Solar RC Boat 49

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1 Introduction

1.1 Objective

Typical RC boats have terrible battery life and long charge times (10 minutes of use for 1.5 hours of charge [1]). This is incredibly frustrating because the boat is charging out of the water and cannot be used the majority of the time. To provide longer playtime, we plan to mount four solar panels on the boat to provide an alternate power source in addition to the original battery. The solar power will be used as the main power source for the boat's motor, theoretically providing an infinite amount of playtime so long as solar energy is available. Since solar energy will not always be sufficient to power the motor, we will use battery power as a backup. The boat's motor will always be connected to a power source, and we will switch between solar and battery power, depending on the amount of solar energy available.

Along with poor battery life, RC boats also have a very limited signal radius for control, and the boat is often driven out of range of the controller. This is a problem because it is difficult to get the boat back once the signal is lost. We will expand on our RC boat solution by addressing this signal range problem. We will implement an RF detection circuit to warn the user if he is driving the boat out of range. The circuit will sense the signal strength received from the remote controller; once that signal reaches a minimum power threshold, we will alert the user with enough time to respond to the signal and turn the boat around. The user will be warned via an LED on the controller indicating poor signal strength.

These two enhancements will allow for longer use of the boat since the battery life will be extended, and the user will be warned of poor signal so the boat stays within range. Thus our objective is to innovate the RC boat to allow for longer playtime and signal detection.

1.2 Background

RC boats are commonly bought for recreational purposes because they are fun and easy to use as well as affordable. Typically, these toy boats are available from around $30 [1] to $80 [2]. The cheaper boats are generally slower and have a smaller operating radius of around thirty meters. The more expensive boats can go up to 18 mph with a remote control distance of up to 150 meters. Regardless of the price, however, typical boats only allow for around ten minutes of playtime on a fully-charged battery, and the batteries themselves take at least an hour to charge completely, sometimes up to two hours. This minimal playtime is the greatest complaint for any type of RC boat [1]; users often seek to purchase multiple batteries so that they can extend their playtime by using them one after another [2].

RC boats are generally used in a pool, on a lake, or on a pond. Although their operating ranges are specified, users usually cannot determine if the boat is about to go out of range by simply looking at how far away the boat is on the water. This is very inconvenient if the boat is accidentally driven at top-speed out of range. It becomes difficult, especially on a lake or a pond, to retrieve the boat once it can no longer respond to the remote controller.

Our design will address both of these problems to allow for longer playtime and feedback to the user about the range and power of the boat's signal.

1.3 High-Level Requirements List

- Motor must receive sufficient power from solar cells to operate as it normally would on battery power.
- Voltage comparator will determine when to switch between battery power and solar power to provide consistent and continuous operation when solar energy is insufficient.
- User will be notified via LED added to controller that the boat is within approximately 5 meters of going out of range.

2 Design

From a high-level perspective, our design is composed of five subsystems, shown in Figure 1. We will have a power block that supplies power to our communication control as well as our power regulating circuit. The regulator circuit will supply power to the motor controller and motor. The communication control subsystem includes the communication hardware that determines if the boat is going out of range and when we need to warn the user. We will design a

PCB that contains the power and RF subsystems, along with the microcontroller that determines their behaviors.

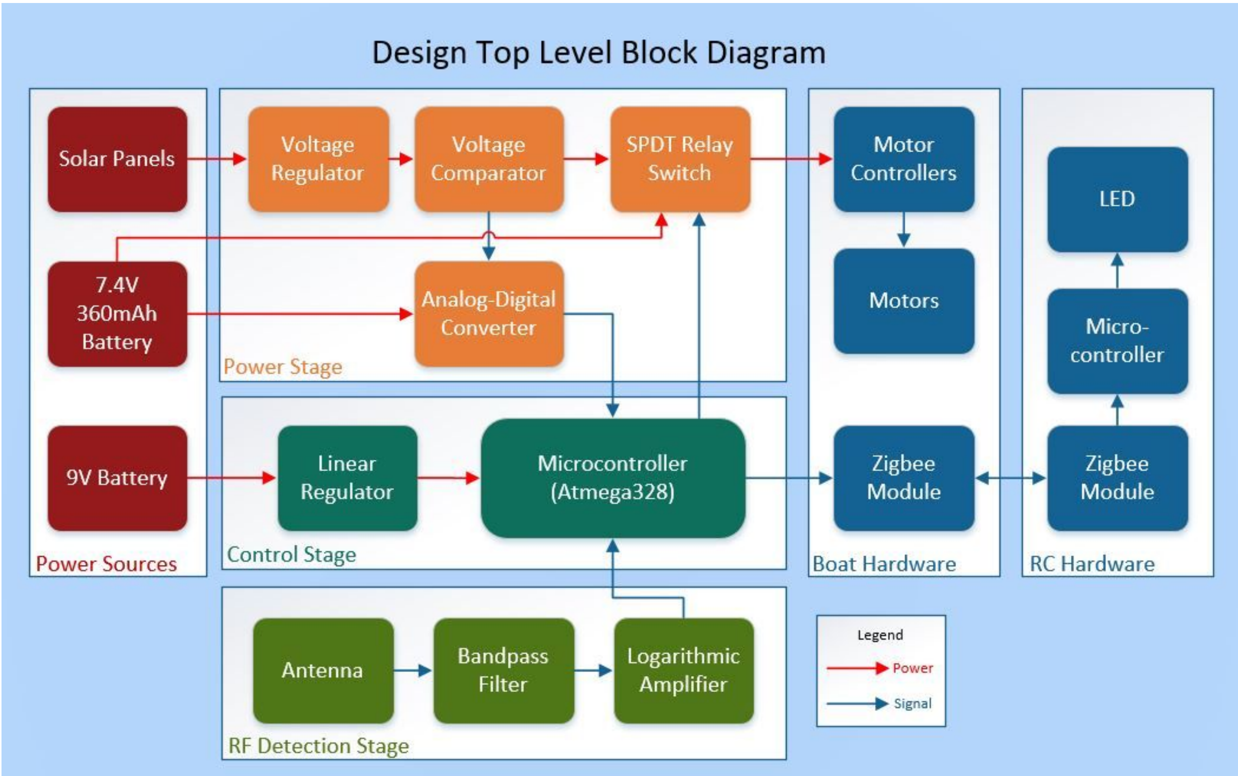

Figure 1. Block Diagram for Overall System

2.1 Power Supplies

Our design consists of three power sources that will be used to power the boat, motor, and our circuitry. We do not plan to use the solar panels or the boat's internal battery to power our own circuitry; instead, we will provide power to our microcontroller and circuitry using an external battery.

2.1.1 Solar Panels

We plan to work with a FunTech RC Boat [3] and ALLPOWERS solar cells [4] to capture solar energy and power the boat. The solar cells are 5V 2.5W mini encapsulated epoxy solar panels. Theoretically, 4 of these solar panels produces 10W of power, and our battery calculation shows that the battery produces 10.8W during its discharge cycle. However, this calculation is for the boat's total power consumption including its circuitry, so we should not need to produce all 10.8W just for motor operation. Once we have the boat, we will be able to characterize the motor and see what voltage causes the motor to stall; using this data, we will be able to determine how much power the motor actually consumes at peak performance.

Requirement: *Must provide 10W of power with a tolerance of +/- 0.1W.*

2.1.2 7.4V 360mAh Battery

The FunTech RC Boat has a rechargeable 7.4V 360mAh battery that lasts for at most 15 minutes on a full charge. When our solar energy drops below a threshold level we will first connect the battery to the motor controller and then disconnect the solar power so that we deliver seamless power to the motor controller. Once solar power is above the threshold again, we will connect it to the motor controller and then disconnect the battery. We will also implement a circuit protection diode scheme to block back EMF produced from switching between power sources from destroying our circuitry. Our boat has been ordered and we need to characterize its motor as well as our solar panels to determine the minimum power the boat needs to maintain adequate speed before switching between battery and solar power. Once we have that data, we will be able to select a power threshold.

Requirement: *The boat must operate longer than 15 minutes when using both solar power and its battery.*

2.1.3 9V Battery

Our solar energy and the boat's internal battery will only power the boat's motor; therefore, we will use an external 9V battery to power our microcontroller and circuitry.

Requirement: *The 9V battery must last longer than the internal boat battery and solar power during playtime.*

2.2 Regulator Circuit

The regulator circuit will determine which power source will supply the motor, using solar power as its default.. If the solar energy falls below a certain threshold (i.e. it gets cloudy), we will switch to providing battery power until sufficient solar energy returns (i.e. clouds go away). When the solar energy is sufficient, the internal battery will then be disconnected, and the solar energy will supply power to the boat motor again.

2.2.1 Voltage Regulator

The voltage regulator will take the energy from the solar panels as an input, and the circuit will boost/buck the voltage such that a smooth and controlled DC voltage is supplied to the voltage comparator. We will implement the boost/buck converter on our PCB, but we must first characterize the solar panel output as well as boat motor demands before we can specify the exact tolerances of each component and overall tolerance of the voltage regulating stage. Once we have the solar panels and boat motor we can determine what voltage the motor needs and how to manipulate the solar power to supply that.

Requirement: *Provide regulated voltage from the solar panels.*

2.2.2 SPDT Relay Switch

The regulated solar voltage and internal boat battery will be connected to the relay switch and controlled by the microcontroller. The microcontroller will receive a digitized signal by the ADC from the voltage comparator and then use that data to determine which power source should be connected to the motor controller. The microcontroller will take the output of the voltage comparator and determine if it meets the threshold required for the motors to work properly. The microcontroller will then switch the relay as necessary to provide constant power to the motors. The de-energized state of the relay will have the solar power as its output.

Requirement: *One power source must be connected before the other power source is removed to ensure continuous power supplied.*

2.2.3 Voltage Comparator

The voltage comparator takes the regulated solar voltage and the battery voltage as inputs and determines which voltage is larger. The output of the voltage comparator is sent to an analog to digital converter and then to the microcontroller to be compared against a threshold value so that the relay can be switched to provide power to the motor controller. The voltage comparator helps determine which power source is supplied to the motor. We will be able to select a voltage comparator IC once we have the motor and solar power characterization.

Requirement: *Determine if the solar panel voltage is large enough compared to the 7.4V internal battery.*

2.2.4 Analog-Digital Converter

The analog-to-digital converter (ADC) will convert the output of the voltage comparator into digital data to pass to the on-boat microcontroller. We plan to use a Maxim Integrated 8-bit analog to digital converter with a sampling rate of 25kS/s [7].

Requirement: *Must have an 8-bit resolution width to pass to the ATmega328 [6], which uses an 8-bit architecture.*

2.3 Boat Hardware

We will be working with the existing hardware that comes with the boat. We will need to integrate our design with this hardware without compromising the boat's integrity.

Requirement: *The boat hardware must not break or allow water onboard once we modify the boat.*

2.3.1 Motor Controller

The motor controller will be included in the boat that we purchase. We do not plan to alter the communication and connection between the controller and the motor. Once the boat arrives we will characterize the motor controller by varying the boat throttle and recording the voltage signals it sends to the motors.

Requirement: *The motor controller must take our switching power sources and control the boat's motor.*

2.3.2 Motor

The motor will be included in the boat, controlled by the boat's own motor controller. We will be modifying the power supplied to the motor heavily. We will go through careful calculations to ensure that the power matches with the original specifications. The boat has not arrived yet so given the timeline, we are currently unable to characterize the motor and calculate exactly how much power it will need.

Requirement: *The motor must be able to propel the boat forward at 15km/hr.*

2.4 RF Detection Stage

The purpose of the RF Detection circuit is to detect the strength of the signal received from the remote controller and determine if it is above a certain threshold. We will use a bandpass filter and a log amplifier to condition the signal before it is passed to the microcontroller. The microcontroller will then determine if the signal is getting too weak and control communication between two Zigbees to notify the user that the boat should be turned around.

2.4.1 Antenna

The antenna on the boat will sense the signal received from the remote controller and send it through the bandpass filter where any noise picked up by the antenna will be discarded. We will use an AN043 PCB antenna [8].

Requirement: *Must be able to capture channels at 2.4GHz.*

2.4.2 Bandpass Filter

The bandpass filter will filter out other frequencies captured by the antenna. We will use a TDK Multilayer Bandpass Filter [9].

Requirement: *The filter will allow a tolerance of +/- 1% around 2.4GHz.*

2.4.3 Logarithmic Amplifier

The logarithmic amplifier will be used for receiver signal strength indication. It will take the output of the bandpass filter and convert the signal level to decibel form to pass to the on-boat microcontroller. We'll be using the AD8307 log amplifier, which has a 92 dBm range [10].

Requirement: *Must be able to amplify our detected signal so the microcontroller can interpret it.*

2.4.4 On-Boat Zigbee Module

The Zigbee module on the boat will communicates with a second Zigbee module on the remote controller. The on-boat Zigbee will be controlled by the on-boat microcontroller to communicate with the controller Zigbee. The Zigbees will communicate at 2.4GHz on a channel separate from that of the RC Boat.

2.5 Control Stage

This module will control the relay switch for the power stage as well as the communication between the two Zigbees for the RF Detection stage.

2.5.1 On-Boat Microcontroller

The microcontroller we have chosen is ATmega328 [6]. It will be powered by the 9V battery. For the power stage, it will control the relay switch based on the output of the voltage comparator. For the RF detection stage, it will determine if the boat is near its maximum range based on the output from the log amplifier. It will also handle communication between the on-boat Zigbee and the controller Zigbee.

Requirement: *The microcontroller must be able to switch the power sources and determine if the boat is going out of control range.*

2.5.2 Linear Regulator

The ATmega328 microcontroller operates at 5V, so there will be a linear regulator to step down the voltage from the battery to 5V. We need to be careful with the current because the linear regulator will melt with current that is too high. We will use an ON Semiconductor 5 V linear regulator IC [11].

Requirement: *Must take 9V +/- 1.8V and provide constant 5V +/- 0.2V.*

2.6 RC Hardware

The boat comes with a remote control that we will modify in order to communicate with the circuitry we add to the boat. We do not plan to alter the actual control of the motor.

2.6.1 RC Zigbee Module

The Zigbee module on the remote controller will communicate with the on-boat Zigbee. The Zigbees will communicate at 2.4GHz on a channel separate from that of the RC Boat.

2.6.2 RC Microcontroller

There will be a microcontroller on the remote controller to enable or disable an LED based on the data received from the Zigbee.

Requirement: *Must receive data from the Zigbee and turn on LED when the boat is 5m away from going out of range.*

2.6.3 LED

We will modify the remote controller to include an LED. Its purpose is to notify the user that the boat will soon be out of range and should be turned around.

Requirement: *Must notify the user that the signal strength is getting too weak.*

2.7 Risk and Mitigation

There are two primary risks that can impact the success of this project. In order to complete this project, we must first address these risks and have mitigation plans. The integration of the solar panels can be challenging and poses several risks. We must consider the physical integration and ensure that the boat does not sink due to the weight and the placement of the solar cells. We plan to work with a FunTech RC Boat [3] and ALLPOWERS solar cells [4] to capture solar energy and power the boat. The solar cells are 5V 2.5W mini encapsulated epoxy solar panels. The boat size is 10.9 x 5.9 x 2.9 in. and each solar panel is 5.1 x 5.9 x 0.2 in., so we will be able to mount 4 of these cells to our boat. The cells can be mounted in a few different ways. If we do not want the cells to overhang the width of the boat, we can use right-triangle trigonometry to show that our tilt angle for each panel will be 55^o. Half of the boat is 2.95 in., and the solar panel is 5.1 in., so we make a right triangle and use the inverse cosine to find the angle. However, we can achieve shallower tilt angles if we allow for the solar panel to overhang the boat. For example, we can use a tilt angle of 45^o if we allow for 0.65 in. of overhang. We have ordered the parts, but they have not come in yet, so we have not yet decided upon which tilt angle will offer the greatest illumination of the panels. Once we get the panels, we plan to characterize them at different tilt angles and find the one that produces the greatest solar power. We then will see if that angle and amount of overhang from the boat will cause any mechanical instability and make adjustments as needed.

Theoretically, 4 of these solar panels produces 10W of power, and our battery calculation shows that the battery produces 10.8W during its discharge cycle. However, this calculation is for the boat's total power consumption including its circuitry, so we should not need to produce all 10.8W just for motor operation. Once we have the boat, we will be able to characterize the motor and see what voltage causes the motor to stall; using this data, we will be able to determine how much power the motor actually consumes at peak performance. If we cannot supply that power via solar cells, we will scale the motor's performance down so that we can provide enough power to the motor via solar cells at a cost of less speed. If all of this does not work, we can add on smaller solar panels between the larger solar panels and leave a larger overhang to compensate for the 0.8W. We also found additional motors [5] to use if the original boat motor requires more power than we can supply with the solar panels.

Another risk is having a correct and robust layout for the microcontroller. PCBs can take weeks of manufacture and delivery lead time, so we must complete our PCB on time without pivotal errors. Both of these risks can be reduced and mitigated with rigorous simulation and small scale testing.

3 Ethics and Safety

There are a few safety concerns with our RC boat project since we are manipulating the boat's power module. We must be highly cautious when taking apart the boat for modification; we need to maintain the battery integrity and make sure that the internal power circuitry remains protected. This is especially important because we will be doing a variety of testing in wet environments. Maintaining a protected power module is the most beneficial to the boat as well as the team members.

Although the voltage and current running through the circuitry are typically not life threatening, it could still dissipate a large amount of heat if the circuit is short circuited. This could cause burns if skin is in contact with the module, or possibly the boat. We must be careful when handling the boat, especially when we are testing our circuitry near water. A first aid burn kit should be ready at hand in case such an incident occurs.

We are responsible to make decisions consistent with the safety and health of the public and disclose any factor that might endanger the public or the environment as per Section 1 of the IEEE Code of Ethics [12]. As long as we properly handle our project during design and complete rigorous testing, none of the notable potential hazards would remain to cause any harm.

We will closely follow Section 5 and 7 in the IEEE Code of Ethics: to understand the application as well as the potential hazards of our project and promptly acknowledge and correct future errors of our design.

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