Navigation and Thrust System for AUVSI RoboBoat

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EXECUTIVE SUMMARY

Bradley University Department of Electrical and Computer Engineering has dedicated a senior capstone project to designing an autonomous robotic boat to compete in the Association for Unmanned Vehicle Systems International (AUVSI) RoboBoat competition. However, the task of designing the boat for competition has proven a task that is seldom completed within the time span of the senior capstone project timeline. To make the task of building a competition RoboBoat more feasible, the Navigation and Thrust System is being proposed. This system will function as the basis for any future attempts at designing a competition RoboBoat. This system will deliver the means of propulsion for the physical boat, as well as providing location and orientation information upon request. This system will reduce the requirements of a competition RoboBoat design to allow future senior capstone projects the ability to compete in the RoboBoat Competition.

The designed Navigation and Thrust system will consist of two main subsystems. The first subsystem is thrust, also called propulsion. This aspect of the system will be responsible for moving the RoboBoat frame around a body of water. Propulsion will be achieved utilizing four Blue Robotics T100 thrusters, which is a constraint for the system because the department has previously attained these thrusters and they can be inherited at no cost. To control the speed and direction of the RoboBoat the system will utilize a remote control (RC) signal processor as well as a motor control unit. Together these two components will achieve the task of moving the RoboBoat in a body of water, completing the thrust subsystem.

The second subsystem designed for the Navigation and Thrust system is navigation. This aspect of the system will be responsible for sending the location and orientation of the RoboBoat in a preprocessed packet, upon request from an outside processing unit. Historically the RoboBoat competition has been hosted on a five-acre lake, so it is essential to have the ability for a RoboBoat to know accurately where it is located and oriented at any time. The autonomous aspect of the competition requires that the boat be capable of collecting data to know what it takes to manipulate the boat to achieve the desired tasks. This task will utilize a global position system (GPS) and a compass to read the information on the current location and orientation of the RoboBoat. The data will then be processed and placed into a packet that can be sent out of the Navigation and Thrust system upon an external request signal.

Due to previous designs of the Bradley University RoboBoat, the Navigation and Thrust system design will be constrained to use previously purchased hardware. The thrusters that this system is required to utilize are the Blue Robotics T100 Thrusters, as previously stated. The RC signals must be sent and received using the Futaba T6EX transmitter and 617FS receiver. The department has previously purchased these components. Therefore, their cost will not be considered in budget of $500 for the Navigation and Thrust system. The most important aspect of the system is that future Bradley University RoboBoat teams easily reuse.

The proposed Navigation and Thrust system will allow future senior capstone projects to compete in the AUVSI RoboBoat competition. The ability for these future teams to compete will provide a great engineering experience for the team members, as well as exposure to the Bradley University Department of Electrical and Computer Engineering.

ABSTRACT

In this document a navigation control system capable of collecting data from a global positioning system (GPS), compass, and remote control (RC) transceiver is proposed. This system will serve as a framework for future senior projects from the electrical and computer engineering (ECE) department intended to compete in the Association for Unmanned Vehicles Systems International (AVUSI) Roboboat competition. This competition, hosted by a non-profit organization devoted to advancing the unmanned systems community, provides an opportunity for student teams to race autonomous service vehicles on water. The proposed system will interpret the location and orientation of the boat in addition to controlling the movement of the boat. Location and Orientation data will be processed and sent out upon a request from an external processor. Interpretation of RC signals will result in movement of the boat by actuating four brushless direct current motors, also known as thrusters. The Bradley University ECE department has attended the AVUSI Roboboat competitions in the past and noted an extreme amount of time that the competition requires from students. The functionalities of this system will allow for reduced development time of an autonomous vehicle for future senior projects to participate in the AUVSI Roboboat competition.

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I. INTRODUCTION

A. Problem Background

The Association for Unmanned Vehicle Systems International (AUVSI) is a non-profit organization devoted to advancing the unmanned systems community. AUVSI is responsible for the creation of the International RoboBoat Competition, an event that allows student teams to race autonomous surface vehicles (ASVs) on the water. Participating teams are tasked with designing an ASV that can navigate through an aquatic obstacle course to complete various challenges.
Bradley University participated in the RoboBoat competition in 2012 and 2013. The inaugural launch of the boat was the product of seniors Jeremy Borgman and Max Christy with the assistance of juniors Zackary Knoll and Steven Blass. The boat featured a catamaran style frame that relied on dual pontoons to float. This design allowed for slow speed and stability. Both pontoons allowed for a flat surface on which electronic systems could be mounted. Two direct current (DC) motors delivered propulsion to the boat. Additionally, four maneuvering thrusters were used as required by the system. The primary decisions made by the system were completed on an ARM Processor (Beagleboard XM) utilizing a USB Webcam. The first team to compete at the RoboBoat competition earned 8th place out of 16 teams.

The second team to compete at the AUVSI RoboBoat competition did so in 2013. The two primary designers on the team were Zackary Knoll and Steven Blass, the juniors who worked on the 2012 boat. The seniors had assistance from supporting underclassman Bradley Lan and Daniel Van de Water who were able to assist in the development and fabrication of on board systems. Both seniors were able to make several modifications to improve the performance of the entire system. These modifications included a motor controller upgrade, a transition to an Intel i3 primary processor (replacing the Beagleboard XM), and the utilization of two USB cameras. New edge detection capabilities were also added using a laser illuminated detection and ranging (LiDAR) unit. The second team to compete in the RoboBoat competition earned 5th place out of 15 teams.

While the 2016 competition is likely out of reach, designing a platform base offers a challenging and rewarding project. The subsystem being developed will include a remote control (RC) decoder, a global positioning system (GPS) and compass unit to process data, as well as a motor controller for four brushless DC thrusters. While a competition RoboBoat would require much more design, this system will function as a foundation for future projects. This will hopefully lead to future competition for the Department of Electrical and Computer Engineering at Bradley University.

B. Problem Statement

Mr. Nick A. Schmidt, who sponsored and led previous AUVSI RoboBoat teams for Bradley University, requires a system to serve as the framework for the RoboBoat competition. For the competition the boat needs to move and to specific locations around a large lake, so the two main subsystems for the framework accomplish navigation and propulsion. The system is constrained by the past competition rules that have been nearly consistent for the entire history of the competition and are found in [1]. In order for the system to be a useful framework for the competition RoboBoat, it should be reusable and water resistant. Other requirements from the Bradley University Electrical and Computer Engineering Department for the system include a $500 maximum budget and a mode switch for the system. The mode switch increases reusability by adding an RC signal that would switch the competition boat to either RC-controlled propulsion or autonomous mode.

C. Constraints

The proposed Navigation and Thrust system must meet all of the constraints listed in Table I. All of the constraints besides the cost are derived from past AUVSI RoboBoat competition rules found in [1]. The Navigation and Thrust System must meet the constraints for the actual competition because it is serving as a framework for it. The competition rules set the weight and physical dimension constraints. Runtime communication for the RoboBoat is constrained to not changing any software or logic. The T100 thrusters are 12 volt (V) brushless DC thrusters that will be used to execute the RC commands for the propulsion system. The RC commands must be an input to the system using the Futaba T6EX RC controller and received by the Futaba 617FS RC receiver. The propulsion system must also include a physical motor kill switch that shuts off any power to the motors for safety. The maximum budget for the project is $500.

TABLE I. LIST OF CONSTRAINTS

The system must not have communication that can change its software and/or logic during a runtime
The system must use the T100 thruster
The system must use the Futaba T6EX Transmitter and 617FS Receiver
The system must be under 5 kg
The system must cost less than $500.00
The system must be contained within 30 cm x 30 cm x 20 cm
The system must be powered by a 12 V battery
The system must include a physical kill switch

D. Scope

Due to the fact that the Navigation and Thrust system is a subsystem of a competition RoboBoat it is imperative to define what is within the scope of the proposed system. Defining what will be designed in the Navigation and Thrust system is vital to the project’s success. Table II that follows defines what is in and out of scope for the designed system.

TABLE II. PROJECT SCOPE

In Scope	Out of Scope
Motor Control	Image Processing
Remote Control	Central Processor
GPS & Compass Data Processing	Autonomous Control

As can be seen in Table II the design of the central processor to handle interfacing the entire boat is not within the scope of the Navigation and Thrust system. This will force the team to design methods to test the various aspects of the system. The RC system will issue commands to the motor system. Note that motor and thruster are used interchangeably because in our case we only have one type of motor, which is the T100 thruster. The motor control system will be a microcontroller-based system that receives instructions from the RC system and controls the thrusters through software to provide thrust instructed by the RC system. Together these aspects should allow the boat to predictably move through the water from the speed and direction commands. The GPS and compass data processing will require an external processor to make a request for the information. Once the request signal is received then the microcontroller-based controller will accept the signal and transmit a bundled sensor data. The external system will then be responsible for the receiving of the data packet.

II. Statement of Work

A. System Description

The input-output relationship of the Navigation and Thrust system is visually represented in Figure 1 on the next page. The system will accept a 12 V DC battery supply to power the system. As previously discussed, GPS and compass processing must accept a request signal as an input to know when this data is required by the external processor. Historically the RoboBoat competition has required a kill switch to remove power to all thrusters in case of an emergency. With this requirement the Navigation and Thrust system must have the ability to accept a hardware motor kill signal. Finally, the designed system must have the ability to accept the RC signals generated by the Futaba T6EX transmitter. These signals include both speed and direction controls through the joystick movement, a mode switch to allow the user to choose between autonomous and RC mode, and a kill signal that will shut down the thrusters through software.

i. System Block Diagram

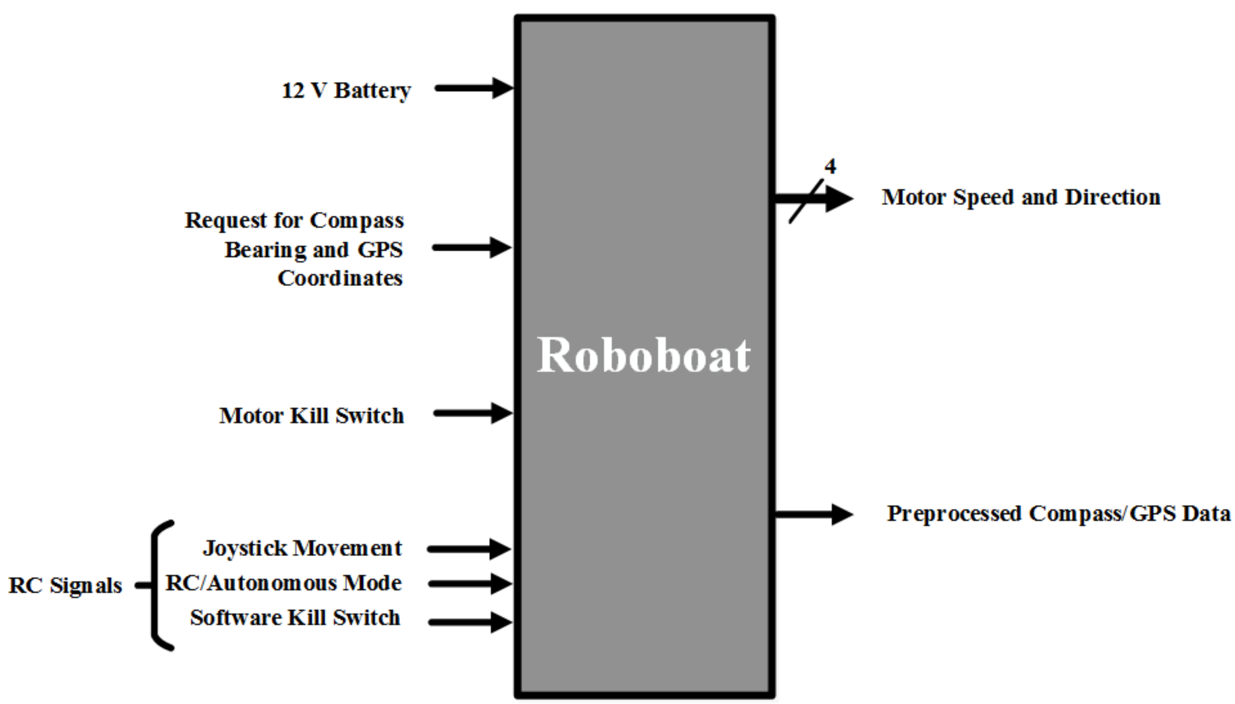


Fig. 1 System Block Diagram for Navigation and Thrust system

The overall system block diagram in Fig. 1 shares a 12 V battery as the power source. The other inputs and outputs for the system are independent for the propulsion and thrust systems. The propulsion system inputs include the motor kill switch and the RC signals. The RC signals are sent to the system with the Futaba T6EX Transmitter and received by the Futaba 617FS Receiver. The signals control the movement of the four T100 thrusters with a joystick that sends signals for forward movement and another designated for turning left or right by changing which direction each motor shaft rotates. The motor movement is the speed and direction output for the system. A toggle switch on the RC transmitter sends a signal to shut off the motors when active. Another switch is used to determine if the system is in RC or autonomous mode. The autonomous mode functionality will not be completed but the switch is still necessary to meet a constraint for the system. The navigation system inputs include requested GPS coordinates and compass bearing determined by sensors. The GPS and compass signals will be preprocessed and output from the system as packaged data.

ii. Subsystem Block Diagram

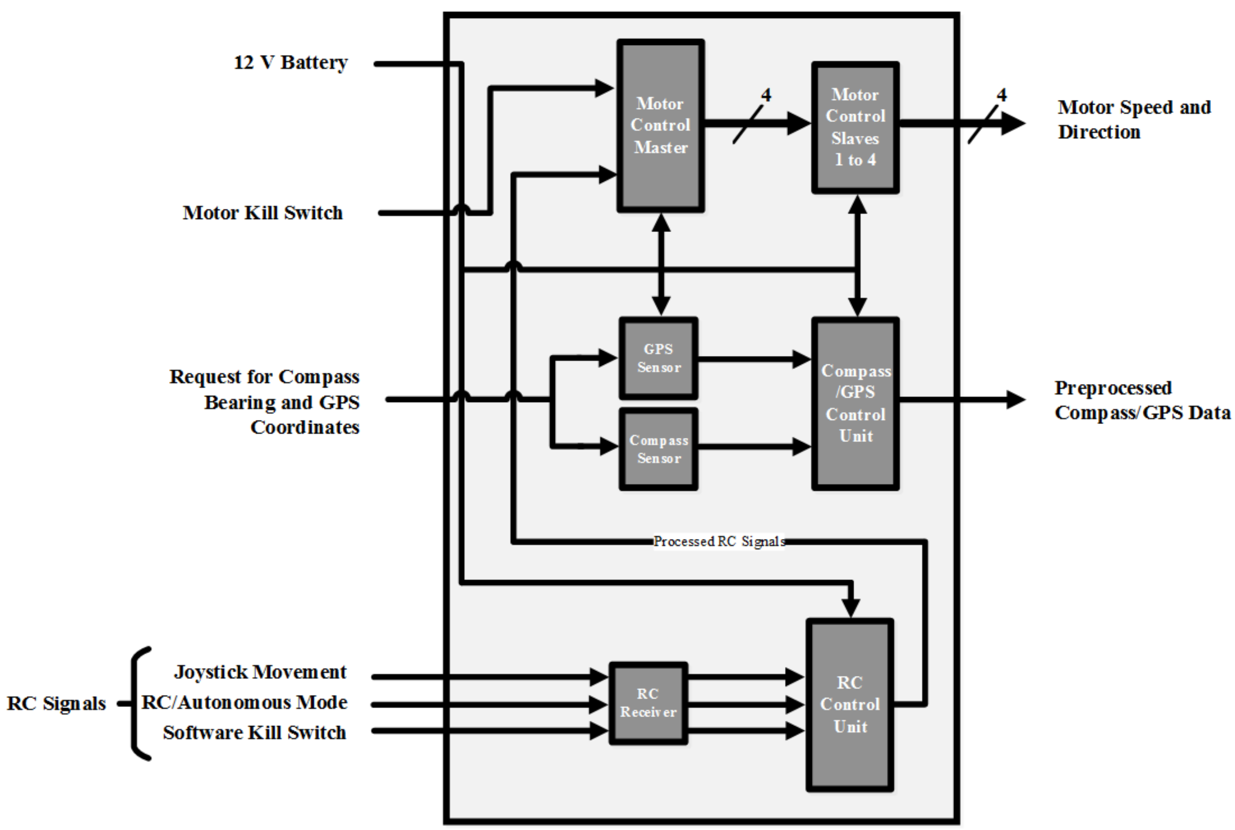


Fig. 2 Subsystem Block Diagram for Navigation and Thrust system

Figure 2 displays how the inputs to the Navigation and Thrust system will be converted into the stated outputs. All of the RC signals connect to the RC receiver, which then communicates the data to the RC control unit through a serial connection. This unit then processes all of that information and sends the information to the master motor control block. This block will be responsible for parsing the RC data into individual motor speed and direction commands to be sent on to the four separate motor control slaves. The motor control slaves are then responsible for executing the speed and directions commands from the master motor controller, by actuating their specified motor in the manner required.

As can also be seen, the request for compass bearing and GPS coordinate signal will trigger the most recently collected data from the GPS and compass controller to be sent out. Both sensors will be continually accumulating and keeping only the most recent set. The RC control unit will then be responsible for converting this data into a defined packet that contains all of the necessary information. This information will then be sent out for interpretation and use by an external processor in future versions of the RoboBoat. The 12 volt battery input is also distributed to all of the blocks, displaying that the power for the system will come entirely from the input battery.

iii. High-Level Flowchart

Both the navigation and the thrust aspects of the Navigation and Thrust System will require software to control their operations. The flowcharts that follow describe how the designed software will achieve the desired tasks.

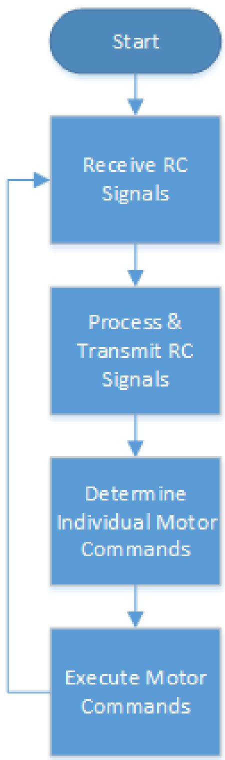


Fig. 3. Thrust Aspect Flowchart

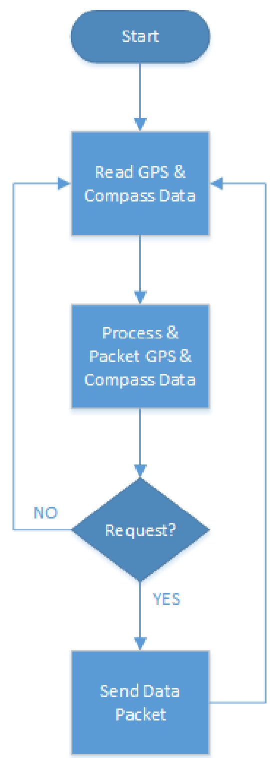


Fig. 4.Navigation Aspect Flowchart

Figure 3 describes the functionality of the software that will control the movement of the RoboBoat in water. After initialization the system will receive RC signals from the Futaba T6EX transmitter. These signals will then be processed into a speed and direction for the boat. This speed and direction information will be sent to the master motor controller that will determine how each motor needs to turn to achieve the desired motion. Turning will be the result of a velocity difference between thrusters. The master will then control four slave controllers to execute the commands to the Blue Robotics T11 thrusters.

The most significant portion of the navigation aspect of the system is based on the software describe by Figure 4. This flowchart describes how the system will interpret the boat's location and orientation. Once the devices are initialized the system will read the data sent by the sensors that collect GPS and compass data. Once this data is collected, the system will then process that data into a predetermined data packet that will make the data more useable by an outside source. Next the system will check if an external request signal has been sent into the system. If this request has been made the system will send out the data packet and then begin collecting the next data point. If no request has been made, the system will simply read the next data point and begin processing that information.

iv. Nonfunctional Requirements

TABLE III. LIST OF OBJECTIVES

The system should be reusable.
The system should be water resistant.

The nonfunctional requirements, as listed in Table III above, are requirements of the system that will not be evident through the inputs and outputs. As the Navigation and Thrust system is to be utilized as a building block for future RoboBoat teams, the system must have the ability to be utilized as designed in the future. For the system to be reusable, it must be designed effectively and documented such that new can acclimate to the system quickly. This means that the inputs and outputs to the system must have a very firm definition of what will be accepted and sent out of the system. This will allow outside users the ability to quickly and effectively utilize the Navigation and Thrust system.

Due to the fact that the system will be implemented onto a boat, the system must be resistant to normal splash that may occur as well as handle any weather that may arise. The failure to create a water resistant design will prove to result in an obsolete product. The components designed must be housed in a manner that will prevent normal operation of the boat from destroying the designed system.

v. Functional Requirements

Table IV that follows displays the functions that the Navigation and Thrust system will accomplish and how they will be deemed a success. This table spells out what the system must be able to do and how it should function.

TABLE IV. FUNCTIONS AND SPECIFICATIONS

Subsystem	Function	Specification
Thrust System	The system must accept a mode signal.	*Interface*: The system will have two modes of operation. RC mode will execute motor speed and rotational direction instructions based on the status of the RC transmitter. Autonomous mode will receive and execute motor speed and rotational direction instructions from an external processor (not developed in this project).
	The system must accept a software kill signal to shut down the thrusters.	*Interface*: The system should accept a kill signal sent from the RC controller that will issue a shut down instruction to the master motor controller. The system will then physically disconnect the motor power bus from the FET system. The shutdown process will take less than 1.5 seconds.
	The system must include a physical kill switch.	*Performance*: The system should have a switch that will physically disconnect the motor power bus from the FET system (taking less than 1.0 second for completion).
	The system must execute motor speed and direction commands.	*Performance*: The system will receive and execute at least 5 motor speed and rotational direction signals per second from the RC control unit.
Navigation System	The system must transmit, on request, GPS and compass processed data.	*Interface*: The system should accept a request signal from an external CPU. *Performance*: Accuracy of compass signal will have an error less than +/- 2°. Accuracy of GPS signal will have an error less than +/- 2.0 meters.

B. Design Approach and Method of Solution

The navigation system consists of a GPS and compass unit because the RoboBoat competition area is a large lake. GPS coordinates are provided for each of the missions and in order for the vehicle to travel to each mission area its GPS coordinates are necessary. A compass is needed as well so the vehicle can be properly orientated as it navigates the competition area. On request, the system must transmit global positioning system (GPS) and compass readings; therefore, a GPS and compass sensor are needed. These sensors are commonly sold as a single, combined unit or sold separately. The GPS and compass readings also need to be preprocessed and sent on request. Determining whether one microcontroller unit (MCU) or multiple are needed for the preprocessing and what kind of communication is best to send out the data packets was explored in the design space. Options considered for GPS and compass communication were are, Wi-Fi, Ethernet, and inter-integrated circuits (I^2C).

These communications methods are a factor in selecting the GPS and compass units as well as the microcontrollers used to preprocess the readings. The communication technologies are all compatible with standard computer motherboards, which positively contributes to the objective of having a system that is reusable.

The design method for the navigation system is to have separate compass and GPS sensors. The main reasons the sensors were not selected to be on a single chip is because the compass needs to have tilt-compensation built in and this was only found when the compass sensor was sold separately. One microcontroller will be used for processing the GPS coordinates and compass bearings. The selected compass transmits data via I^2C so that is the communication technology between the device and the microcontroller. The GPS chip can communicate via I^2C or serial and serial was chosen because of more experience programming serial connections in previous Bradley coursework. The control unit microcontroller will send the data, on request, via a serial connection such that it can be viewed and troubleshooter on computer terminal software.

To test the results of the navigation system the GPS coordinates and compass bearings data will be compared with other traditionally reliable devices to verify accuracy. Testing space includes outside areas on Bradley University's campus. A cart will be pushed around with the system transmitting the data to a computer via serial connection from the navigation control unit. The data will be stored along with the same data from a cellular phone to analyze the accuracy. The error will be later plotted in MATLAB.

To achieve the tasks of thrust, the system is constrained to using the Blue Robotics T100 thrusters as has been stated. This thruster is a brushless, sensorless DC motor. To control a brushless DC motor current needs to flow in the specified path, with the specified sequence for the motor to operate as intended. There are a couple of main strategies that have been used to control brushless DC thrusters. The first option is to use a motor driver. This device would accept a serial communication that delivers speed and direction commands for the motor. The second option is to use a motor predriver. This would work in a similar fashion to the motor driver however the motor predriver requires external circuitry to achieve full control of the brushless DC motor. The motor driver has internal metal-oxide-semiconductor field-effect transistor (MOSFET or FET) circuitry to properly switch the high and low sides of the thruster, this adds design to the use of the predriver. However the research on motor drivers showed that the power required by the Blue Robotics T100 thrusters was too great for any of the motor drivers. This led the design choice for controlling the thrusters to a motor predriver and external circuitry to convert the predriver signals into current for the thrusters

The next aspect of thrust is the need to convert a boat speed and direction command into speed and direction commands for the four individual thrusters. To handle this, the team will design a master-slave relationship between the boats speed and direction commands and the individual thrusters. The choice that was made was to use one master controller that would have control over four slave controllers, one for each motor. The master controller will be responsible for interpreting the speed and direction commands for the boat and determining the speed and direction for the thrusters. Once these commands are determined, communication between the master and slaves will control the thruster. The slave controller will then interface with the predriver set up that was discussed above. The slave will convert the motor speed and direction commands into signals that are acceptable to the predriver. Together the master and slave configuration will be able to control the speed and direction of the boat.

To complete the thrust aspect of the system, RC signals will be sent and received to generate the signals for speed and direction commands for the boat. The signals will be sent to the system using the Futaba T6EX transmitter. Once these signals make it into the system they will be received by the Futaba 6 17FS receiver, as this transmitter-receiver combination is a constraint given to this system. The RC signals received will then be sent to a microcontroller to process the string of characters into a form that will be common between the RC output and the motor control input. These signals will then be sent onto the master motor controller, to begin the process described above.

To ensure that the thrust aspect of the Navigation and Thrust System works as expected the system will be mounted onto the frame of the previous RoboBoat. Together the system will be placed into the pool at the Markin Recreational Center to test that the system is operating as expected.

C. Economic Analysis

A constraint upon the Navigation and Thrust System is that it cannot cost above $500. As is true with any project, it is vital to plan how this budget will be spent to best optimize the system. The given budget is attainable for this project due to the fact that the Bradley University Department of Electrical and Computer Engineering had previously purchased the high cost items. The Blue Robotics T100 thrusters, as well as the Futaba T6EX transmitter and 617FS receiver are the devices that the department had previously purchased. The two largest portions of the budget will come from the compass and GPS units that will be purchased for the design of the navigation aspect of the system. Outside of these components the budget will be used to purchase a variety of microcontrollers as well as power electronics to handle the processing and execution of the systems functions. For a table that displays the budget in more depth, please see Appendix A.

D. Project Timeline

The Navigation and Thrust System is scheduled for completion the week of March 6th. This date was calculated by taking the amount of lab time that is given to and estimating the amount of time it would take to complete the task. The equation below was used to improve the estimation accuracy. Parameter t_M is the most likely length of time based on productivity, realistic expectations for the activity, and dependencies on other participants and interruptions. The parameter t_O is the optimistic amount of time, and t_P is the pessimistic amount of time.

$$t_E = \frac{t_O + 4t_M + t_P}{6} \qquad (1)$$

Estimated time for project tasks was created using Equation 1. A table of estimated duration can be found in Appendix B.

E. Division of Labor

The high level tasks that must be completed for our project to be complete are RC control, Compass, GPS, FET system, and the Motor controller. These five tasks have been divided such that a team of three people can complete it.

RC control, Compass, and GPS can be grouped into one section, the navigation system, due to the similar requirements of all of the tasks (interfacing with sensors). This navigation system will require research into proper interfacing protocols. The current understanding is to use serial and I^2C communication protocols to communicate with the sensors. This task has been given to Evan Dinelli because of his interest in communicating with sensors, knowledge in programming microcontrollers, and experience with I^2C in previous lab work.

The thrust system is composed of two parts: the FET system and motor controller. The FET system will require research and knowledge on transistors and how to accurately assemble the circuit and adjust the switching time of the transistors to power the thrusters. This part of the thrust system has been given to

Michael Barnes due to his interest in interfacing with the thrusters and knowledge in development of physical circuits.

The motor controller will require research and knowledge on control algorithm development and interfacing with separate microcontrollers and predrivers. This task has been given to Dan Van de Water because of his interest in interfacing with the predriver and experience taking two controls courses.

When referencing Table 1 in Appendix B it is noted that the navigation system (RC control, Compass, and GPS) accumulate to 145 hours, and the FET system requires 185 hours, while the Motor controller requires only 110 hours. This time difference was done on purpose such that the individual working on the motor controller has time to integrate their system with their peers. The amount of time spent integrating has been included in the duration estimation of the navigation subsystem and FET system.

F. Societal and Environmental Impacts

The proposed RoboBoat design has a limited societal impact because it is merely a framework for a complete system. The technology and design could be used positively in many situations such as emergency remote rescues, marine exploration, and research.

The system can impact the environment in multiple ways. Potential safety hazards exist with the thrusters, power source, and circuitry. The system is constrained to use a 12V battery as the power source, which could be harmful to the environment if the battery leaks. For protection the battery will be enclosed in a plastic container that is resistant to battery acid. The thrusters are shrouded in order to prevent the propellers from damaging anything while in use. This will also prevent damage to the thruster itself. The system is specified to be water resistant; therefore, circuit covers will be used to shield all circuitry from causing fires by short-circuiting. These safety measures will ensure that RoboBoat has a limited impact on the environment. RoboBoat can positively impact the environment with its technology being utilized in oil spill rescues and remote aquatic fire suppression.

III. CONCLUSION

The Navigation and Thrust system is proposed as a senior project to serve as a platform for future Bradley University students to develop a system capable of competing in the AUVSI Roboboat challenge. Participating in the AVUSI competition would bring prestige to the University, and irreplaceable experience to the students. The system has several specifications that should be met including the acceptance of a mode signal from the RC controller, the acceptance of a kill signal from the RC controller, a physical kill switch, and the acceptance of a request signal for the navigation data. Our system should move the Roboboat once given instruction through the RC and the navigation system should transmit a data packet after receiving a request signal. Once complete, the proposed system will provide future teams more time to work on the autonomy of the Roboboat. This additional time will allow for a refined Roboboat to be created for the prestigious participation in the AUVSI Roboboat competition. The Roboboat produced would then accurately reflect the capability of the students and faculty of Bradley University.

IV. References

[1] 2015 RoboBoat Competition Final Rules and Task Descriptions. [Online]. Available: http://higherlogicdownload.s3.amazonaws.com/AUVSI/fb9a8da0-2ac8-42d1-a11e-d58c1e158347/UploadedFiles/RoboBoat_2015_final_rules_20150527.pdf [Accessed: 28- Aug.- 2015].

IV. Appendix A

TABLE I. BUDGET WITHOUT COST OF PREVIOUSLY PURCHASED COMPONENTS

Part	Unit Cost	Quantity	Total Cost
Blue Robotics T100 Thrusters	$109.00	4	--
Internal Rectifier IRLB8748PbF HEXFET	$0.72	24	$25.00
Microcontrollers	$7.67	7	$60
Predriver	$7.01	4	$30.00
Futaba T6EX Transmitter	$150.00	1	--
Futaba 617FS Receiver	$69.98	1	--
Adafruit Ultimate GPS Breakout	$39.95	1	$40.00
Compass – CMPS 10	$57.33	1	$60
Unplanned Expenses	$200.00	1	$200.00
			$415

Table I details the cost of the Navigation and Thrust system with components that have already been purchased by the department, which have not been accounted for in the cost of the system.

TABLE II. DETAILED BUDGET

Part	Unit Cost	Quantity	Total Cost
Blue Robotics T100 Thrusters	$109.00	4	$436.00
Internal Rectifier IRLB8748PbF HEXFET	$0.72	24	$17.28
Master Controller – ATmega 1284	$7.67	1	$7.67
Slave Controller – ATmega 644A	$6.75	4	27.00
Allegro MicroSystems A4960	$7.01	4	28.04
Futaba T6EX Transmitter	$150.00	1	$150.00
Futaba 617FS Receiver	$69.98	1	69.98
RC Controller – ATmega 328	$3.24	1	$3.24
Adafruit Ultimate GPS Breakout	$39.95	1	$39.95
Compass – CMPS 10	$57.33	1	$57.33
GPS/Compass Controller – ATmega 1284	$7.67	1	$7.67
			$844.16

Table II details the cost of the Navigation and Thrust system with all components and associated costs accounted for.

V. APPENDIX B

TABLE I: TASK DURATION ESTIMATION

Task Name	Duration (hours)
RC control	50
Compass	55
GPS	40
FET system	185
Motor controller	110

Table I was generated to establish a timetable in which the project would be completed. The duration of the project is consistent with the March deadline.

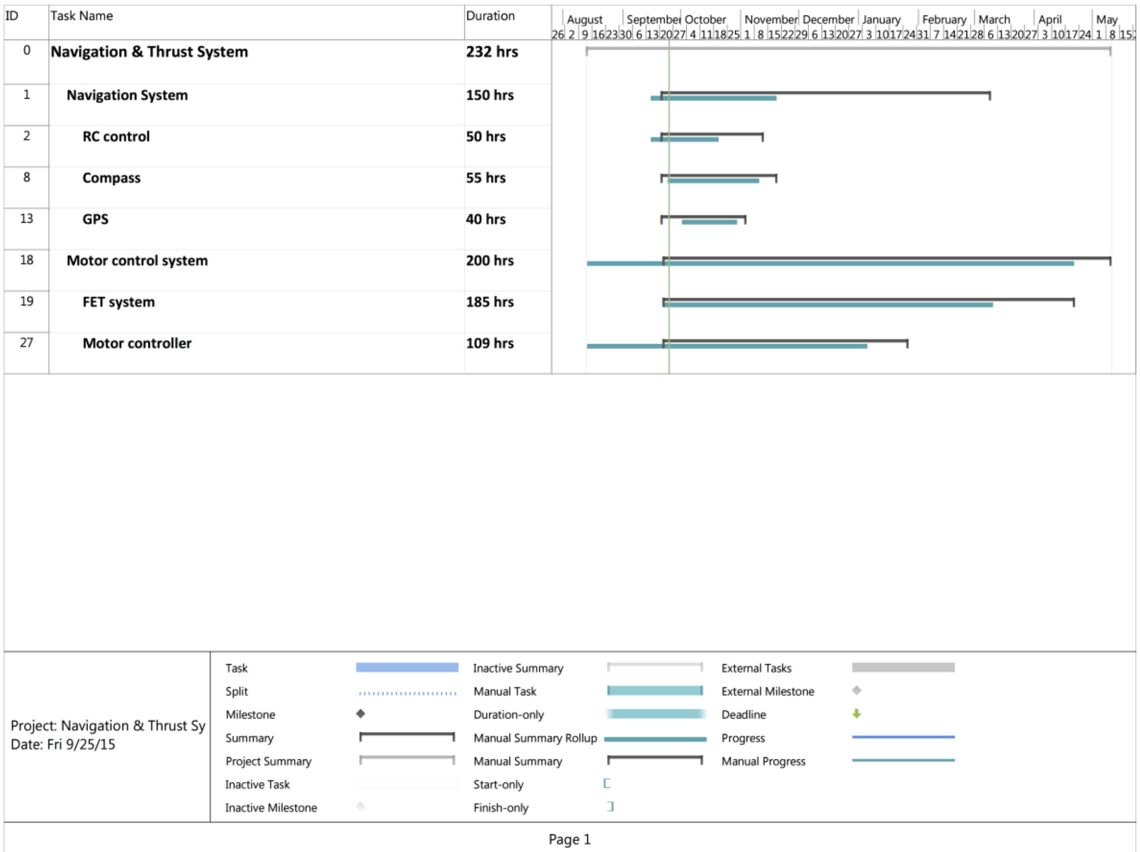
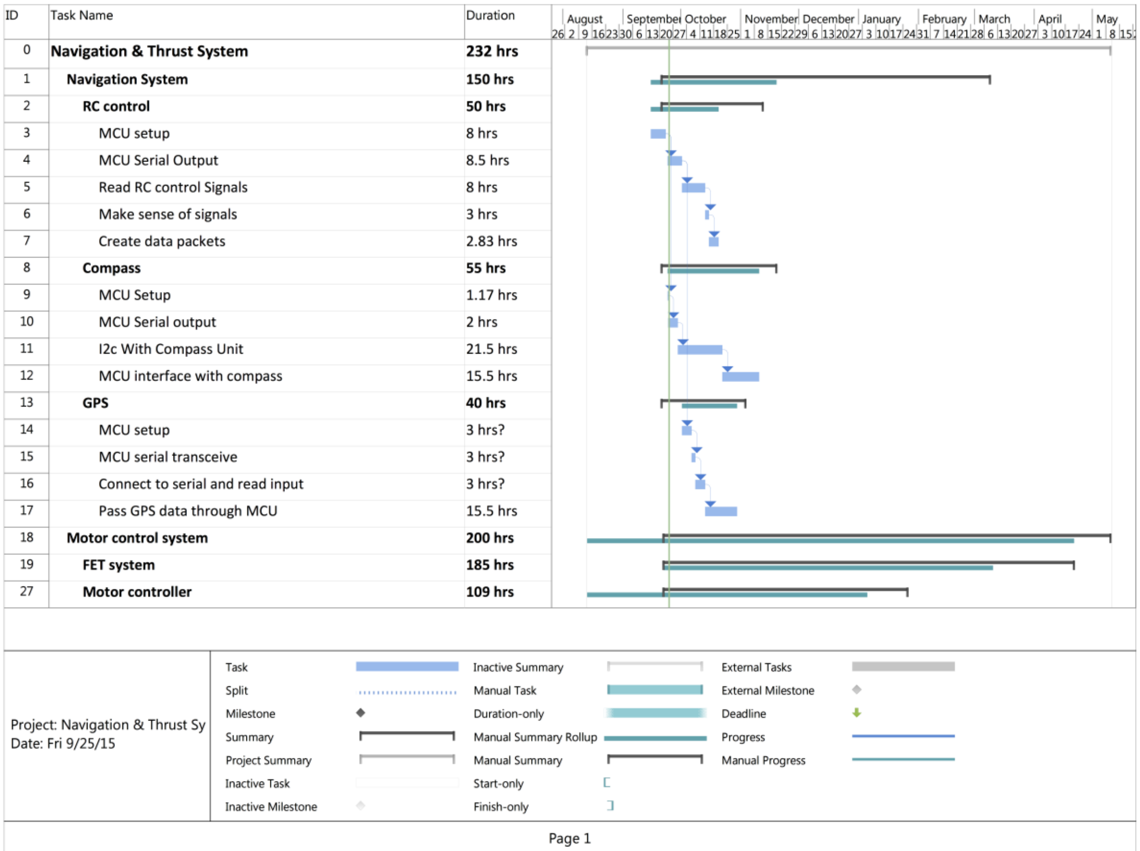


Figure 1: High Level Gantt Chart

Figure 1 is a visual representation of our schedule. Refer to Fig. 2 and Fig. 3 for expanded views of the navigation and thrust system separately.



ID	Task Name	Duration
0	**Navigation & Thrust System**	**232 hrs**
1	**Navigation System**	**150 hrs**
2	**RC control**	**50 hrs**
3	MCU setup	8 hrs
4	MCU Serial Output	8.5 hrs
5	Read RC control Signals	8 hrs
6	Make sense of signals	3 hrs
7	Create data packets	2.83 hrs
8	**Compass**	**55 hrs**
9	MCU Setup	1.17 hrs
10	MCU Serial output	2 hrs
11	I2c With Compass Unit	21.5 hrs
12	MCU interface with compass	15.5 hrs
13	**GPS**	**40 hrs**
14	MCU setup	3 hrs?
15	MCU serial transceive	3 hrs?
16	Connect to serial and read input	3 hrs?
17	Pass GPS data through MCU	15.5 hrs
18	**Motor control system**	**200 hrs**
19	**FET system**	**185 hrs**
27	**Motor controller**	**109 hrs**

Figure 2: Navigation System Expanded Gantt Chart

Figure 2 shows the expanded view of the navigation system. Observed is parallel aspect of the RC control, Compass, and GPS. This was done because each of the subsystems within the navigation system are independent. The only system that requires work to be completed for the motor system as a whole is the RC control system. However, this can be digitally replicated for testing purposes and only needs to be completed for final integration. The signal that will be received with be discussed when programming the motor controllers to ease system integration.

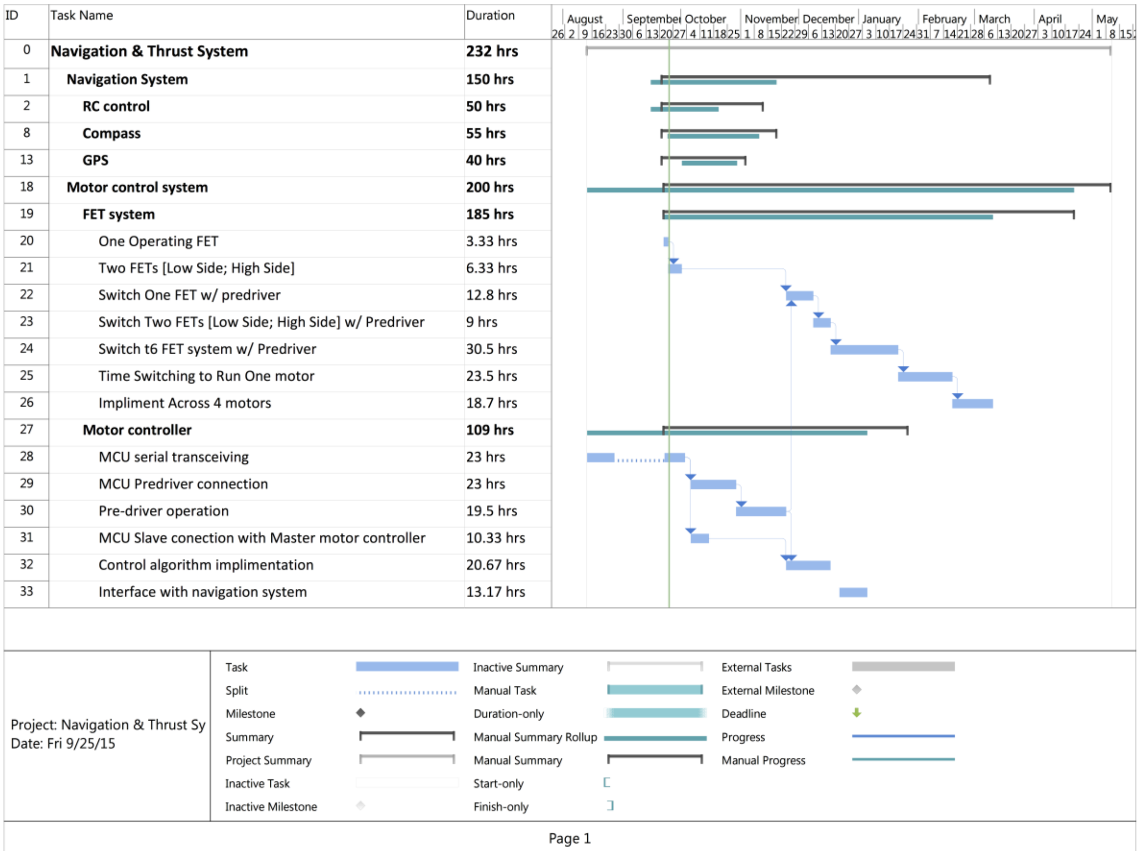


Figure 3: Thrust System Expanded Gantt Chart

Figure. 3 presents the expanded Gantt chart of the thrust system. The predriver must be capable of sending out signals so that FET system can be developed past elementary stages. Programming this functionality is prioritized to maintain the critical path. If this is delayed then the entire project timeline is delayed.