Autonomous Systems; Theory and Design Applied to Small Watercraft.

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This journal paper is designed to help future engineering students at the University of West Florida (UWF), and other universities and colleges, continue their education by learning from past students who have helped design, build, and test autonomous watercraft as well as compete in the RoboBoat competition. This paper will cover topics such as the approach to designing an autonomous system, team planning and management, successful methods of building and testing, competition strategies, as well as lessons learned.

I. Introduction

The main subject of this paper is the *Argo*, an autonomous watercraft built and designed by several UWF juniors during the fall and spring semester of 2015-2016. The *Argo* was built to compete in the RoboBoat competition of 2016 but has many applications outside of the competition. In this paper, a start to finish approach of how the *Argo* was designed, built, and tested will be covered. Furthermore, some of the many lessons learned both positive and negative will also be discussed. Future students reading this paper should take note and learn from the mistakes and successes of this project. It should also be noted that the students of this team, prior to joining the UWF Unmanned Systems lab had little, if any experience in engineering. It is okay to be nervous or slightly intimidated when starting a project. Use this paper as a guide to help along the way. Have fun working with fellow students and friends and learn as much as possible while doing so.

II. Design Strategy

The strategy for building the *Argo* and getting involved in the RoboBoat competition was done with a very straight forward approach. The team first looked at the problem at hand and then designed a solution to that problem. The problem in this case was building an autonomous boat that could navigate the given course at the RoboBoat competition. The team was provided with a detailed outline of the course that included buoy colors, distances to and from areas of the course, as well as shapes and colors to be used for docking the boat. Future students should take this information to heart. When designing anything, figure out exactly the problem at hand is so an exact solution can then be built.

Starting at this point, the students on the team first came up with a hull design and then figured out what propulsion system they wanted to incorporate into the design. This was followed by choosing several options for making the *Argo* autonomous. The main areas of the competition that were targeted were the speed trial and weight to thrust ratio competition. Taking this into consideration the team moved forward to design and build a fast and light weight watercraft. The team set a goal of having the boat weigh less than 80lbs with a max speed of 40 mph. To achieve these goals much attention would need to be paid to the weight of every single item added to the Argo.

The next strategy would be time management. This was a critical portion to building the *Argo*. The students broke up their school semesters into 2 week sections that they put on a white board. From here they assigned work that was to be accomplished during each two week period. This was a very useful tool in making sure the team was focused on what needed to be accomplished. Furthermore, it allowed for the team to write down quick notes as to what each team member had been working on each day. This made sure all the team members were on the same page about progress even when not all of them were in the lab. Another important tool utilized was group email and Google Docs. Keeping up a good amount of communication between team members was very important. This allowed for the member to easily plan out when everybody could work or could have meetings when it came down to making decisions about the *Argo*. Future students should not overlook any of these aspects of the competition. There will be many times in which students need to meet in order to make decisive plans about their project. In fact, it should be expected that at least once a week students should meet and discuss what is going on with progress towards their project. A basic calendar should also be kept on hand that allows all students and team members to write down when they can and cannot be available to work. This way everyone knows when members are not going to be available due to outside circumstances such as school, work, and family situations.

Finally, the last design strategy used was to build a platform that could be used for many years to come. The *Argo*'s hull would be built to last and it would be built so it could compete for several years and allow for easy modification down the road. The team spent several months designing a hull that would stand out from the competition and would specifically focus on a lightweight, fast, highly reliable hull. This was achieved by researching several boat hull designs and narrowing it down to a fiberglass racing hull. This hull allows for any and all propulsion systems to be used and due to its fiberglass structure it can easily be modified if anything needs to be attached or taken away from it. Future students should take note on this strategy and be sure to plan for the future. Not only should they think about and plan for what they are doing now but what they will be doing two or more years from now closer to their senior year.

III. Watercraft Design

To start with, when it came down to design the team sat down and mapped out how to build the Argo. The starting point used was the hull. Following this, work on the propulsion system and remote control (RC) systems would begin. At this point the boat would be tested for speed and reliability. Once it was established that the Argo could go fast, work would proceed on the autonomous systems. The team worked as a single unit completing tasks in order of one another. Future student may wish to consider altering this plan. The advantage to this was each team member knew exactly how every aspect of the Argo operated. However a disadvantage to this approach was that the team spent lots of extra time in getting the Argo built.

Following the planning phase, the boat team started working on the Argo's hull. This was a joint collaboration between the engineering and art departments at UWF. Two members of the art department had previous experience working with boats from both the U.S. Navy and with racing boats. These art students were a great help. Future students should not be afraid to work with or request help from other department. Students should learn all they can from what other departments may have to offer. Other departments that students may want to look into are the media department for help with building a website and taking photos as well as the business department for finding a way to market your project. This may prove useful in finding potential sponsors for your project.

Moving on, the Argo needed to be fast and retain a small profile while on the water. Using the 3D design software SolidWorks, the boat team having help from the art department, created the *Argo's* initial hull. Using SolidWorks to do this was a great advantage. It allowed the team to create a very professional looking design that could then be modified at any other time. Many modification were made as time progressed. Students should become familiar with this program and learn its advantages when competing in the future. The biggest advantage of using SolidWorks was the ability to use a CNC machine to cut out a foam mold of the *Argo's* hull. This mold was then used to make the fiberglass hull of the *Argo*. Fiberglass was chosen over other materials due to it being light weight yet very strong. Fiberglass is used to build many small to medium sized vessels in the sailing, fishing, and boating community. The ability of fiberglass to hold a lot of weight while still remaining buoyant is very impressive. Future students may look into other materials such as wood, rubber, plastic, carbon fiber, or even aluminum but keep in mind fiberglass. It is not as complicated to use as one might think.

Once the team had a fiberglass hull built they had to sand down the fiberglass and coat the hull in an epoxy resign. This would further waterproof the vessel as well as make it stronger. Once the epoxy had set up, several coats of primer and paint made the hull look like a true boat. It was now that the team had to make a big decision as to which type of propulsion system to use. Their options were to use fixed motors with series of rudders and servos, fixed motors using a motor controller system to create a differential drive system similar to how a tracked vehicle operates, or use motors that incorporate vector thrust. Each of these systems had advantages and disadvantages. After evaluating each system the team chose to go with the differential drive system due to it being easier to code and having less hardware to use. Looking back at the original course it would have been easier to go with the vector thrust system. However the team members agreed that more time should be spent in building a strong hull and platform this year. Next year they will focus more on perfecting their propulsion system. Future students should spend a good bit of time researching their propulsion options.

The items needed in making the propulsion system included; two Leopard 4074 1050KV Motors, two Swordfish Pro 120 Amp 6s Lipo Electronic Speed Controllers (ESC's), two Turnigy 6 cell batteries, two 48 mm stainless propellers, two OSE 3/16" Flex Shafts, two 3/16" K&S Brass Tubes for covering the flex shafts, as well as two custom stainless mounts for the motors and two custom transom mounts for the propellers. The Leopard motors were chosen due to them being built specifically for watercraft as well as them being variable controlled. They also came with water cooled jackets which help greatly with keeping the motors cool while under operation. The ESC's were chosen based on their ability to handle the current drawn from the motors as well as requiring a liquid cooling system. The Turnigy batteries were used because they fit all the requirements for the ESCs as well as the motors. The propellers were both CNC machined from high grade stainless. These propellers were slightly heavier than their plastic counterparts but the amount of durability and balance they had were positive tradeoffs. The flex shafts were used so we could position the propellers exactly where we wanted to on the outside of the hull. These shafts also allowed us to angle the motors in a position that made for easy access in the event something failed or needed to be worked on. The brass tubes were used to cover the flex shaft from inside the hull to outside the hull where the propellers were connected. This helped to make a waterproof propulsion system that would be very durable in the event the *Argo* hit something or was damaged.

Once the propulsion system was built, the next issue was how to keep all the components inside the Argo cool. This was done by installing a redundant system of water pumps that pump in cool water from the bottom of the stern of the Argo and push it forward through the boat and then back out again at the top of the stern. Several components throughout the boat including already mentioned motors and ESC's required water cooling systems. By simply splicing and reconnecting sections of water hoses, all of these parts could be kept cool. By having two water pumps and splicing the hoses correctly a redundant system was achieved. In the event that one pump malfunction or fails, all of the internal components are still kept cool. Furthermore, this large amount of water running throughout the hoses inside the hull helped to cool the inside of the boat. It should be noted that there were several issues with the cheap water pumps used to make the cooling system. The gears in the pumps would occasionally break so when purchasing pumps buy several so they can be easily changed out in the event that one malfunctions. To help with this the team also added small fuel filters to the hosing to keep out small amounts of debris that may be floating in the water. These filters required periodic cleaning but greatly increased the life and durability of the water pumps. Also two DC-DC converters were needed to step down the battery voltage of 22.2V to 4V to power the water pumps.

From here the team also spent a good bit of time researching other ways to cool down the *Argo*. On top of the water cooled system, the team also considered using a system of fans and portholes throughout the boat. However, this seemed as the though the risk of a leak would be entirely too great and all of these systems were disregarded. Another way to keep the boat cool was in the paint job. By painting the boat a neutral tone it was found that the boat remained a few degrees cooler than if it was painted a dark color. The team opted out for any kind of shiny color as this may cause for additional heat retention. The team also opted out for the color white due to amount of staining that may occur if the *Argo* is used in dirty water.

The next component to building the *Argo* was the remote control system. For this the team purchased a Radio Frequency (RF) controller and a RF receiver. The RF controller had a good sized antenna which allowed for a good amount of range for when practicing with the *Argo*. In addition to this the boat team had to custom build a remote control for the boat since the only controllers available were made for either ground or air vehicles. The problem encountered here was that one stick on each controller would move back and forth to its original starting position due to a spring system located in the controller. The other stick would move forward or backward only when moved by the operator. These types of controls do not work well for differential drive because it would require the operator to constantly apply pressure to one side of the controls. By modifying the controller so that both sticks worked the same way, the controller was then perfect for the job at hand.

At this point the team needed to choose batteries to start testing the *Argo* with. The batteries were chosen based on both the engine requirements and electronic requirements. The team was already using the two 6 cell Turnigy batteries but decided to add two 4 cell Turnigy batteries to operate the electronics off of. This was a big step in the design process and future students should take note that the batteries will make up the majority of the weight of the boat as well as take up a great deal of room within the hull. Looking back, this should have been thought about much more carefully during the design phase. Lithium ion batteries are very expensive and weigh quite a bit. If a team is working under tight budget and or weight restraints the batteries and engines should be compared heavily during the design phase. Also, the team had to construct four battery boxes to make sure the batteries did not move around inside the hull while the *Argo* was running. These were built easily using a 3D printer.

At this point, the boat team started testing the *Argo* at a local pond. The controls proved to work quite reliably and the range for the RC controller also worked well. However, during the testing process a small leak was discovered in the hull. This is where the fiberglass proved its worth. The team was easily able to find the leak toward the stern of the boat and patch it within a few hours. However, this situation caused the team to research health sensors for the *Argo*. The first sensor the team built was a water sensor that could detect when standing water was inside the hull. This sensor then sent a message to the operator as well as sounding a high pitch alarm. The second sensor installed was a thermostat. This would alert the team if the internal temperature of the boat ever rose too high for the internal components to work. The last health system was a battery monitor that would constantly update the team as to the level of charge on the batteries. This is very important as it helps to make sure the *Argo* does not run out of power far away from the dock. Once these components were all added, a few more test runs were performed before work began on the autonomous systems of the boat.

From this stage on, the team split into two groups to help speed up the building process. One group of students (Group A) focused on the coding of the autonomous systems while the other team (Group B) kept working on installing the hardware. Future students should learn from this divide and conquer method and use it frequently in building their own projects.

The majority of the coding is split between C and Python, depending on the level of the controls. All low level controls such as the health sensors, global positioning system (GPS) and inertial measurement unit (IMU) were put on two separate Arduinos and used C programming. All high level controls used Python programming and were put on a Dell PC with a 3rd generation I7 processor. The high level controls use a pure pursuit algorithm, the IMU, and the GPS to navigate waypoints. The team also used the program Robotic Operating Systems (ROS) to help with systems integration between hardware and software as well as interfacing between the high level controls and low level controls. The Argo works by using various GPS waypoints to navigate through a specific predesignated course. The team is also using two cameras to achieve stereovision. Stereovision allows the Argo to identify different colors and by using a system of algorithms, can determine the distance to an object. Future teams need to utilize or at least review the codes as well as the notes on file for these programs and systems. The UWF

Unmanned Systems Boat Team plans to continue testing all of these programs on the Argo until the day of competition. This Journal will be updated after the competition to include notes from the event.

In conclusion, this paper should allow future students to build off of the knowledge obtained from the students during this year's RoboBoat Competition. Many important ideas are discussed through this paper and they should all be seriously considered and built off of. This will hopefully allow for more advances to be made in the field of autonomous systems at UWF.

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