The Auto-Returning Remote Control Boat

Group #47

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Abstract

The Auto-Returning Boat was designed to solve two very simple issues faced by hobbyist remote control users, however the project developed into a comprehensive endeavor which encompassed power, control, and signal components. The purpose of the Auto-Returning Boat was to allow the user to avoid issues when the boat had low battery or was navigated out of signal range. The main components of the Auto-Returning Boat were a Low Voltage Detector, Programmed Microcontroller, Schmitt Trigger, and Bang-Bang Controller. The changes were implemented onto an existing remote control with independent hardware. This report provides further details on both the hardware and software design of the project, along with a detailed discussion of the verifications and the conclusion.
1 Introduction .................................................................................................................. 3
1.1 Purpose ....................................................................................................................... 3
1.2 Objective .................................................................................................................... 3

2 Design .......................................................................................................................... 4
2.1 Block Diagram ........................................................................................................... 4
2.2 High-Level Functional Overview and Physical Design .................................................. 4
2.3 Power Unit .................................................................................................................. 5
2.3.1 Batteries ................................................................................................................ 5
2.3.2 Low Voltage Detector Circuit .............................................................................. 5
2.3.3 Voltage Regulator ................................................................................................ 7
2.4 Control Unit ............................................................................................................... 8
2.4.1 Microcontroller ..................................................................................................... 8
2.4.2 Power Control Logic ............................................................................................ 10
2.5 Signal Unit ............................................................................................................... 12
2.5.1 Overview .............................................................................................................. 12
2.5.2 Relative Signal Strength Indicator ..................................................................... 12
2.5.3 Schmitt Trigger .................................................................................................... 14
2.5.4 Sensor .................................................................................................................. 15
2.5.5 Antenna Array ..................................................................................................... 15

3 Verifications .................................................................................................................. 16
3.1 Power Unit ............................................................................................................... 16
3.2 Control Unit ............................................................................................................. 16
3.2.1 Microcontroller and Software ............................................................................. 16
3.2.2 Power Control Logic ........................................................................................... 17
3.3 Signal Unit ............................................................................................................... 17

4 Conclusion .................................................................................................................... 18
4.1 Accomplishments ....................................................................................................... 18
4.1.2 Power Unit ............................................................................................................ 18
4.1.3 Control Unit ......................................................................................................... 18
4.1.4 Signal Unit .......................................................................................................... 18
4.2 Uncertainties ............................................................................................................. 18
4.2.1 Antenna Array ..................................................................................................... 18
4.2.2 Electronic Speed Control ................................................................................... 19
4.3 Ethics ......................................................................................................................... 19
4.4 Future Work ............................................................................................................. 20

5 Costs .................................................................................................................................. 20
5.1 Labor Cost .................................................................................................................. 20
5.2 Parts Cost ................................................................................................................... 20

References ....................................................................................................................... 22
Appendix .......................................................................................................................... 24
1 Introduction

1.1 Purpose

The average remote control boat has very limited capabilities. Beyond the basic navigation of the boat there is very little technological innovation in the design of the boat. This has led users of the boat to face several issues whenever the boat has low power or low signal. However, there does not exist a boat on the market which can alleviate these issues. The goal of this project was to address both of these issues and provide a more sophisticated control to allow for a seamless integration of all new elements added to the boat. The parts used for this project were all readily available and fairly inexpensive. This was important to ensure that the boat will stay in the same price range for the users of the product. The software and hardware features were added in order to provide the user with a definitive better experience using the boat.

1.2 Objective

Professor Oelze presented what seemed to be a very straightforward problem with a model boat of his to the ECE 445 class. He sails this remote control boat on a lake and while the functionality works well, when the boat runs out of battery or the signal from the remote control becomes too weak, he must physically retrieve the boat from the lake. In order to tackle the problem at hand we had to create several different modules to ensure that the boat returns to its designated location. First, we had to create a battery management system. This would be done by making a low voltage detection circuit which would act when the battery supply is low and be used to guide the boat back to shore. The next key module would be the signal unit. This component would detect when the boat receives low signal from the handheld remote controller and make it return to a region of stronger signal strength. This would be achieved by using an antenna array and a signal strength detection circuit. Lastly, we would need to implement a control unit for the boat. The controller would communicate with the signal unit and steer the boat accordingly. Finally, all of these components will be integrated and controlled by a microcontroller. This is a high-level description of the solution. Each technical component is discussed in much further detail below.
2 Design

2.1 Block Diagram

![Block Diagram Image]

Figure 2.1: High level block diagram

2.2 High-Level Functional Overview and Physical Design

The block diagram design consists of four primary units: The Handheld Remote Control, the Signal Unit, the Control Unit, and the Power Unit. The Handheld Remote Control communicates directly with the Signal Unit via IR signals to determine the location, route, and the ‘home destination’. The Signal Unit consists of an RSSI (Relative Signal Strength Indicator) module which measures the relative signal strength from the user. The Control Unit, which controls the motor and rudder, uses data received from the Power System and the Signal unit to evaluate if the boat needs to return home or to a region within the RSSI requirements. In addition to
powering the boat, the power system includes a circuit that detects when the battery level is only high enough to manage a one-way trip back home. (‘Home’ is defined as a location where the RSSI signal strength is the maximum).

For our physical design, the integrity and shape of the boat will be kept intact. The boat was previously sealed which we opened to add all of our electrical components in order to integrate with the existing hardware. To mitigate all safety concerns we used a similar grade epoxy to seal the boat. The physical shape was left intact with some added weight and all safety concerns were solved by using the epoxy to waterproof the boat. The performance of the boat should not have been affected significantly by the additions that were made.

2.3 Power Unit

2.3.1 Batteries

Parts: (6x) Duracell AA Alkaline Batteries 1.5V MN1500 (LR6)

The boat is powered by 6 AA, 1.5V batteries adding up to produce a total of 9V. The total operating range of the combined batteries is 4.5V to 9V [1].

2.3.2 Low Voltage Detector Circuit

Parts: TI LM393, 2.4V Zener Diode (BZX79C2V4)[3], 1MΩ Resistor (x2), 330 kΩ, 33 kΩ, 500 Ω Resistors

The low voltage detector circuit (LVDC) will monitor input from the batteries and communicate with the control unit to indicate when there is only enough power left for the boat to return to the home location. This would be achieved by outputting a HIGH to the control unit once the battery reached the “indication” voltage.

The operating voltage for each battery in use has a lower limit of 0.75V [1]. Since we have six of those batteries, the lowest voltage level before the batteries are ineffective is 4.5V. As a result, the voltage level at which the circuit signals the control unit to force the boat back home should be at a value greater than 4.5V. Henceforth, this voltage will be referred to as the indication voltage.

To test for the indication voltage, we first measured the voltage of the battery. Next, we physically set the boat on a body of water and had it complete a round-trip from the user to its maximum range. Upon the boat’s return, the voltage of the batteries was re-measured. Since the battery level consumed would represent two full-range trips of the boat, the total battery
level consumed will be divided by 2. The test was performed thrice and the average values were taken to ensure accuracy. Finally, the resultant voltage consumed would be added to the minimum operating voltage of 4.5V to obtain the indication voltage.

We realized while performing this test, that the voltage consumption of the battery was linked to the time the boat covered a certain distance and not the distance itself. Therefore, the results would essentially be inept unless there was a way to predict the strength and direction of the flow of the water. Consequently, we took the safe approach and chose the value of 5V instead of the originally estimated 4.8V to be the indication voltage.

Figure 3.1 shows the low voltage detector circuit.

![Figure 3.1: Low voltage detector circuit](image)

As can be seen from the circuit, the low voltage detector circuit is a voltage comparator application using the Texas Instruments’ LM393 [2]. The LM393, however, was not our first choice for the comparator; it replaced the Texas Instruments’ TL331 which for some unknown reason was not responding as desired. The positive rail of the LM393 was connected directly to the battery voltage while the negative rail was grounded. The negative terminal was a voltage divider input from the battery voltage while the positive terminal served as a constant reference voltage of approximately 2.4V [3]. The LM393 has an open collector output which meant a pull-up resistor had to be connected across the output and $V_{cc}$ (battery voltage). The bench-test results of the low voltage detector circuit are tabulated in table 3.1 and plotted in figure 3.2.
Figure 3.2: Low Voltage Detector Circuit Test Results

![Graph showing LVDC Test Results]

Table 3.1: Low voltage detector circuit test results

<table>
<thead>
<tr>
<th>Battery Voltage (V)</th>
<th>$V_{in}^-$ (V)</th>
<th>$V_{in}^+$ (V)</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>3.653</td>
<td>2.341</td>
<td>LOW</td>
</tr>
<tr>
<td>8</td>
<td>3.247</td>
<td>2.294</td>
<td>LOW</td>
</tr>
<tr>
<td>7</td>
<td>2.841</td>
<td>2.236</td>
<td>LOW</td>
</tr>
<tr>
<td>6</td>
<td>2.435</td>
<td>2.171</td>
<td>LOW</td>
</tr>
<tr>
<td>5</td>
<td>2.029</td>
<td>2.091</td>
<td>HIGH</td>
</tr>
<tr>
<td>4.9</td>
<td>1.989</td>
<td>2.083</td>
<td>HIGH</td>
</tr>
<tr>
<td>4.8</td>
<td>1.948</td>
<td>2.074</td>
<td>HIGH</td>
</tr>
<tr>
<td>4.7</td>
<td>1.908</td>
<td>2.064</td>
<td>HIGH</td>
</tr>
<tr>
<td>4.6</td>
<td>1.867</td>
<td>2.055</td>
<td>HIGH</td>
</tr>
<tr>
<td>4.5</td>
<td>1.827</td>
<td>2.045</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

2.3.3 Voltage Regulator

Parts: STMicroelectronics L4931

The voltage regulator was used to supply a constant voltage to the control unit and the RSSI
(Relative Signal Strength Indicator) circuit that adheres to their input requirement. In this case the input voltage required was 3.3V, therefore the STMicroelectronics L4931 was chosen. The L4931 is a linear voltage regulator outputs 3.3V for any value in our battery’s operating range (4.5V-9V) [4].

2.4 Control Unit

2.4.1 Microcontroller

Part: ATmega328P

The microcontroller is the primary component of the control unit. The microcontroller takes inputs from the RF receivers and sensor. This will be an 8-bit microcontroller to properly execute the computation required for our Bang-Bang Control Loop. While this could be done on a 4-bit microcontroller, the sensor we used had an 8-bit resolution [5].

The microcontroller will take an interrupt from the Power Control Logic. When this interrupt is triggered, we will disable sleep mode. We will also check the value of this whenever we complete an entire control loop to see if we need to reactivate sleep mode. We reactivate sleep mode when we want to allow the user to control the boat.

We chose the ATmega328P as the microcontroller for this project for a variety of reasons. Mainly because it is a low cost [6], readily available 8-bit microcontroller. It also satisfies all the requirements of having interrupt pins, PWM output and supports operation at 3.3V [7]. Additionally, the current at 1MHz frequency and 3.3V is 0.92mA, which yields low power consumption [8].

The MCU chosen would have worked fine, but unfortunately the design for the originally ordered PCB did not work. We did succeed in implementing the desired functionality of the MCU with the use of an Arduino. We were also able to read interrupts to enter and exist sleep mode properly. Additionally, dynamically changing the PWM based on input voltage was achieved.

The major design change during the microcontroller process was the control loop. Rather than jumping to instructions uncompleted, we had a set series of reads. Once we get to the point that we read the Magnetometer, we enter a while loop. During this while loop, we wait for an interrupt flag to be turned to TRUE. This flag is changed in an interrupt handler for when the magnetometer is ready to read. Then the data is read and we drive the PWM accordingly.

We tested the sleep cycle by putting in high and low to the interrupt pin, and outputting (via serial interface) a simple string of what mode we are entering or exiting. If out of sleep mode, it
continually printed the string. If it was in sleep mode, it printed one time that it was in sleep mode. We switched modes many times to see the effectiveness and it worked as expected.

**Controller**

The Bang-Bang controller for the motion of the boat was simulated on MATLAB. We utilized the Simulink tool to create a State Transition Table which included the states that the boat would encounter during its travel and the next action it would need to take when in each state. The states were designed such that there were 2 main states – the Normal State and the Out_of_Range State. The Normal State was for general use of the boat when the signal strength was high. The Out_of_Range State was for when the boat lost signal strength. It can be seen in table 4.1 that when the signal is greater than the reference_high the boat will remain in the Motor_ON state and when the signal falls below the reference_low the boat will move to MOTOR_OFF state. It will stay in the MOTOR_OFF state until the boat reaches sufficient signal strength. When this is achieved, the boat will enter the Warmup state and then the Motor_ON state where it can continue normal navigation. The simulation in figure 4.1 below shows that when the command goes low (the boat is out of range and the motor will need to decrease speed) the motor speed on the boat reaches 0. This is the desired behavior of the controller on the boat.

<table>
<thead>
<tr>
<th>STATES</th>
<th>TRANSITIONS IF</th>
<th>ELSE: IF(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Out_of_Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor_ON</td>
<td>$[\text{sig} \geq \text{reference}_{\text{high}}]$</td>
<td>Motor_OFF</td>
</tr>
<tr>
<td>Motor_OFF</td>
<td>$[\text{sig} \leq \text{reference}_{\text{low}}]$</td>
<td>Warmup</td>
</tr>
<tr>
<td>Warmup</td>
<td>$[\text{done}_{\text{Warmup}}]$</td>
<td>Motor_ON</td>
</tr>
<tr>
<td>Out_of_Range</td>
<td>$[\text{CLEAR}]$</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.1. State Transition Table**
The purpose of the PWM was to send information to the electronic speed controller. The PWM sends a message signal to the electronic speed controller containing information on the desired power output to the motor and the necessary direction of travel to re-enter a stronger signal range or return to shore because of low battery. The encoded message contains both the speed and angle that the boat will need to travel in. The speed is the amplitude of the pulse and the angle is the phase of the pulse. The PWM sends a signal every 2-3 milliseconds and operates at a frequency to match the Electronic Speed Control (ESC).

We tested proper operation by inputting a sine wave and reading the PWM output. When the analog signal increased, we kept the same PWM because that meant we were in the correct direction. If the change was negative we turned in a separate direction, because that meant we were headed the wrong way.

2.4.2 Power Control Logic

Part: SN74LVC2G32 Dual 2-Input Positive-OR Gate, SN74LS00NSR

Power Control Logic (PCL) outputs a digital signal to an interrupt pin on the microcontroller. The Power Control Logic implements the state machine using 3 states. The finite state machine diagram for the PCL is shown in figure 4.2 below.
With the original configuration of gates shown in Figure 4.3, we can turn the switch on and off based on SSD’s output, and keep it turned on when the LVD triggers at least once. Our preferred chip for this is a Texas Instruments SN74LVC2G32 [9]. This is a dual gate chip with 2-bit gates. We chose this chip due to its reliability, low cost, and ability to have an operating voltage of 3.3V [9].

The power control logic worked as expected after we fixed a small error. The problem with the initial design was a static hazard. We fixed this by, instead of looping input back into the OR gate, adding a NAND gate [10] based D latch to the LVDC OR gate. This stored the value properly, fed it into the OR gate, and eliminated the static hazard while maintaining the required functionality.

**Electronic Speed Controller (ESC)**

Part: Hobbywing Quicrun 60A 2S-3S Waterproof Brushed ESC
The purpose of the ESC in an RC boat is to control both the speed and the direction of the boat. The ESC receives a message signal from the Pulse-Width Modulator. This is at a 1 kHz frequency and the encoded message communicates the direction at which the motor should travel. The ESC is connected to the existing DC motor in the boat. We planned to use the Hobbywing Quicrun 60A 2S-3S Waterproof Brushed ESC. We made this choice primarily because it was one of Hobbywing’s waterproof options. This option also had low-voltage cut-off for the battery, operates at 7.2 V (compatible with our motor), overheat protection for the motor, and signal loss protection for the Pulse Width Modulator [11]. This was also the most cost-effective option containing all of these features that we have found.

Unfortunately, this component did not arrive in time, thus it was never implemented.

2.5 Signal Unit

2.5.1 Overview

The Signal Unit was perhaps the most essential module of the project. It consisted of two major parts for signal strength detection: The Relative Signal Strength Indicator (RSSI) circuit and a Schmitt trigger. The RSSI was calculated through the implementation of an IC which sent information that was filtered by the Schmitt Trigger and finally communicated to the PCL. Figure 5.1 shows a basic high level block diagram of the signal unit interface.

![Figure 5.1: High level layout of the Signal Unit](image)

2.5.2 Relative Signal Strength Indicator

Part: Analog Devices AD8317

The RSSI (Relative Signal Strength Indicator) is used to calculate the signal strength relating to
the current position of the boat. This is a vital component to have since it will determine when the boat needs to return to the ‘region of operation’. For this project the ‘region of operation’ is defined to be a location where the signal detected is greater than -35 dBm.

The RSSI circuit monitored the signal strength corresponding to the boat’s current location. This was achieved using the Analog Devices’ AD8317 chip. The AD8317 took in an RF input and outputted a voltage that related to the signal strength (measured in dBm). Figure 5.2 displays the basic pin layout schematic while table 5.1 describes the circuit specifications for the 2.2 GHz frequency operation.

![Schematic of the AD8317 IC](image)

**Figure 5.2: Schematic of the AD8317 IC [12]**

**Table 5.1: Circuit specifications for 2.2 GHz frequency operation [12]**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Minimum</th>
<th>Type</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage (High Power In)</td>
<td>PIN = -10 dBm</td>
<td>0.35</td>
<td>0.54</td>
<td>0.80</td>
<td>V</td>
</tr>
<tr>
<td>Output Voltage (Low Power In)</td>
<td>PIN = -35 dBm</td>
<td>0.75</td>
<td>1.21</td>
<td>1.35</td>
<td>V</td>
</tr>
</tbody>
</table>
2.5.3 Schmitt Trigger

Parts: TI LM393; TI 7805; 2.2 MΩ, 1 MΩ, 33 kΩ Resistor

By setting a threshold value to compare against, the Schmitt trigger used the output received from the RSSI circuit to determine if the boat needed to return to the region of operation or not. Similar to the LVDC, the TL331 was also replaced by the LM393 chip used in the low voltage detection circuit.

The comparator used the output from the voltage regulator TI 7805 [13] and voltage divider as the input to $V_{in}^-$. This served as the threshold reference voltage of approximately 1.2V. $V_{in}^+$ took in the output of the AD8317. The positive rail of the LM393 was connected to the battery voltage while the negative rail was grounded. The output of the Schmitt trigger was finally fed into the PCL (power control logic). Figure 5.3 shows the circuit schematic of the Schmitt trigger.

![Figure 5.3: Schmitt trigger circuit](image)

Our requirement for the circuit was that, an input of 1.2V from the AD8317 gives us an output HIGH for the entire operating range of the batteries (4.5V-9V) which was attained.
2.5.4 Sensor

Part: Xtrinsic MAG3110

For the sensor unit, we used one sensor, a magnetometer. A magnetometer is used to calculate the direction with regards to the magnetic poles of the earth. By using this we can align the boat in accordance to the desired heading. This sensor operated at a voltage of 3.3V [5]. It used I2C communication because of the fewer I/O ports required and a faster read speed. Lastly, this sensor was polled. The optimization the microcontroller would take could only be achieved if it was able to process instructions while the magnetometer was getting its data ready. Due to the presence of “DR_STATUS” this device was able to be polled to see if the data was ready. Combining this with the slower ODR meant that we could do many calculation optimizations based on when the data was ready.

2.5.5 Antenna Array

Part: Texas Instruments CC2500RGPR

For the antennas, we chose the Texas Instruments CC2500RGPR transceiver because of its low cost, availability, and ability to achieve the desired functionality. Unfortunately, we were unable to implement and test the antenna array, however the theoretical plan is described below.

We planned ordering several of these devices, most likely 6. We then planned on constructing a testing methodology to decide where the antennas need to be, based on a set of experiments done in Slovenia. To calculate angle of arrival we planned to use the algorithm documented on page 240 and 241 of Angle of Arrival estimation algorithms using Received Signal Strength Indicator [14]. We would start by placing the transceivers around on a circular board with diameter 5cm. We would then place them at various points all evenly separated. Using different distances to discover the position that would give us as at most a +/- 10-degree error for the angle of arrival. Next, we would place this antenna array on the ground; test its readings from distances of 1m to 30m and also test for angles, in increments of 20 degrees from 0 to 360 degrees [20].
3 Verifications

3.1 Power Unit

Our requirement for the power module consisted of testing the low voltage detection circuit as the voltage regulator and batteries were standard, unmodified products. For the LVDC, we needed to ensure that an output of a HIGH was generated once the battery voltage dropped to 5V or less while an output of LOW was seen for all battery voltages greater than 5. To test this we used a power supply as to model the battery voltage and measured the output of the LM393 as the voltage was adjusted. As shown in table 3.1, we were successfully able to achieve the results desired.

3.2 Control Unit

3.2.1 Microcontroller and Software

The controller was built using a state transition table on MATLAB’s Simulink tool. The Simulink tool has a built-in simulation capability. The function of the controller was simulated using this tool. Variable values for boat speed were inputted into the table and the simulation was activated. After examining the simulation table, it was apparent that the motor functions normally until the low signal is triggered. At that point the boat speed gradually drops to 0. This was the verification which we needed to confirm that the controller was suitable for our purposes.

To verify the outputs of the microcontroller we monitored a variety of outputs directly. Additionally, we added a portion of the software that would output simple text to the computer connected with a USB cable. To verify the control loop, we directly connected to an oscilloscope and recorded the PWM output. To test, we would raise and lower the analog input voltage very slowly and steadily with some small fluctuations and monitor the output. Time steps were done as four second intervals.

When we started at an analog voltage of .3V and linearly increased to a value of 1.2V at a rate of .1V per time step, the PWM had a duty cycle of 50% signaling a straight rudder. This input was meant to simulate the state of “correct direction home”. We then tested the same way, however at .6V we then started decreasing it for two time steps. The PWM then changed to have a duty cycle of approximately 60%. Since the voltage continued to decrease, it then jumped to a duty cycle of approximately 40%, signaling a rudder direction change in the
opposite direction. It then slowly approached 50% as we reached 1.2V, since we steadily turn less in the same direction.

I2C communication was verified by simulating I2C values from a Raspberry Pi, connected via the GPIO pins. This was the best way to verify the software functionality because we were unable to get the magnetometer working due to PCB problems. We sent a read request to the Raspberry Pi and then output a string with the value received to the USB connection. The value was then checked against the value sent via I2C.

Lastly we validated operation of the sleep cycle by connecting the interrupt pin to a logic signal. We manually changed this logic signal, and output on the USB strings of the state we were in. If the sleep state was on, we would simply print “Entering sleep mode” and then wait. If we left sleep mode, we would continually print “Not in sleep mode”.

3.2.2 Power Control Logic

We successfully verified the power control logic by directly simulating the logical inputs based on our truth table. We then recorded the output and compared to our truth table [Appendix: table 1]. Once the static hazard was fixed, the power control logic worked exactly as expected.

3.3 Signal Unit

For the signal module, the requirements pertained to the Schmitt trigger and the antenna array.

The requirement for the Schmitt trigger was that it would output a HIGH once the output from the AD8317 was a 1.2V. To test this we used two power supplies where one represented the output of the AD8317 while the other power supply represented the battery voltage. By starting at 9 V for the battery voltage, and 0.5 V for the output of the AD8317 we measured the output of the LM393. Next, we kept the battery voltage at 9V while we increased the AD8317 output in steps of 0.1 V. A LOW was seen for a 1.1V AD8317 output while a HIGH was observed when the voltage was changed to 1.2V. Finally, we needed to make sure that the results held for all values for the battery voltage. Thus, this procedure was repeated for all voltages ranging from 4.5V to 9V with successful results.

Unfortunately, we were unable to meet the requirements determined for the antenna array. The reasons are discussed in detail in the “Uncertainties” section.
4 Conclusion

4.1 Accomplishments

4.1.1 Power Unit
- All components of the power were completely functional
- The power unit was integrated and powering the signal unit
- The power unit was also integrated with the Control Unit and the Power Control Logic was functional

4.1.2 Control Unit
- The controller outputted the correct PWM with the encoded phase angle for travel of the boat
- The Bang-Bang Controller had the desired functionality with 2 states
- The Power Control Logic was integrated successfully
- I2C Communication was achieved on the microcontroller

4.1.3 Signal Unit
- The Schmitt Trigger was built and functional
- Design and PCB of AD8317 chip was completed and printed

4.2 Uncertainties

4.2.1 Antenna Array

The purpose of the antenna array was to detect the position of the boat and deliver signal strength and desired direction to the microcontroller. The antenna array failed for several reasons. The first reason was the complex mathematics and physics needed to understand how to create an antenna array. We lacked the necessary expertise to properly design an antenna array. We also did not create a thorough enough testing process for the antennas which we had. Without this testing process we were unable to create an antenna array which could detect the position of the boat or deliver the desired direction. If we were to continue this project, we would formulate a better testing process as well as explore options other than RF.
4.2.2 Electronic Speed Control

The purpose of the electronic speed control was so take outputs from the control system and drive the motor speed of the boat based upon the signal strength and the power in the boat. The ESC was unsuccessful because the part we needed never shipped to us and we were unable to add it into our design.

4.3 Ethics

There are several ethical guidelines from the IEEE Code of Ethics which apply to our project. We will follow these guidelines as closely as possible. The guidelines include – to be honest regarding all collected data [15], reject bribery from any source [15], undertake technological tasks only with the required competence and safety knowledge [15], not to engage in any acts of discrimination, and assist the professional development of our peers [15]. This means that we will work towards building our entire project without any outside help, and under the rules of the class [15]. We will also purchase several components of our design; however, we will individually build a majority of our design uniquely and independently. When discussing with our advisor and the professors of the class we will always present accurate data and truthfully present our project regardless of its functionality [15]. Lastly, we will adhere to all safety guidelines and take every precaution necessary to safely test our boat [15]. Our boat will have electrical components and will need to have several extra precautions taken to make it safe for the general community. We will also not discriminate in the use of this boat or the boat technology amongst anyone (save for young children who will need supervision).

There are several safety guidelines that we will adhere to closely as well. First, we will follow all of the given safety guidelines put forth by ECE 445, ECE Illinois, and the University of Illinois while using the laboratory equipment. Seeing that we are also modifying a children’s toy with electronics that will be on the water we will take precautions when testing such as testing as a group, testing in empty open water, and thoroughly working to waterproof the boat. The boat will have many electrical components which we will have to make sure will not be dangerous in the water. We will use a marine-grade epoxy which will be used to re-seal pre-existing electrical components and seal all new electrical components within the hull of the boat.

There are no existing regulations for modifying replica boats, however, there does exist a North America Model Boat Association (NAMBA). This governing body has safety regulations about racing model boats. If there is overlap on any of the technology on our boat with their standard model boat, we will adhere to their regulations. Currently,

For testing, we have contacted the Activities and Recreation Center on campus and will look for approval to safely test there.
4.4 Future Work

- Integrated PCB: We would ideally want a boat that does not have its movement impaired with multiple PCBs and extra weight. Our goal would be to make an integrated PCB to place inside the boat.
- Computer Vision Control: The antenna method was incredibly finicky and difficult to implement. We would opt for computer vision to control the boat’s path for the next iteration. This would also help navigate the boat through different obstacle and rough water.
- Programmable Path: A feature we would like to add would be programmable paths. This would allow the user to watch the boat without worry about issues of navigation.

5 Costs

5.1 Labor Cost

<table>
<thead>
<tr>
<th>Engineer</th>
<th>Hourly Rate</th>
<th>Hours Invested</th>
<th>Total = Hourly Rate x Hours x 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grant Everett</td>
<td>$30.00</td>
<td>250</td>
<td>$18,750</td>
</tr>
<tr>
<td>Somak Ghosh</td>
<td>$30.00</td>
<td>250</td>
<td>$18,750</td>
</tr>
<tr>
<td>Zain Zaman</td>
<td>$30.00</td>
<td>250</td>
<td>$18,750</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$30.00</strong></td>
<td><strong>250</strong></td>
<td><strong>$56,250</strong></td>
</tr>
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</table>

5.2 Parts Cost

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 pF Capacitor</td>
<td>$.019</td>
<td>10</td>
<td>$0.19</td>
</tr>
<tr>
<td>0.1 uF Capacitor</td>
<td>$.118</td>
<td>10</td>
<td>$1.18</td>
</tr>
<tr>
<td>(Shipping 1)</td>
<td>$3.03</td>
<td>1</td>
<td>$3.03</td>
</tr>
<tr>
<td>2.4 V Zener Diode</td>
<td>$.192</td>
<td>10</td>
<td>$1.92</td>
</tr>
<tr>
<td>Description</td>
<td>Quantity</td>
<td>Price</td>
<td>Total</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>3.3 V Zener Diode</td>
<td>10</td>
<td>$0.192</td>
<td>$1.92</td>
</tr>
<tr>
<td>1kΩ Resistor</td>
<td>10</td>
<td>$0.011</td>
<td>$0.11</td>
</tr>
<tr>
<td>1mΩ Resistor</td>
<td>10</td>
<td>$0.012</td>
<td>$0.12</td>
</tr>
<tr>
<td>100 kΩ Resistor</td>
<td>10</td>
<td>$0.012</td>
<td>$0.12</td>
</tr>
<tr>
<td>8 kΩ Resistor</td>
<td>10</td>
<td>$0.012</td>
<td>$0.12</td>
</tr>
<tr>
<td>8.2 pF Capacitor</td>
<td>10</td>
<td>$0.08</td>
<td>$0.80</td>
</tr>
<tr>
<td>0.1 uF Capacitor</td>
<td>10</td>
<td>$0.041</td>
<td>$0.41</td>
</tr>
<tr>
<td>200Ω Resistor</td>
<td>10</td>
<td>$0.011</td>
<td>$0.11</td>
</tr>
<tr>
<td>(Shipping 2)</td>
<td>1</td>
<td>$18.80</td>
<td>$18.80</td>
</tr>
<tr>
<td>Hobbywing Brushed ESC</td>
<td>1</td>
<td>$25.99</td>
<td>$25.99</td>
</tr>
<tr>
<td>ATMEGA328P-AURCT-ND</td>
<td>1</td>
<td>$2.14</td>
<td>$2.14</td>
</tr>
<tr>
<td>296-38562-1-ND (RF Transciever)</td>
<td>6</td>
<td>$2.91</td>
<td>$17.46</td>
</tr>
<tr>
<td>GATE OR 2CH 2-INP SM8</td>
<td>1</td>
<td>$0.67</td>
<td>$0.67</td>
</tr>
<tr>
<td>SENSOR MAGMTR I2C 10DFN</td>
<td>1</td>
<td>$2.12</td>
<td>$2.12</td>
</tr>
<tr>
<td>IC DIFF COMPARATOR SNGL SOT23-5</td>
<td>5</td>
<td>$0.58</td>
<td>$2.90</td>
</tr>
<tr>
<td>Texas Instruments TL331</td>
<td>10</td>
<td>$0.465</td>
<td>$4.65</td>
</tr>
<tr>
<td>Texas Instruments LM393</td>
<td>2</td>
<td>$0.355</td>
<td>$0.71</td>
</tr>
<tr>
<td>Texas Instruments 7805</td>
<td>3</td>
<td>$0.44</td>
<td>$1.32</td>
</tr>
<tr>
<td>Shipping (3)</td>
<td></td>
<td></td>
<td>$18.80</td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
<td></td>
<td>$105.59</td>
</tr>
</tbody>
</table>

Total Cost = $56,355.59
References


### Appendix

**Table 1: Truth table for the PCL [K-Map]**

<table>
<thead>
<tr>
<th>Truth table for Power Control Logic</th>
<th>Low Voltage Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 1</td>
</tr>
<tr>
<td>Signal Strength Detector</td>
<td>0 0 1</td>
</tr>
<tr>
<td></td>
<td>1 1 1</td>
</tr>
</tbody>
</table>
### POWER Unit

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verifications</th>
<th>Point Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The LM393 should output a logical HIGH instead of LOW when the battery voltage drops below or equals 5 V (+/- 5%)</td>
<td>1. Use a dc power supply to power the circuit and then use the oscilloscope to detect if: A. a HIGH output is generated when the voltage across R1, 1MΩ is less than or equal to 5 V (+/- 5%) (figure 3.2)</td>
<td>12.5/12.5</td>
</tr>
<tr>
<td>Requirements</td>
<td>Verification</td>
<td>Point Allocation</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>1. Desired Sleep Mode functions as expected:</td>
<td>1. Simulate a PCL HIGH value when microcontroller is in sleep mode, ensure</td>
<td>3/3</td>
</tr>
<tr>
<td>a. Exit sleep mode when PCL is logical HIGH</td>
<td>microcontroller wakes up</td>
<td></td>
</tr>
<tr>
<td>2. Enter sleep mode when PCL is logical LOW</td>
<td>2. Simulate a PCL LOW value when microcontroller is in sleep mode, ensure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>microcontroller does not wake up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Simulate a PCL LOW value when the microcontroller is not in sleep mode,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ensure the microcontroller enters sleep mode after the current control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>loop has finished</td>
<td></td>
</tr>
<tr>
<td>2. Drive PWM such that the frequency and amplitude represent the angle change</td>
<td>2. Given outputs (phase, speed) from the Bang-Bang controller, ensure the</td>
<td>3/3</td>
</tr>
<tr>
<td>we need to make</td>
<td>PWM has the correct duty cycle, frequency and amplitude as described in</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the PWM Requirements and Verifications. These outputs will be an angle,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and this angle is the difference in direction we need to take.</td>
<td></td>
</tr>
<tr>
<td>Requirements</td>
<td>Verifications</td>
<td>Point Allocation</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>------------------</td>
</tr>
</tbody>
</table>
| 1. The boat has 2 behaviors-  
A. the motor is on when the boat has both sufficient power and signal  
B. when boat has either low battery or low signal the motor will shut off and wait for instructions for correct direction to travel in. | 1. Test the behavior of the control system (simulated using Simulink on MATLAB) on a motor for requirements  
2. Input a 0 for motor speed and ensure that the motor is not running.  
3. Input a speed greater than 0 to the motor and ensure that the motor is running. | 3/3 |
| 2. The boat’s Electronic Speed Control can successfully receive correct pulse information-  
A. the pulse amplitude will encode the speed within (+/- 5% error)  
B. the pulse phase will encode the angle within (+/- 5%) | 2. Test the behavior of the control system using Simulink and the microcontroller. Input a desired angle and speed to the microcontroller and verify if the Pulse Width Modulator is sending the correct direction to the electronic speed control and the motor. This behavior can be simulated and the data will be returned in the same script. | 0/1 |
<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verifications</th>
<th>Point Allocation</th>
</tr>
</thead>
</table>
| 1. Output a logical HIGH 3V (+/- 5%) when Signal Strength Detector outputs a logical HIGH. | 1. Use the oscilloscope to detect whether a HIGH 3V (+/- 5%) output is generated when the Signal Strength Detector outputs a logical high  
A. Test the transition from logical LOW to HIGH | 1/1 |
| 2. Output a logical LOW 0V (+/- 5%) when Signal Strength Detector outputs a logical LOW, and Low Voltage Detector has not output a logical HIGH 3V (+/- 5%) yet. | 2. Use the oscilloscope to detect whether a low 0V (+/- 5%) output is generated Signal Strength Detector outputs a logical LOW  
A. Test the transition from logical LOW to HIGH | 1/1 |
| 3. Output a logical HIGH 3V (+/- 5%) when Low Voltage Detector outputs a logical HIGH 3V (+/- 5%), and does not change output when Signal Strength Detector changes value. | 3. Use the oscilloscope to detect whether a HIGH 3V (+/- 5%) output is generated when Low Voltage Detector outputs a logical HIGH  
A. Test starting from SSD logical LOW  
B. Test continuous switching SSD logical HIGH and LOW | 1/1 |
| 4. Output a logical LOW 0V (+/- 5%) when Low Voltage Detector outputs a logical LOW 0V (+/- 5%) | 4. Use the oscilloscope to detect whether a LOW 0V (+/- 5%) output is generated when both the Low Voltage Detector and Signal Strength Detector output a LOW | 1/1 |
| 5. Unable to output a logical LOW 0V (+/- 5%) once the Low Voltage Detector has output a logical HIGH 3V (+/- 5%) at least once. | 5. Use the oscilloscope to detect whether a HIGH 3V (+/- 5%) output is generated after a LOW 0V (+/- 5%) once the Low Voltage Detector outputs a logical HIGH, after it had been outputting a zero  
B. Test starting from SSD logical LOW  
C. Test continuous switching SSD logical HIGH and LOW  
D. Test continuous switching LVD logical HIGH and LOW (to simulate fluctuation of LVD out) | 1/1 |
### SIGNAL Unit

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verifications</th>
<th>Point Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Output a:</td>
<td>1. Use a dc power supply to power the circuit and then use the oscilloscope to detect if:</td>
<td>12.5/12.5</td>
</tr>
<tr>
<td>A. logic HIGH to the microcontroller when the RSSI output is greater than or equal to 1.2V (+/- 5%).</td>
<td>A. a HIGH output is generated when the voltage across R4, 1MΩ, is greater than or equal to 1.2V (+/- 5%) (figure 5.3)</td>
<td></td>
</tr>
<tr>
<td>B. logic LOW to the microcontroller when the RSSI output is less than 1.2V (+/- 5%)</td>
<td>B. a LOW output is generated when the voltage across R4, 1MΩ, is less than 1.2V (+/- 5%) (figure 5.3)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
<th>Point Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Algorithm estimates angle of arrival within 10 degrees of true value.</td>
<td>1. Use 6 antennas to create an antenna array in a variation of a hexagon. Try various distances from being 1cm to 3cm apart. Test estimated angle of arrival using the algorithm documented in the aforementioned paper.</td>
<td>0/10</td>
</tr>
</tbody>
</table>