2016 USNA RoboBoat

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***Abstract* – A team of newly commissioned Naval Officers from the United States Naval Academy have designed an autonomous boat to compete in AUVSI foundation's 9th International RoboBoat Competition. The competition requires a sea-worthy vessel to autonomously navigate an obstacle course lined with buoys, and to demonstrate successful autonomous docking abilities. This endeavor necessitates skillful programming, and in depth understanding of sensors, control theory, and a great deal of teamwork between the officers. The design for this year's competition (July 2016) is a dual pontoon watercraft, whose electrical components are contained in two waterproof Pelican cases mounted onto the top of the pontoons. The team will measure their success during their testing phase where the boat's control system (image processing and position tracking) will be tested in a controlled water environment (pool/creek). Adjustments will be made for optimal performance at the competition.**

I. Introduction

Every year the AUVSI Foundation hosts an international RoboBoat Competition that has competitors coming in from all over the world. The United States Naval Academy will be sending a team of four recently commissioned naval officers to compete in this year's competition in Virginia Beach, VA from July 5th to the 10th. The team's goal was to design and construct a marine vehicle that has the ability to autonomously navigate through floating obstacles and complete certain predetermined tasks including autonomous docking, and radio frequency detection.

II. Design Process

A. Objectives

Essentially the team wanted the USNA RoboBoat to be durable and have a lot of utility, which is why they are at the top of the team's objectives list. The following are the team's list of objectives:

- **Durability:** the ability of the platform to withstand common environmental hazards to the physical vessel and onboard sensors.
- **Utility:** the ability of the vessel to successfully complete the tasks of the competition. This would be measured by the following accuracy metrics: consistency, versatility, and maneuverability.
    - **-- Accuracy:** is the ability to correctly perform an assigned task within specific degrees of success.
    - **-- Consistency:** the ability to complete tasks consecutively within error limits.
    - **-- Versatility:** the ability of the system to overcome unforeseen obstacles with minimal alterations to the system's coding and hardware.
    - **-- Maneuverability:** is defined as the degrees of freedom in the X motion, Y motion, and the rotation motion about the Z axis. These are effected by the following boat and environmental factors: turn radius, navigational draft, speed and beam of the boat.

B. Constraints

The following list of constraints are directly from the 2015 RoboBoat Competition Final Rules and Task Description:

- **Autonomy:** the vehicle must be fully autonomous and all decisions must be taken onboard the ASV/UAV.
- **Buoyancy:** the vehicle must be positively buoyant and stay buoyant for at least 30 minutes in the water.
- **Communication:** no communication to the vehicle can change its software and/or logic during a run.
- **Deployable:** the vehicle must have its own 3 or 4 point harness for crane deployment.
- **Energy source:** the vehicle must use self-contained electrical energy source(s). Sailboats are permitted.
- **Kill Switch:** the vehicle must be equipped with at least one 1.5in diameter red button that, when actuated, disconnects 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 forward facing location where a GoPro or similar device might be attached.
- **Propulsion:** any propulsion system can be used (thruster, paddle, etc.), but moving parts must have a shroud.

- **Remote-control:** the vehicle must be capable of remote control to be brought back to the dock.
- **Safety:** all sharp, pointed, moving, sensitive, or dangerous parts must be covered and clearly identified.
- **Size:** the vehicle must fit within a six-foot long, by three-foot wide, by three-foot high "box".
- **Surface:** the vehicle must float or use ground effect of the water. Mostly submerged or flying craft are forbidden.
- **Towable:** the vehicle must have designated tow points and a tow harness installed at all times.
- **Waterproof:** the vehicle must be rain/splash resistant. The competition is held "rain or shine."
- **Weight:** the vehicle and all sub-vehicles must have a combined weight of 140 lbs. or less.

C. *Functions*

USNA RoboBoat's functions are:

- Communication with User
- Remote Control
- Navigate Inland Channel Buoy
- Autonomous Docking
- Obstacle Avoidance

D. *Ethical Considerations*

The team understood that they represent the United States Navy, and that they are held to high ethical and moral standards. Safety and following competition rules were the team's specific ethical considerations. There are a lot of dangerous electrical equipment onboard USNA RoboBoat. For example, there are two 12 volt batteries in one of the waterproof Pelican cases. In order to make sure those batteries don't get wet the team made sure that the Pelican cases were completely waterproof and that the batteries ran through a panic switch to break the circuit in the event of an emergency in accordance to the safety procedures of the RoboBoat boat competition. This is a prime example of why following procedures have important consequences.

E. *Engineering Analysis or Simulations*

The autonomy portion of this comes from control theory techniques that the team learned in their junior year at the Naval Academy. The team started by acquiring equations of motions from the boat itself and Lagrangian equations that relate drag forces to input forces input by the motors using three degrees of freedom: x and y translations and rotation about the z axis. The team then designed a simulation in Simulink that modeled the boat's dynamics. Knowing the dynamics of USNA RoboBoat was essential for the team to design a controller for the system. In this case the team designed a proportional-derivative controller (PID Controller). This proportion aspect of this controller means the system will make big corrections if it is very far from its desired state, and small corrections if it is close to its desired state. The derivative portion of the controller means the system will make changes in accordance to the rate of change of the heading (in this case).

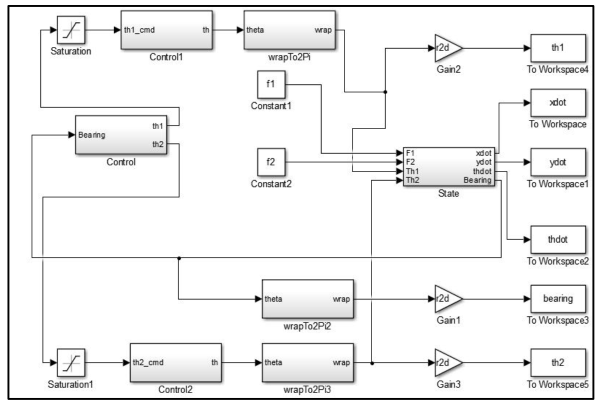

Figure 1: Full model in Simulink.

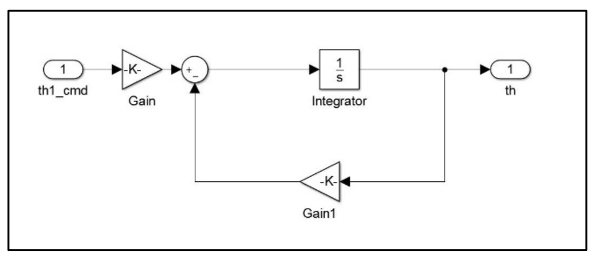

Figure 2: Controller designed for steering the servos.

F. *Component List and Selection*

- **2 Lenovo ThinkPads** with the following features: 64-bit Windows 7 OS, Intel(R) Core(TM) i5-4300M CPU @ 2.60GHz, and 8.00GB of RAM. These are used to run MATLAB, to power the Mbed Microprocessor via USB, and for Remote Desktop Communication.
- **EnGenius Wireless Outdoor Multi-Function AP:** with the following features: Weather Resistant, High Power up to 28dBm in 802.11b/g, SNMP, WPA/WPA2, 802.1x Authenticator, and Propriety 24v PoE. This is used for the wireless network so that the two Lenovo Think Pads can talk with each other via Remote Desktop Communication

- **mbed microprocessor:** used to generate pwm signals for the motors and servos.
- **Two ROBOTEQ 0353:** These are motor drivers that take in 5v pwm signals and apply appropriate power from a 24v supply to the motors. Each ROBOTEQ 0353 can power 2 motors.
- **MM74HCT245 Octal 3-STATE Transceiver:** used to bump mbed's 3.3v RC signal to a 5v signal that ROBOTEQ 0353 could understand.
- **REG3ASW Voltage Regulator:** Takes 24v down to 6v while maintaining amperage. It understands the 3.3v RC signals from mbed and can apply the appropriate power to the servos to move them to the requested position. This is used to power both servos.
- **Motors\Servos**

III. Design Evolution

A. Midshipmen Days

When all the team members were still Midshipmen at the Naval Academy they met once a week to work on the boat and to plan what each member would do individually until the next meeting. They did not have a lot of time to work on the boat due to their busy schedules, but managed to build the boat, wire all the motors and servos, create a test program to move each motor and servo, establish communication between the AIRMAR and MATLAB, and create a control simulation in Simulink.

B. Post-Graduation

After graduating from the Naval Academy, the teammates came in every work day to work on the boat. They gutted the entire circuit board and started over as it was a big mess. Getting the motors to spin and servos to move was actually really tricky, but fortunately the team worked in USNA's Weapons and Systems Engineering Department, which has a very helpful tech support team. With some help from the internet and tech support team, like getting an Op Amp and its data sheet, the team was able to get the motors and servos working. The team also worked on getting the controller, which needed the AIRMAR and Camera to be operational. Once the AIRMAR was able to generate headings, the Camera was able to recognize red and green buoys, the PID Controller was able to track the heading generated by MATLAB to travel between the closest red and green buoys.

RoboBoat needed a portable stand so that the team could take it out of the pool for maintenance and adjustments. One day when the pool was closed the team went to Home Depot and bought wood, screws and water sealant. They made a robust stand and made working on the boat a lot easier.

Additionally, the team needed a good way to make changes to the onboard computer's code. The team created a wireless network so that the teammates can remote desktop the onboard computer. The router itself was tricky because it is powered by the ethernet RJ45 cable alone. We had to pull out the power wires from the RJ45 cable and connect it to a power supply's wires. Surprisingly it worked. The only issue with the Remote Desktop communication is that there is a lag, which makes any corrections take a while to take effect.

The team was very excited when it came to start testing RoboBoat in the pool. The first day in the pool, however, the team noticed the boat was sinking! They yanked it out of the pool and noticed that the pontoons were flooded with water. The only way to drain the water out was to drill a hole in the bottom of each pontoon. As the water drained they went to Home Depot and bought two water drains and tub sealant. The team installed the water drains in where the holes were drilled. It was later determined that the water leaked in from holes where the motor cables fed through the pontoons and where the beams holding the servo and moment arms were attached to the pontoons. Accordingly the team applied the tub sealant where these holes (originally covered with duct tape) were. The next day, the team tested it seaworthiness and found only minor leaks. On the next pool testing day, the team tried to get the controller working so that the boat would locate two buoys, and drive through them. Unfortunately the camera detected a lot of red and green objects. Because of this the onboard computer essentially lost its mind, and wrecked USNA RoboBoat into the side of the pool and then had the boat loop around in a violent circle until the team managed to get control of it via remote desktop. To make matters worse, when pulling the boat out the pool the team noticed that the pontoons had a decent amount of water in them, again. Needless to say further waterproofing was needed.

After some reflection in the wake of the pool crash the team realized that color segmentation alone was not going to be enough to get the USNA RoboBoat through a buoy gate. They needed to refine their computer vision. They reduced the height that the camera can see, they searched for circular shapes, and then did color analysis. Essentially the team narrowed the view, and coupled shape and color for buoy gate detection.

Further testing is needed to confirm that the re-waterproofing is successful, and to determine if the modifications to the computer vision code is enough to go through a buoy gate. Additionally the team is working on a laser range finder to do obstacle avoidance. The team is confident that this will be done in time before the competition.

IV. Final Design

The final design for this year's competition (July 2016) is a dual pontoon watercraft, whose electrical components are contained in two waterproof Pelican cases mounted onto the top of the pontoons. USNA RoboBoat will use four omni-directional propellers mounted on two separate moment arms underneath the boat, which will be controlled by two servos, both wired to an mbed microprocessor. The mbed will be controlled by MATLAB running on an onboard computer using serial communication. For testing and safety purposes the onboard computer (slave) will be remote desktop accessible to the onshore computer (master) via a wireless network. Lidar will be integrated to provide obstacle avoidance, video input from a mounted camera will be used to differentiate between different colored buoys, and an AIRMAR sensor will be used to track position and orientation. Both the camera's and the AIRMAR's data will be used as inputs in USNA RoboBoat's proportional-derivative controller (PDC).

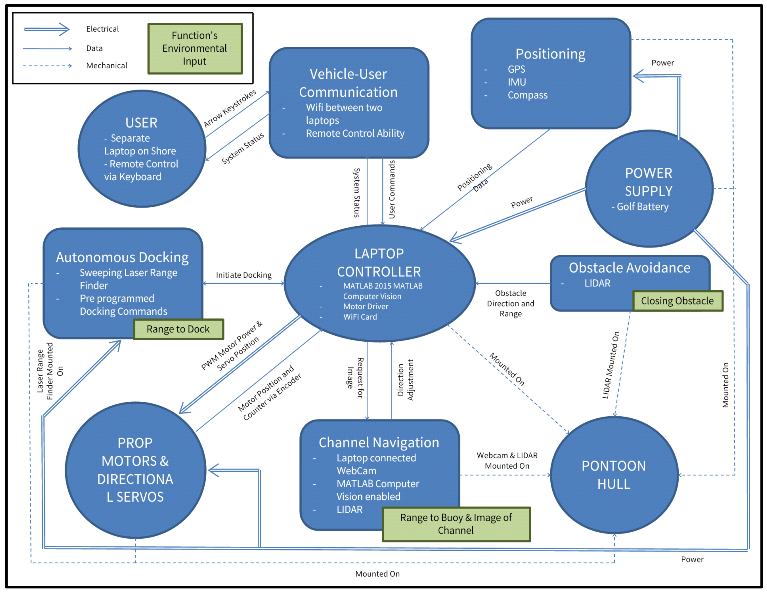

Figure 3: Overview illustration of USNA RoboBoat's subsystems and their relationships to other subsystems.

A. *Mechanical Subsystem*

USNA Roboboat is essentially comes from Venture Outdoor's Modular 5 Pontoon Kick Boat except that the team took out the seat and mounted two beams between the pontoons. These beams each house a servo which connects downward to a moment arm that holds a motor at each end. This creates the dual-axle, omni-directional propulsion system for the boat. Mounted on top of the boat itself are two waterproof Pelican cases.

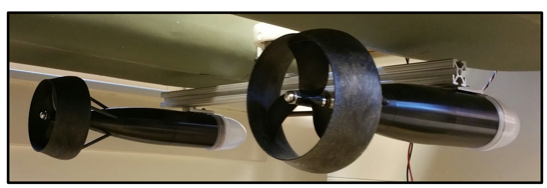

Figure 4: One of USNA RoboBoat's moment arms holding two underwater motors.

One Pelican case houses the electronic board and the onboard (slave) computer underneath. The other Pelican case houses the battery, which are two 12 volt batteries tapped and wired together. This battery is wired to a red panic switch button, which is fixed between the top cover of the Pelican case.

As mentioned above, USNA RoboBoat had leaking issues when testing in the pool. The team therefore installed two drains on the bottom of the pontoons to drain water out in the case of flooding, and sealed all holes in the pontoon with caulk from Home Depot (normally used for bathroom tubs).

B. *Electronic Subsystem*

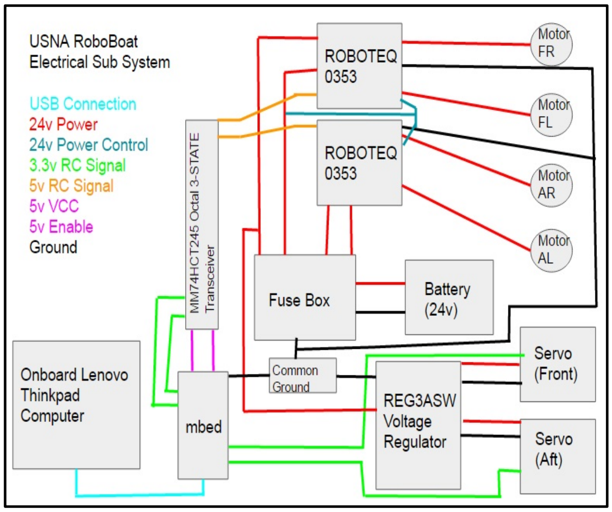

Figure 5: Overview illustration of USNA RoboBoat's electrical sub system.

C. *Software Subsystem*

The overall software components are a MATLAB run processing program and C code run via an mbed controller. The MATLAB program performs all the higher order processes while the code on the mbed controller runs the RC input to the roboteq drivers and thus controls the motors and servos. The two programs have established communications over a serial port on the on-board computer. The C program accepts a continuous stream of string inputs commanding a desired angle for both servos as well as overall power. The desired angles are given by the MATLAB code as a result of information given by the computer vision program. The computer vision operates primarily on color thresholds, background subtraction, and objects properties: area and eccentricity. The computer vision program outputs an index of all possible targets and their heading relative to centerline of the vessel ordered from greatest area to least area. The MATLAB master code is broken down into sub programs that perform various necessary functions. There is a computer vision sub-program, a Global Positioning System sub-program, and sub-programs for every individual competition task. For most tasks the vision system will identify the two largest objects with the desired properties as the two closest objects and drive in-between them by feeding that heading into the C program. The GPS is primarily used for general guidance and avoiding running aground whereas the camera is used for fine navigation. Course over ground is also retrieved from the GPS systems to determine drift by comparing COA to true heading.

D. *Feedback Control*

The controller is a basic proportional derivative controller with a maximum settling time of five seconds for a turn under 50 degrees, which is the camera's field of view, and a negligible percent overshoot. The settling time for the servos is one second, again, with an insignificant percent overshoot. The derivative gain is based on change of heading between readings over the time it took to take readings and these values are obtained from the GPS system which runs a Kalman filtering program between its gyro's and magnetic compass to determine true course.

V. Pre-Competition Analysis

A. *Lifelong Learning*

The team learned a great deal of life long lessons during the construction of UNSA RoboBoat. Specifically they learned about software (drivers, c coding, MATLAB coding, and methods of communication), electrical engineering, and sensor interfacing. The boat honestly took a lot more work than the team anticipated. Nonetheless the team learned a few life lessons: how to accomplish the same goal in different ways, finding another area of the project to work on when the main part cannot be worked on, and thinking ahead so as to avoid future problems.

B. Cost and Parts List

- **Boat Hull –** $150
- **4 Motors w/ Props –** $300
- **2 Servo Motors –** $200
- **Onboard Laptop –** $1000
- **Shore-Based Laptop –** $1000
- **Golf Cart Battery –** $70
- **Camera –** $30
- **Lidar –** $300
- **ArduPilot –** $300
- **mbed –** $65
- **ROBOTEQ –** $300
- **EnGenius Wireless Outdoor Multi Function AP –** $160
- **Waterproof Pelican Cases –** $40
- **Wire Breadboards –** $10
- **Mounting Pieces (Screws, Washers, etc…) –** $45
- **Wires (Multi Colors) –** $40
- **Solder –** $20

2016 USNA RoboBoat Logo
(USNA Class of 2016 Crest)
Go Navy! Beat Army!

VI. Conclusion

2016 USNA RoboBoat will pave the way for future Naval Academy teams. It will be a solid foundation for other teams to build upon. Hopefully one day USNA RoboBoat will be a very competitive boat for future RoboBoat competitions. The main mission for this year's boat was to get the basics right. This is stressed a lot at the Naval Academy and is vital to success in a lot of life's challenges. The team had a blast even when they were frustrated with the boat. The team feels fortunate to have been a part of this competition because they have learned the great satisfaction overcoming challenges that initially seem impossible.

VII. Acknowledgements

The 2016 USNA RoboBoat team would like to thank the following people who helped them along the way:

- Professor Mathew G. Feemster
- USNA Weapons and Systems Engineering Tech Support team
- Professor Randy Broussard

VIII. References

- https://developer.mbed.org/