subsystems are established, methods of accomplishing each are chosen. Completing this project will require skills in areas of electrical engineering, and other engineering disciplines, that the design team does not currently have experience. The final product has potential utility in military, environmental, and recreational applications while keeping negative societal and environmental impacts minimal. Finally, the timeline and division of labor for the project tasks are provided and an economic analysis is performed. The project budget is provided and the primary expenses, including boat frame, circuitry, waterproof housing and propellers, are discussed. Participation in the 2015 RoboBoat competition will not only benefit the students involved, but the entire Bradley University Electrical Engineering Department as well.

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I. Introduction

Every year teams of students from across the globe mentally exert themselves for months. These students innovate, implement, and test. While broadening their knowledge through research and experience, these teams fail and forge on towards success. These students are not aimless in their tasks; these students work with a single goal in mind. The goal of Team OBSCENE (on board self-governed computer engaging in nautical events) is to join the ranks of these students and compete in the 8th RoboBoat Competition.

The RoboBoat Competition is an annual event held by the AUVSI (Association for Unmanned Vehicle Systems International) Foundation and co-sponsored by the ONR (Office of Naval Research). "During the competition, student teams race autonomous surface vehicles (ASVs) of their own design through an aquatic obstacle course [1]." Teams receive points for attempting or completing missions and a winner is named when the competition is complete. This event occurs in Virginia Beach, Virginia during June or July. The ASV proposed in this document will be designed to satisfy the guidelines of the AUVSI competition, while also being a robust, versatile platform. The design constraints and requirements of this system are taken from the AUVSI constraints, as shown in Table 1 and Table 2. In Table 1, column one lists the constraints and column two lists the description associated with each constraint. In Table 2, column one lists the requirements and column two lists the description associated with each requirement. The specifications of the final system, which will be presented to the Bradley University ECE Department in the spring of 2015, are shown in Table 3.

Many disciplines of engineering are involved in the creation of this platform, and the desire to learn about these areas through design experience motivates Team OBSCENE. These areas include but are not limited to communications, embedded programming, power electronics, and image processing. Creating components to complete these tasks will strengthen Team OBSCENE as engineers. Not only will this student development reflect well on Bradley University, but the competition itself will draw interest to the ECE Department.

As is shown throughout this proposal, the RoboBoat competition is highly technical. The competition is also highly prestigious; many large and well-known engineering schools such as Embry-Riddle, University of Florida, Georgia Institute of Technology, and University of Michigan compete regularly [4]. Not only do many prominent engineering schools compete, but many large companies such as Northrop Grumman, MathWorks, and Boeing sponsor the RoboBoat competition [4]. Competing will increase the exposure of Bradley University to these large names in engineering.

Teams of students from Bradley University have competed in the RoboBoat competition in the past. In 2012, seniors Jeremy Borgman and Max Christy placed eighth out of sixteen contenders during Bradley University's first attempt at the competition [3]. In 2013, seniors Zach Knoll and Steven Blass placed fifth, winning $1,500 [4]. Because Zach Knoll and Steven Blass assisted Jeremy Borgman and Max Christy in creating the ASV which competed in the 2012 RoboBoat competition, Knoll and Blass were able to reuse the systems that had been developed during the prior year in the 2013 RoboBoat competition. For this proposal, the entire system will be redesigned, but the batteries, camera, and processor, will be reused from previous Bradley RoboBoat groups.

Table 1. CONSTRAINTS OF THE AUTONOMOUS BOAT PLATFORM

Constraints	
Buoyancy	the vehicle must be positively buoyant and be buoyant for at least 30 minutes in the water.
Communication	the vehicle cannot send information or receive instruction while in autonomous mode.
Deployable	the vehicle must have its own 3 or 4 points harness for crane deployment.
Energy Source	the vehicle must use self-contained electrical energy source. Sailboats are permitted.
Kill Switch	the vehicle must have at least one 4 cm diameter red button located on the vehicle that, when actuated, must disconnect power from all motors and actuators.
e-Kill Switch	in addition to the physical kill-switch, the vehicle must have at least one remote kill switch that provides the same functionality.
Payload	the vehicle must have a place to mount a payload up to a 1.5-meter cube weighing up to 7 kg.
Payload Location	the payload must have an unobstructed view of the sky and front of the vehicle.
Safety	all sharp, pointy, moving, sensitive, etc. parts must be covered and clearly identified.
Size	the vehicle must fit within a two-meter long, by one-meter wide, by one-meter high “box”.
Towable	the vehicle must have designated tow points and a tow harness installed at all times.
Weight	the vehicle must be 73 kg. or less.

Table 2. REQUIREMENTS OF THE AUTONOMOUS BOAT PLATFORM

Requirements	
Autonomy	the vehicle must be fully autonomous and all decisions must be taken onboard the ASV.
Coordinate Navigation	the vehicle must be capable of travelling from one GPS coordinate to a second GPS coordinate.
Propulsion	any propulsion system is fine (thruster, paddle, etc), but moving parts must have a shroud.
Remote-Controllable	the vehicle must be remote-controllable to be brought back to the dock.
Safety	all sharp, pointy, moving, sensitive, etc. parts must be covered and clearly identified.
Surface	the vehicle must float or use ground effect of the water. Mostly submerged/flying is forbidden.
Visual Navigation	the vehicle must be able to travel through a set of buoy gates.
Waterproof	the vehicle must be rain/splash resistant. The competition is held “rain or shine”!

Table 3. SPECIFICATIONS OF THE AUTONOMOUS BOAT PLATFORM

Specifications		
Coordinate Navigation	**ASV Starting Angle**	±180 degrees
	Destination Accuracy	< 5 m
Propulsion	**Thrust**	> 27 N
	Current Draw	< 120 A·h
Remote-Controllable	**Distance**	100 m
Surface	**Submersion**	50% > x > ~0%
Ambient Operating Temperature	**Max**	45 °C
	Min	0 °C
Visual Navigation	**Buoy size**	A-1 (Diameter x Length: 27.9 x 38.1 cm, Circumference: 91.1 cm)
	Buoy shape	Spherical, cylindrical
	Buoy gate distance	0.914 - 6.096 m
	Buoy gate width	1.524 - 1.829 m
	Buoy Midpoint Angles	< 46 degrees
	Buoy color	red & green
	Number of gates	3
	Time Limit	5 min.

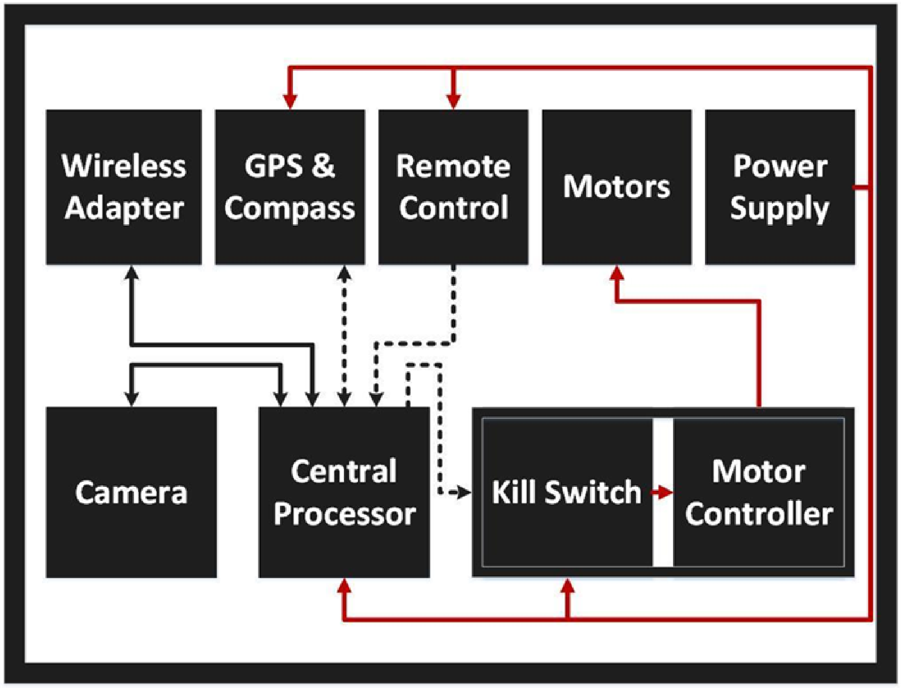

Fig. 1) High-level autonomous system block diagram. Red lines indicate power, dashed lines indicate serial connections, and solid black lines represent USB connections.

II. Design Approach and Methods of Solution

A new robust and versatile autonomous navigation system will be designed using the guidelines created by the AUVSI Foundation. While the competition is outside of the scope of this capstone project, the ASV must meet the competition constraints in order to compete. Designing subsystems to meet RoboBoat competition constraints and complete competition missions and tasks is a sound choice because the competition missions are so widely varied that only an extremely versatile platform would be able to complete them. Each of the subsystems is designed by following the process below:

1. A set of requirements, constraints, tasks, or missions are chosen.
2. A subsystem is derived from the requirements, constraints, tasks, or missions.
3. The design alternatives are researched.
4. An educated design choice is made.

A. Block Diagram

A complete high-level block diagram of the design is shown in Fig. 1. The design of each subsystem is described in the following sections.

B. Boat Frame

The necessity of a boat frame can be derived from the buoyancy, deployable, payload, payload location, surface, and towable requirements and constraints (see Table 1 for details). Size, waterproof, and weight are additional requirements and constraints that affect the boat frame design choice. Five design alternatives were researched: V bottom, flat bottom, catamaran, trimaran, and circular boat frames.

The V bottom design is highly maneuverable, but the V bottom is also physically unstable. The flat bottom design is less maneuverable than the V bottom, but the flat bottom is much more stable. The V bottom and flat bottom also have limited motor configurations and flooding potential. The catamaran and trimaran designs are very stable and difficult to flood, but less maneuverable and heavier than the V bottom and flat bottom designs. The circular frame is experimental, and therefore its performance untested, but theoretically allows any part of the boat frame to act as the front of the boat.

No final decision has been made regarding the boat frame design. When the official rules for the 2015 RoboBoat competition are released, a decision will be made based on the types of missions present in the competition.

B. Power Supply

A power supply is inferred from the power source requirement (see Table 1 for details). The waterproof and weight requirements and constraints must also be considered when selecting a power supply. Batteries were the only reasonable design alternatives considered by the design team. The design team proposes that two Lithium Iron Phosphate (LiFe) 15 A-h batteries be used in the boat design. A previous RoboBoat team researched and purchased these LiFe batteries because of their high energy density to weight ratio. The original LiFe batteries are used by the current team at no additional cost.

C. Motors and Controller

A propulsion mechanism also needs to be identified. According to the propulsion requirement any method of propulsion is permissible in the AUVSI competition; however, all moving parts must be shrouded. This would include any propellers used to move the boat through the water. Other important requirements and constraints to consider include: energy source, safety, size, waterproof, and weight.

Several design alternatives were considered, including: two motors placed in the rear of the boat, four motors placed at offset angles, and a single pivoting motor. Each motor configuration has its own benefits and challenges. A motor configuration of two rear motors is advantageous because this configuration can be controlled by the actuation of one or both propellers. However, that simplicity comes at a cost of reduced maneuverability and no ability to move laterally. A single pivoting motor, placed in the rear of the boat, has similar disadvantages. The single propeller is simply controlled using a single PWM (pulse width modulation) signal; unfortunately, the single motor also has limited maneuverability and no ability to move laterally. Another disadvantage is that an additional motor would be needed to change the direction of the propeller. A final option is the use of four motors; one placed at each corner of the boat at outward facing angles. Using this configuration the boat would be able to move in all directions, including lateral movement, and rotate. Unfortunately, this motor configuration increases the control complexity and is a somewhat inefficient design. For example, in order to propel the boat straight forward both rear motors must be powered at equal speeds, however, because the motors face slightly outward the two motors cancel out a portion of the motion. Thus, there is wasted power inherent in this design.

At this time the 2015 AUVSI missions and tasks have not yet been released. For this reason, the design team has decided to wait until the official rules are released to commit to one of the above motor configurations. After the missions and tasks that the boat will be expected to carry out are known the design team will choose a boat design that best suits those conditions, and a motor configuration that compliments the boat frame.

D. Kill Switch

The kill switch constrain mandates that at least one kill switch button exist on the physical boat. These switches must disconnect power from all motors, propellers, and actuators on the boat. Due to the strict nature of these requirements there are no possible design alternatives regarding the physical kill switch. Therefore, the boat will include one 1.5" diameter red button, which will stop the boat motors and actuators when pressed.

E. Central Processor

The AUVSI requirement that makes the RoboBoat competition so distinctive is the requirement that all tasks and missions be carried out autonomously. To satisfy this constraint a central processor, which will make decisions regarding the motion of the boat, must be included in the system design. An x86 mini-ITX motherboard (i3 processor) will be used. This board has been used by previous RoboBoat teams with no deficiencies and will be available to the current design team at no cost.

F. Remote Control

In order to comply with the remote controllable and e-Kill switch constraints a form of remote controllability must be implemented in the boat design. The design alternatives to achieve this include: using an 8-channel RC (remote control) unit, and using a WiFi (wireless fidelity) connection to manually control the boat. The design team proposes that the 8-channel RC unit, which was used by a previous RoboBoat team, be implemented to accomplish this remote controllability. The RC option is simpler to implement than the WiFi option, and still provides all the needed functionality.

G. Vision

The system should detect its environment; specifically, identify shapes and colors that surround it. The most feasible method to collect visual data from the environment is to use a camera to capture images of the boat's surroundings. These images can then be processed in the central processor to extract information that will help navigate the boat. Implementing a camera in addition to the central processor will give the boat the ability to recognize shapes and colors, which is a necessity to go through buoys and avoid obstacles. A LiDAR (light detection and ranging) system is also under consideration to be used in addition to the camera. Using a LiDAR in conjunction with the camera would enable the system to detect depth, as well as shape and color. The LiDAR system is not necessary because the camera images can be used to calculate relative distance; however, LiDAR is more effective because it directly measures depth. A LiDAR system may be implemented in addition to the camera if the 2015 missions deem it necessary. At this time, however, it is proposed that only a single camera be implemented.

H. Positioning

The RoboBoat missions are located in different parts of the competition area. GPS coordinates are provided for each of the missions making it possible for the competing ASVs to travel to the mission areas. The only feasible way of utilizing GPS coordinates is by identifying the GPS location of the boat with a GPS sensor. Many GPS sensors were considered and the Adafruit Ultimate GPS Breakout

(Adafruit, New York, USA) was chosen because it has low power consumption, a breakout board, adequate accuracy, and a low price.

I. Heading

The system should determine which direction it is facing and in which direction it needs to be traveling. The heading of the boat can be determined by recording GPS measurements as the boat travels. These readings could then be used to determine the direction the boat is facing. The main disadvantages of this method are that the boat must be in motion to determine direction, the GPS readings must be highly accurate, and only the direction in which the boat is traveling is provided, which may be different that the direction the boat is facing. For these reasons it is more reliable to use a dedicated compass to determine the direction the boat is facing. The compass sensor needs to have tilt compensation and operate on low power in order to be considered as a viable design option. The CMPS10 (Devantech LTD, England) was the compass sensor that best met these standards for the lowest cost.

J. Wireless Adapter

For the past four years, the RoboBoat competition missions have required communication between the competing ASV and an AUVSI server via 802.11b/g/n protocol. The odds that another mission of this type will be presented for the 8th RoboBoat competition are highly likely. Even if no such mission is offered, the wireless adapter and WiFi communication system can be utilized to remotely access the central processor of the ASV to send and receive data, and update code, which will streamline the debugging process.

J. Testing

Each subsystem of the design will be tested individually to verify proper operation. The subsystems will then be combined in small groups and tested again. Finally, larger groups will be tested until the final product is functional. The GPS and compass subsystem can be used as an example. First, compass operation is verified by checking the compass output against an actual compass. Next, proper operation of the GPS is confirmed by comparing the GPS output to the actual GPS location of the device (considering the room for error specified in the GPS datasheet). The GPS is then integrated with the central processor and the output is tested by providing a desired GPS coordinate. The system displays an error while the desired and actual positions do not match. When the desired and actual GPS coordinates match (considering the same margin of error specified above), the system will provide a confirmation signal. After GPS integration is complete, the compass is integrated. This test will be similar to the last, but movement of the device will be coordinated by the heading provided by the compass and the current GPS location. Finally, this system group must be implemented with the boat itself, which will use the compass heading and GPS location to actuate the propellers to direct the boat to its destination. A similar testing methodology will be used on all subsystems. Many of the early tests performed will only require the resources in senior lab, but some of the later tests will require Markin pool, or another body of water to verify proper operation.

III. Economic Analysis

Team OBSCENE requires $1500 to design and implement the ASV design. A concise list of expenses are shown in Table 1. The boat frame cost includes the main buoyant materials, waterproofing the exterior, mounting and brackets, the central platform, and also a 3- or 4-point harness. Using past RoboBoat team expenses, and the experience of team advisors, Team OBSCENE allocated $500 to the construction of a boat frame. Because the motor configuration is currently unknown, the most costly of the motor design alternatives was assumed, resulting in an allocation of $350 for motors. The miscellaneous cost includes any unforeseen costs, such as replacement parts.

IV. Project Timeline

In Table 2, the project timeline is projected in a high-level Gantt chart. The Gantt chart shows the key milestones that the design team must attain from October 2nd until the end of April in order for the ASV to be completed on time. The first eight tasks are the design of the RoboBoat subsystems and contain the critical path of the project, while the last three tasks are the primary ECE 498/499 milestones. These milestones include the progress reports in November and February, and the final project demonstration and presentation in April. The critical path of the RoboBoat project includes motor driver development, development of the central processing unit, and total system integration. For a more detailed Gantt chart see Tables 6 through 8 in Appendix B. In these tables the critical path is reflected by the tasks with red borders.

V. Division of Labor

Darren McDannald will be responsible for researching and developing a stable, low level code for the central processing unit. Image processing will be accomplished by Leah Cramer and Noah Dupes. The GPS/compass and remote control subsystems will be assigned to Ryan Burke. The motor control/motor driver task will be divided evenly between Darren, Ryan, and Noah. Each ECE 498/499 milestone will require an even contribution from each team member. If realization of the critical path exceeds the provided timeline, then the technical aspects of the critical path can be simplified (as long as the final

Table 1. Estimated Expense Report For The ASV

Item	Cost
Boat Frame	$500
Circuitry	$150
Waterproof Housing	$300
Motor(s)	$350
Miscellaneous	$200
TOTAL DESIGN COST	**$1500**

product will still meet specifications) or other team members can shift tasks temporarily to assist Darren. For a more detailed listing of the division of labor, see Tables 9 through 10 in Appendix B.

VI. Environmental and Societal Impact

Although the proposed RoboBoat design has limited societal impact, an ASV could be used in many situations, such as naval reconnaissance applications, hazardous rescue, recreational vehicle safety systems, and marine research and exploration.

The RoboBoat can impact the environment in several ways. The LiFe batteries, which are used as the onboard power source, could be harmful to the environment if corrosion occurs. For proper safety measures, the batteries will be enclosed in a battery acid resistant container. The boat's motors will be shrouded in order to prevent the propellers from damaging objects in the competition lake. Protective circuit covers will be used to prevent water from entering the system and causing short circuits and electrical fires. These precautions will ensure that the RoboBoat will not harm its environment in any way.

VII. Summary and Conclusions

The objective of Team OBSCENE is to design and implement an ASV that can be further developed to contend in the 8th annual international RoboBoat Competition. The ASV must meet all constraints set by the AUVSI Foundation and the Bradley University Department of Electrical and Computer Engineering. Winning the competition is the ultimate goal of the RoboBoat project. Due to the currently unreleased rules for the 2015 RoboBoat competition, the design team proposes that a flexible and robust platform be developed and delivered in accordance with deadlines set forth by the ECE Department.

The proposed design includes a boat frame, and two to four motors. Once the 2015 AUVSI competition rules are officially released a boat frame and motor type will be decided. Until that time, the design team does not have enough information to make well-informed boat frame and motor design choices. A single camera will provide visual feedback to an x86 mini-ITX motherboard which executes the image processing as well as high level controls of the boat. The Adafruit Ultimate GPS Breakout and Robot Electronics CMPS10 will return GPS and compass readings to the central processor, enabling the boat to

Table 2. GANTT CHART OF THE CAPSTONE PROJECT

ID	Task Name	Duration	Start	Finish	Oct 2014	Nov 2014	Dec 2014	Jan 2015	Feb 2015	Mar 2015	Apr 2015
1	Motor	230h	10/3/2014	12/5/2014							
2	Boat Frame	10h	12/8/2014	12/9/2014							
3	Central Computer	200h	12/8/2014	1/30/2015							
4	Control	30h	2/2/2015	2/9/2015							
5	System Integration	190h	2/11/2015	4/3/2015							
6	GPS/Compass	170h	10/3/2014	11/19/2014							
7	RC	30h	11/21/2014	11/28/2014							
8	Image Processing	190h	10/3/2014	11/25/2014							
9	Progress Report 1	140h	10/13/2014	11/19/2014							
10	Progress Report 2	140h	1/13/2015	2/19/2015							
11	Final Report	140h	3/24/2015	4/30/2015							

travel autonomously. An 8-channel remote control unit will make remote, manual control of the boat possible. Microcontrollers interface the GPS and compass sensors to the main processor. A microcontroller will be used to decode and send RC signals to the boat's motors. A wireless adapter will allow remote access the main processor (x86 mini-ITX motherboard) and thereby increase the productivity of the team's debugging and testing time.

The proposed boat will carry out several key functions including the ability to be manually controlled from a remote location, identify and avoid obstacles autonomously, travel to a given GPS coordinate autonomously, and operate motors for a minimum of 30 minutes. The RoboBoat team proposes that a design meeting the above requirements be implemented within a budget of $1,500. This cost includes the boat frame, circuitry, waterproof housing, and propellers. Participation in the 2015 AUVSI RoboBoat competition will not only benefit the students on the design team, it will benefit the Bradley University ECE department as well. The student members of the design team will gain valuable hands-on experience in multiple disciplines of engineering through this project. Participation in this prestigious event will show that Bradley University ECE students are technically proficient and skilled engineers, and will contribute to Bradley University's positive reputation.

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Appendix A - Acronyms

ASV - Autonomous Surface Vehicle

AUVSI - Association For Unmanned Vehicle Systems International

ECE Department - Bradley University's Electrical and Computer Engineering Department.

GPS - Global Positioning System

LiDAR - a detection system that utilizes radar in conjunction with lasers.

LiFe - Lithium Iron Phosphate

OBSCENE - On Board Self-Governed Computer Engaging in Nautical Events

ONR - Office of Naval Research

PWM - Pulse Width Modulation

RC - Remote Control

USB - Universal Serial Bus

WiFi - A network allowing for wireless communication between two devices within a particular area.

Appendix C - Gantt Chart

Table 6. Gantt chart: start of the project to the first progress presentation.

ID	Task Name	Start	Finish	Duration
1	Research and Determine Motor Configuration	10/16/2014	10/17/2014	10h
2	Research Bi-directional Motor Control	10/20/2014	10/23/2014	24h
3	Electromechanical	10/24/2014	11/3/2014	40h
4	Establish Method of Communication to Micro-controller	11/4/2014	11/4/2014	1h
5	Implementation of Communication to Micro-controller	11/5/2014	11/6/2014	12h
6	Motor Hardware Design and Testing	11/7/2014	11/18/2014	48h
7	Build and Test Motor driver Circuit	11/19/2014	12/1/2014	54h
8	Write Code to Get Compass Heading	10/16/2014	10/17/2014	9h
9	Test Compass Code	10/17/2014	10/20/2014	9h
10	Write Code to Get GPS Data	10/21/2014	10/21/2014	6h
11	Write Code to Decode GPS Data	10/22/2014	10/23/2014	9h
12	Test GPS Code	10/23/2014	10/24/2014	9h
13	Test in MATLAB “GPS”	10/27/2014	10/30/2014	24h
14	Establish Method of Communication “Compass”	10/31/2014	10/31/2014	1h
15	Establish Data Format “Compass”	10/31/2014	11/3/2014	4h
16	Implementation of Communication “Compass”	11/3/2014	11/4/2014	6h
17	Establish Method of Communication “GPS”	11/5/2014	11/5/2014	1h
18	Establish Data Format “GPS”	11/5/2014	11/6/2014	4h
19	Implementation of Communication “GPS”	11/6/2014	11/7/2014	3h
20	Build and Test GPS Compass Circuit	11/7/2014	11/18/2014	45h
21	Research and Order GPS Compass Housing	11/18/2014	11/19/2014	3h
22	GPS/Compass housing Building	11/19/2014	11/20/2014	9h
23	Research Method of Circle Detection	10/16/2014	10/16/2014	6h
24	Research Rectangle Detection	10/17/2014	10/17/2014	6h
25	Test Shape Detection in MATLAB	10/20/2014	10/24/2014	30h
26	Color Space research	10/27/2014	10/28/2014	9h
27	Research Blob Detection	10/28/2014	10/29/2014	9h
28	PC Implementation in C and Testing	10/30/2014	11/11/2014	50h
29	PC Video Mark-up	11/11/2014	11/20/2014	40h
30	Brains Implementation and camera Interface	11/20/2014	11/21/2014	3h
31	Boat Image Processing Testing	11/21/2014	12/1/2014	40h
32	RC Decoder	11/20/2014	11/21/2014	9h
33	Convert RC Signal to Motor Control Signal	11/24/2014	11/24/2014	5h
34	Implement RC Fail Saves	11/25/2014	11/25/2014	3h
35	Test RC Control	11/26/2014	11/27/2014	9h
36	RC Testing Time	11/27/2014	11/28/2014	3h
37	Research and Determine Boat Frame	12/2/2014	12/2/2014	6h
38	Research to Find Best OS	12/2/2014	12/2/2014	5h
39	Install OS	12/3/2014	12/5/2014	18h
40	OS Extension Research	12/8/2014	12/8/2014	3h
41	Set Up Drivers and Interface with Camera	12/9/2014	12/9/2014	1h
42	Install OS Extensions	12/9/2014	12/10/2014	5h
43	OS Extension familarization	12/10/2014	12/24/2014	60h
44	Multi-Threading	12/24/2014	12/26/2014	15h
45	Research and Implementation of TCP/IP Communication	12/29/2014	1/15/2015	80h
46	Controls Research	1/15/2015	1/16/2015	9h
47	Controls Consult With Dr. Dempsey	1/19/2015	1/19/2015	3h
48	Controls First Run	1/19/2015	1/21/2015	15h
49	Establish Data Format for Micro-Controller	1/22/2015	1/23/2015	8h
50	Power Supply Wiring	1/23/2015	1/29/2015	27h
51	Motor and Brain System Integration	1/30/2015	2/9/2015	40h
52	GPS/Compass and Brain System Integration	2/9/2015	2/18/2015	40h
53	Image Processing and Brain System Integration	2/18/2015	2/19/2015	9h
54	Motor, GPS/Compass, and Brain System Integration	2/19/2015	3/2/2015	40h
55	Motor, GPS/Compass, Image Processing, and Brain System Integration	3/2/2015	3/11/2015	40h
56	Overall Boat Testing	3/11/2015	3/20/2015	40h
57	Upload Deliverable to Website	10/27/2014	10/30/2014	20h
58	Make Progress Report 1 Slides	11/11/2014	11/14/2014	24h
59	Individual Progress Report 1 Practice	11/17/2014	11/18/2014	12h
60	Group Progress Report1 Practice	11/19/2014	11/20/2014	12h
61	Make Progress Report 2 Slides	2/9/2015	2/12/2015	24h
62	Individual Progress Report 2 Practice	2/13/2015	2/16/2015	12h
63	Group Progress Report 2 Practice	2/17/2015	2/19/2015	12h
64	Prepare for Spring Demo	3/16/2015	3/18/2015	12h
65	Make Demonstration Presentation Slides	3/18/2015	3/20/2015	12h
66	Demonstration Individual Practice	3/20/2015	3/24/2015	12h
67	Demonstration Group Practice	3/24/2015	3/26/2015	12h
68	Make Final Presentation Slides	3/25/2015	3/27/2015	12h
69	Final Presentation Individual Practice	3/27/2015	4/2/2015	24h
70	Final Presentation Group Practice	4/2/2015	4/7/2015	18h
71	Prepare for Q&A	4/7/2015	4/9/2015	12h
72	Final Paper Detailed	4/2/2015	4/6/2015	12h
73	Final Paper Writing	4/6/2015	4/16/2015	48h
74	Final Paper Combining Sections and Voices	4/16/2015	4/21/2015	18h
75	Final Paper Format	4/21/2015	4/22/2015	8h
76	Final Paper Proof Reading	4/23/2015	4/30/2015	36h

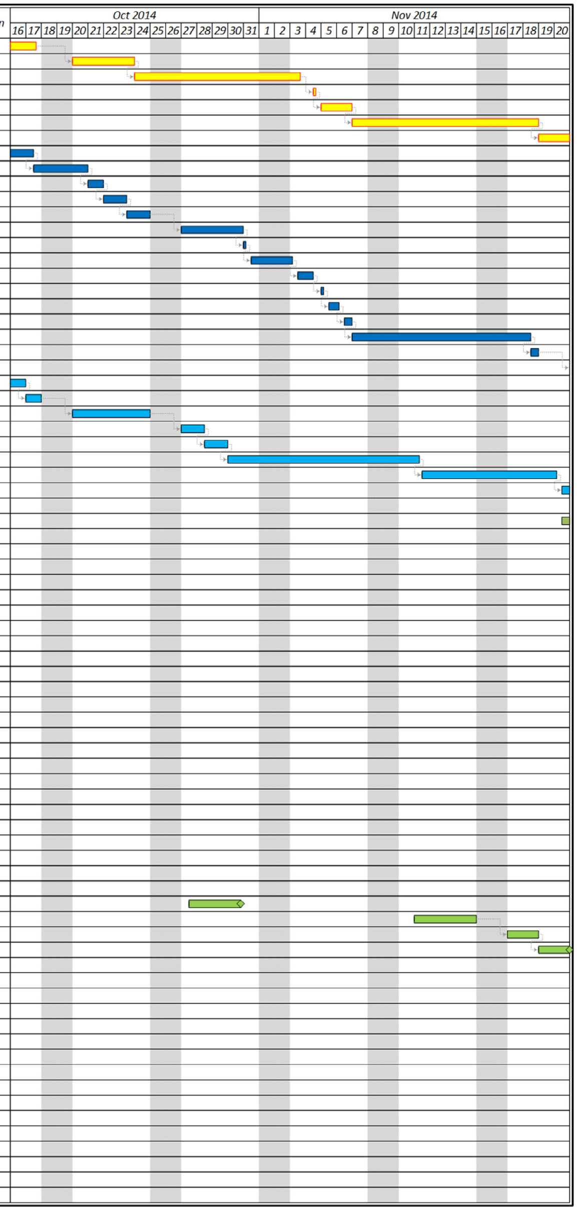
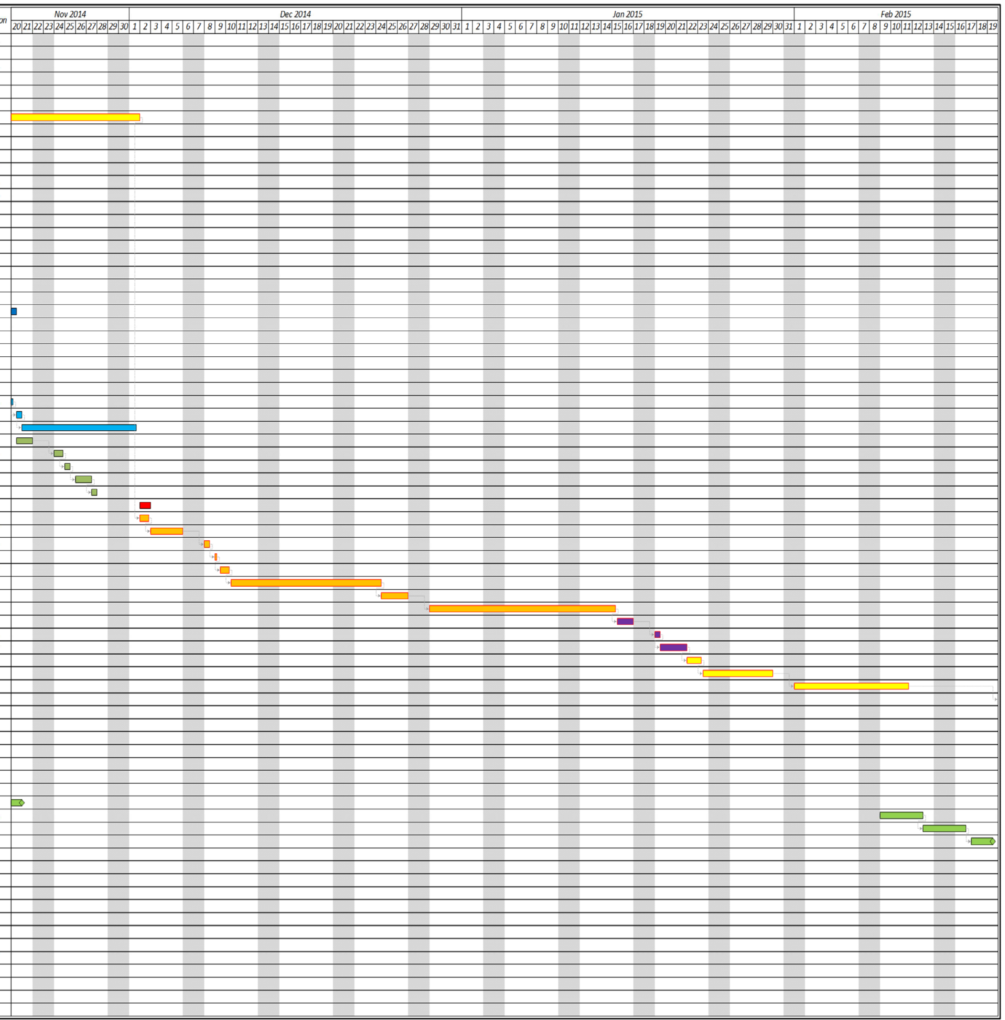


Table 7. Gantt chart: first progress presentation to the second progress presentation.

Table 8. Gantt chart: second progress presentation to the end of the capstone project.

ID	Task Name	Start	Finish	Duration
1	Research and Determine Motor Configuration	10/16/2014	10/17/2014	10h
2	Research Bi-directional Motor Control	10/20/2014	10/23/2014	24h
3	Electromechanical	10/24/2014	11/3/2014	40h
4	Establish Method of Communication to Micro-controller	11/4/2014	11/4/2014	1h
5	Implementation of Communication to Micro-controller	11/5/2014	11/6/2014	12h
6	Motor Hardware Design and Testing	11/7/2014	11/18/2014	48h
7	Build and Test Motor driver Circuit	11/19/2014	12/1/2014	54h
8	Write Code to Get Compass Heading	10/16/2014	10/17/2014	9h
9	Test Compass Code	10/17/2014	10/20/2014	9h
10	Write Code to Get GPS Data	10/21/2014	10/21/2014	6h
11	Write Code to Decode GPS Data	10/22/2014	10/23/2014	9h
12	Test GPS Code	10/23/2014	10/24/2014	9h
13	Test in MATLAB "GPS"	10/27/2014	10/30/2014	24h
14	Establish Method of Communication "Compass"	10/31/2014	10/31/2014	1h
15	Establish Data Format "Compass"	10/31/2014	11/3/2014	4h
16	Implementation of Communication "Compass"	11/3/2014	11/4/2014	6h
17	Establish Method of Communication "GPS"	11/5/2014	11/5/2014	1h
18	Establish Data Format "GPS"	11/5/2014	11/6/2014	4h
19	Implementation of Communication "GPS"	11/6/2014	11/7/2014	3h
20	Build and Test GPS Compass Circuit	11/7/2014	11/18/2014	45h
21	Research and Order GPS Compass Housing	11/18/2014	11/19/2014	3h
22	GPS/Compass housing Building	11/19/2014	11/20/2014	9h
23	Research Method of Circle Detection	10/16/2014	10/16/2014	6h
24	Research Rectangle Detection	10/17/2014	10/17/2014	6h
25	Test Shape Detection in MATLAB	10/20/2014	10/24/2014	30h
26	Color Space research	10/27/2014	10/28/2014	9h
27	Research Blob Detection	10/28/2014	10/29/2014	9h
28	PC Implementation in C and Testing	10/30/2014	11/11/2014	50h
29	PC Video Mark-up	11/11/2014	11/20/2014	40h
30	Brains Implementation and camera Interface	11/20/2014	11/21/2014	3h
31	Boat Image Processing Testing	11/21/2014	12/1/2014	40h
32	RC Decoder	11/20/2014	11/21/2014	9h
33	Convert RC Signal to Motor Control Signal	11/24/2014	11/24/2014	5h
34	Implement RC Fail Saves	11/25/2014	11/25/2014	3h
35	Test RC Control	11/26/2014	11/27/2014	9h
36	RC Testing Time	11/27/2014	11/28/2014	3h
37	Research and Determine Boat Frame	12/2/2014	12/2/2014	6h
38	Research to Find Best OS	12/2/2014	12/2/2014	5h
39	Install OS	12/3/2014	12/5/2014	18h
40	OS Extension Research	12/8/2014	12/8/2014	3h
41	Set Up Drivers and Interface with Camera	12/9/2014	12/9/2014	1h
42	Install OS Extensions	12/9/2014	12/10/2014	5h
43	OS Extension familarization	12/10/2014	12/24/2014	60h
44	Multi-Threading	12/24/2014	12/26/2014	15h
45	Research and Implementation of TCP/IP Communication	12/29/2014	1/15/2015	80h
46	Controls Research	1/15/2015	1/16/2015	9h
47	Controls Consult With Dr. Dempsey	1/19/2015	1/19/2015	3h
48	Controls First Run	1/19/2015	1/21/2015	15h
49	Establish Data Format for Micro-Controller	1/22/2015	1/23/2015	8h
50	Power Supply Wiring	1/23/2015	1/29/2015	27h
51	Motor and Brain System Integration	1/30/2015	2/9/2015	40h
52	GPS/Compass and Brain System Integration	2/9/2015	2/18/2015	40h
53	Image Processing and Brain System Integration	2/18/2015	2/19/2015	9h
54	Motor, GPS/Compass, and Brain System Integration	2/19/2015	3/2/2015	40h
55	Motor, GPS/Compass, Image Processing, and Brain System Integration	3/2/2015	3/11/2015	40h
56	Overall Boat Testing	3/11/2015	3/20/2015	40h
57	Upload Deliverable to Website	10/27/2014	10/30/2014	20h
58	Make Progress Report 1 Slides	11/11/2014	11/14/2014	24h
59	Individual Progress Report 1 Practice	11/17/2014	11/18/2014	12h
60	Group Progress Report1 Practice	11/19/2014	11/20/2014	12h
61	Make Progress Report 2 Slides	2/9/2015	2/12/2015	24h
62	Individual Progress Report 2 Practice	2/13/2015	2/16/2015	12h
63	Group Progress Report 2 Practice	2/17/2015	2/19/2015	12h
64	Prepare for Spring Demo	3/16/2015	3/18/2015	12h
65	Make Demonstration Presentation Slides	3/18/2015	3/20/2015	12h
66	Demonstration Individual Practice	3/20/2015	3/24/2015	12h
67	Demonstration Group Practice	3/24/2015	3/26/2015	12h
68	Make Final Presentation Slides	3/25/2015	3/27/2015	12h
69	Final Presentation Individual Practice	3/27/2015	4/2/2015	24h
70	Final Presentation Group Practice	4/2/2015	4/7/2015	18h
71	Prepare for Q&A	4/7/2015	4/9/2015	12h
72	Final Paper Detailed	4/2/2015	4/6/2015	12h
73	Final Paper Writing	4/6/2015	4/16/2015	48h
74	Final Paper Combining Sections and Voices	4/16/2015	4/21/2015	18h
75	Final Paper Format	4/21/2015	4/22/2015	8h
76	Final Paper Proof Reading	4/23/2015	4/30/2015	36h



ID	Task Name	Start	Finish	Duration
1	Research and Determine Motor Configuration	10/16/2014	10/17/2014	10h
2	Research Bi-directional Motor Control	10/20/2014	10/23/2014	24h
3	Electromechanical	10/24/2014	11/3/2014	40h
4	Establish Method of Communication to Micro-controller	11/4/2014	11/4/2014	1h
5	Implementation of Communication to Micro-controller	11/5/2014	11/6/2014	12h
6	Motor Hardware Design and Testing	11/7/2014	11/18/2014	48h
7	Build and Test Motor driver Circuit	11/19/2014	12/1/2014	54h
8	Write Code to Get Compass Heading	10/16/2014	10/17/2014	9h
9	Test Compass Code	10/17/2014	10/20/2014	9h
10	Write Code to Get GPS Data	10/21/2014	10/21/2014	6h
11	Write Code to Decode GPS Data	10/22/2014	10/23/2014	9h
12	Test GPS Code	10/23/2014	10/24/2014	9h
13	Test in MATLAB “GPS”	10/27/2014	10/30/2014	24h
14	Establish Method of Communication “Compass”	10/31/2014	10/31/2014	1h
15	Establish Data Format “Compass”	10/31/2014	11/3/2014	4h
16	Implementation of Communication “Compass”	11/3/2014	11/4/2014	6h
17	Establish Method of Communication “GPS”	11/5/2014	11/5/2014	1h
18	Establish Data Format “GPS”	11/5/2014	11/6/2014	4h
19	Implementation of Communication “GPS”	11/6/2014	11/7/2014	3h
20	Build and Test GPS Compass Circuit	11/7/2014	11/18/2014	45h
21	Research and Order GPS Compass Housing	11/18/2014	11/19/2014	3h
22	GPS/Compass housing Building	11/19/2014	11/20/2014	9h
23	Research Method of Circle Detection	10/16/2014	10/16/2014	6h
24	Research Rectangle Detection	10/17/2014	10/17/2014	6h
25	Test Shape Detection in MATLAB	10/20/2014	10/24/2014	30h
26	Color Space research	10/27/2014	10/28/2014	9h
27	Research Blob Detection	10/28/2014	10/29/2014	9h
28	PC Implementation in C and Testing	10/30/2014	11/11/2014	50h
29	PC Video Mark-up	11/11/2014	11/20/2014	40h
30	Brains Implementation and camera Interface	11/20/2014	11/21/2014	3h
31	Boat Image Processing Testing	11/21/2014	12/1/2014	40h
32	RC Decoder	11/20/2014	11/21/2014	9h
33	Convert RC Signal to Motor Control Signal	11/24/2014	11/24/2014	5h
34	Implement RC Fail Saves	11/25/2014	11/25/2014	3h
35	Test RC Control	11/26/2014	11/27/2014	9h
36	RC Testing Time	11/27/2014	11/28/2014	3h
37	Research and Determine Boat Frame	12/2/2014	12/2/2014	6h
38	Research to Find Best OS	12/2/2014	12/2/2014	5h
39	Install OS	12/3/2014	12/5/2014	18h
40	OS Extension Research	12/8/2014	12/8/2014	3h
41	Set Up Drivers and Interface with Camera	12/9/2014	12/9/2014	1h
42	Install OS Extensions	12/9/2014	12/10/2014	5h
43	OS Extension familarization	12/10/2014	12/24/2014	60h
44	Multi-Threading	12/24/2014	12/26/2014	15h
45	Research and Implementation of TCP/IP Communication	12/29/2014	1/15/2015	80h
46	Controls Research	1/15/2015	1/16/2015	9h
47	Controls Consult With Dr. Dempsey	1/19/2015	1/19/2015	3h
48	Controls First Run	1/19/2015	1/21/2015	15h
49	Establish Data Format for Micro-Controller	1/22/2015	1/23/2015	8h
50	Power Supply Wiring	1/23/2015	1/29/2015	27h
51	Motor and Brain System Integration	1/30/2015	2/9/2015	40h
52	GPS/Compass and Brain System Integration	2/9/2015	2/18/2015	40h
53	Image Processing and Brain System Integration	2/18/2015	2/19/2015	9h
54	Motor, GPS/Compass, and Brain System Integration	2/19/2015	3/2/2015	40h
55	Motor, GPS/Compass, Image Processing, and Brain System Integration	3/2/2015	3/11/2015	40h
56	Overall Boat Testing	3/11/2015	3/20/2015	40h
57	Upload Deliverable to Website	10/27/2014	10/30/2014	20h
58	Make Progress Report 1 Slides	11/11/2014	11/14/2014	24h
59	Individual Progress Report 1 Practice	11/17/2014	11/18/2014	12h
60	Group Progress Report1 Practice	11/19/2014	11/20/2014	12h
61	Make Progress Report 2 Slides	2/9/2015	2/12/2015	24h
62	Individual Progress Report 2 Practice	2/13/2015	2/16/2015	12h
63	Group Progress Report 2 Practice	2/17/2015	2/19/2015	12h
64	Prepare for Spring Demo	3/16/2015	3/18/2015	12h
65	Make Demonstration Presentation Slides	3/18/2015	3/20/2015	12h
66	Demonstration Individual Practice	3/20/2015	3/24/2015	12h
67	Demonstration Group Practice	3/24/2015	3/26/2015	12h
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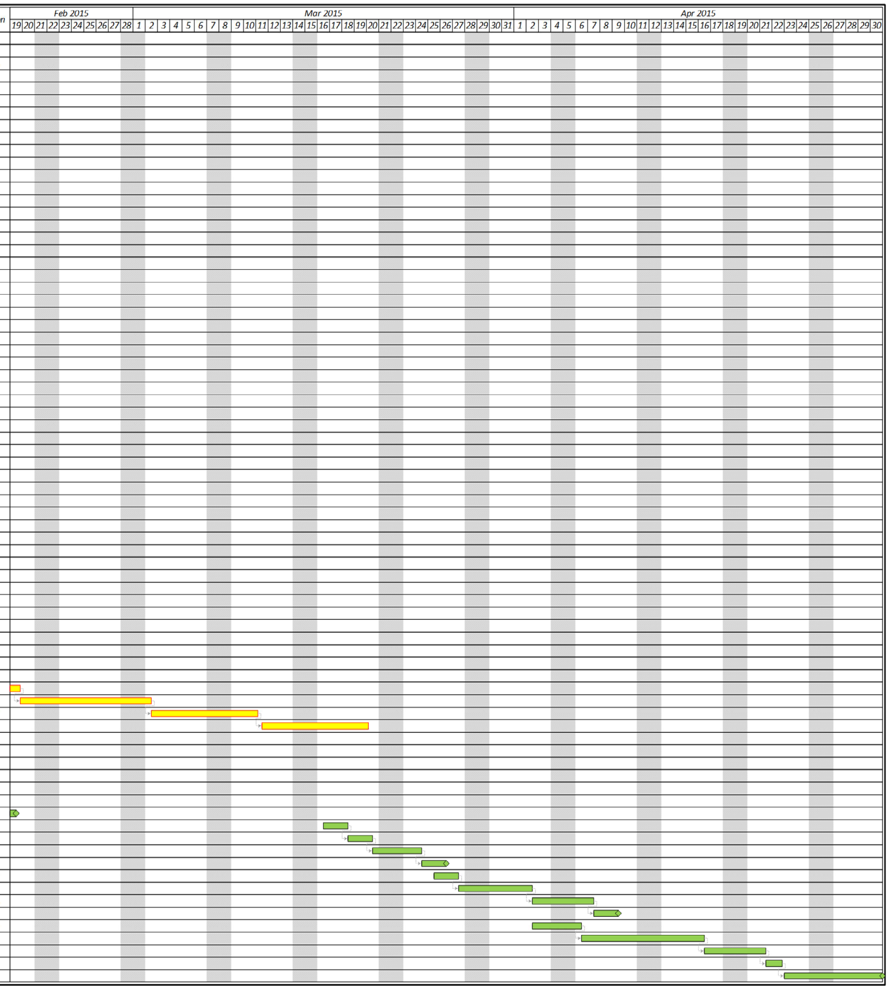
75	Final Paper Format	4/21/2015	4/22/2015	8h
76	Final Paper Proof Reading	4/23/2015	4/30/2015	36h



Appendix C - Detailed Division of Labor

Table 9. Division of Labor Part 1.

Task Name	Resource	Hours
Research And Determine Motor Configuration	Ryan Burke, Noah Dupes, Darren McDannald	10
Research Bi-Directional Motor Control	Ryan Burke, Noah Dupes, Darren McDannald	24
Electromechanical	Ryan Burke, Noah Dupes, Darren McDannald	40
Establish Method Of Communication Motor MCU	Ryan Burke, Noah Dupes, Darren McDannald	1
Implementation Of Communicaiton Motor MCU	Ryan Burke, Noah Dupes, Darren McDannald	12
Motor Hardware Design And Testing	Ryan Burke, Noah Dupes, Darren McDannald	48
Build And Test Motor Driver Circuit	Ryan Burke, Noah Dupes, Darren McDannald	54
Write Code To Get Compass Heading	Ryan Burke	9
Test Compass Code	Ryan Burke	9
Write Code To Get GPS Data	Ryan Burke	6
Write Code To Decode GPS	Ryan Burke	9
Test GPS Code	Ryan Burke	9
Test In MATLAB "GPS"	Ryan Burke	24
Establish Method Of Communication Compass	Ryan Burke	1
Establish Data Format Compass	Ryan Burke	4
Establish Data Format GPS	Ryan Burke	4
Implementation Of Communication Between Compass	Ryan Burke	6
Establish Method Of Comm. GPS	Ryan Burke	1
Implementation Of Comm. Between GPS	Ryan Burke	3
Build And Test GPS Compass Circuit	Ryan Burke	45
Research And Order GPS Compass Housing	Ryan Burke	3
GPS/Compass Housing Building	Ryan Burke	9
Research Method Of Circle Detection	Leah Cramer, Noah Dupes	6
Research Rectangle Detection	Leah Cramer, Noah Dupes	6
Test Shape Detection In Matlab	Leah Cramer, Noah Dupes	30
Color Space Research	Leah Cramer, Noah Dupes	9
Research Blob Detection	Leah Cramer, Noah Dupes	9
Pc Implementation In C And Testing	Leah Cramer, Noah Dupes	50
Pc Video Mark Up	Leah Cramer, Noah Dupes	40
Brains Implementation And Camera Interface	Leah Cramer, Noah Dupes	3
Boat Image Processing Testing	Leah Cramer, Noah Dupes	40
Rc Decoder	Darren McDannald	9
Convert Rc Sig To Motor Control Sig	Darren McDannald	5
Implement Rc Fail Saves	Darren McDannald	3
Test Rc Control	Darren McDannald	9
Rc Testing Time	Darren McDannald	3
Research And Determine Boat Frame	Team OBSCENE	6

Table 10. Division of Labor part 2.

Research To Find Best Os	Darren McDannald	5
Install Os	Darren McDannald	18
Os Exstention Research	Darren McDannald	3
Install Os Extensions	Darren McDannald	1
Set Up Drivers And Interface With Camera	Darren McDannald	5
Os Exstention Familarization	Darren McDannald	60
Multi-Threaded	Darren McDannald	15
Research And Implementation Of Tcp/Ip Comm.	Darren McDannald	80
Controls Research	Leah Cramer, Noah Dupes	9
Controls Consult With Gld	Leah Cramer, Noah Dupes	3
Controls Dev. First Run	Leah Cramer, Noah Dupes	15
Establish Data Format MCU	Team OBSCENE	8
Power Supply Wiring	Team OBSCENE	27
Motor MCU And Brain System Integration And Decision Making Testing	Team OBSCENE	40
GPS/Compass And Brain System Integration And Decision Making Testing	Team OBSCENE	40
Image Processing And Brain System Integration And Descion Making Testing	Team OBSCENE	9
Motor MCU GPS/Compass And Brains System Integration And Decision Making Testing	Team OBSCENE	40
Motor MCU GPS/Compass And Brains Image Processing System Integration And Decision Making Testing	Team OBSCENE	40
Boat Testing Boat In Pool	Team OBSCENE	36
Upload Deliverable To Website	Team OBSCENE	20
Make Progress Report 1 Slides	Team OBSCENE	24
Individual Progress Report 1 Practice	Team OBSCENE	12
Group Progress Report 1 Practice	Team OBSCENE	12
Make Progress Report 2 Slides	Team OBSCENE	24
Individual Progress Report 2 Practice	Team OBSCENE	12
Group Progress Report 2 Practice	Team OBSCENE	12
Prepare For Spring Demo	Team OBSCENE	12
Make Demonstration Presentation Slides	Team OBSCENE	12
Demonstration Individual Practice	Team OBSCENE	12
Demonstration Group Practice	Team OBSCENE	12
Make Final Presentation Slides	Team OBSCENE	12
Final Presentation Individual Practice	Team OBSCENE	24
Final Presentation Group Practice	Team OBSCENE	18
Prepare For Q&A	Team OBSCENE	12
Final Paper Detailed	Team OBSCENE	12
Final Paper Writing	Team OBSCENE	48
Final Paper Combining Sections And Voices	Team OBSCENE	18
Final Paper Format	Team OBSCENE	8
Final Paper Proof Reading	Team OBSCENE	36