Intelligent Battery Controller

ECE 445 Design Document

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Contents

1 Introduction

1.1 Objective

Recreational vehicles such as boats and campers are owned all around the world. As many as 11% of American households own a recreational vehicle and contribute 114 billion dollars of revenue to the economy each year [1]. There is one serious issue with these types of vehicles that has yet to be properly solved. That is: many inexperienced owners of these vehicles may forget to reserve enough charge in their batteries to start the engine after a long day on the water, or weekend in the wilderness. The threat of being stranded with no means to start the engine is a serious one, and one we seek to solve by implementing an intelligent battery controller.

Our solution will overcome this problem by implementing a microcontroller that will control an automatic switching and disconnection control for our batteries. The microcontroller will monitor the charge levels of the batteries in the system and automatically switch between the batteries, disconnecting them from the rest of the vehicle's electrical load once the charge reaches a level just above that necessary to crank the engine. This is important as the batteries can only be recharged by an alternator installed in the engine unless the system has another external charging source, such as roof mounted solar panels.

1.2 Background

Currently, most systems that control load switching in vehicles do not switch batteries automatically and must be switched manually. By having our controller maintain enough power in the batteries to start the engine, we can decrease complications due to user error and make the process of preserving enough battery life to start the engine more seamless. Due to the COVID-19 pandemic, sales of recreational vehicles have soared, with marine sales alone being 30% higher over last year during the months of May and June. Many of these boats were purchased by new operators [2] lacking experience and discipline when it comes to making sure they conserve enough energy to start their boat. Our automated design will ensure that the batteries can still be used for recreational loads for a period of time and disconnect them before they can no longer start the engine. Examples of these loads are stereos, marine VHF radios, fishfinders, and lighting which put a large burden on the electrical system.

The overly simplified solution to the problem of not having enough charge to start the engine would be to increase battery storage by wiring the batteries in parallel, however; this is not without its own issues. For one, this does not prevent the batteries from being discharged too far to start the engine. Additionally, the intended market application of our system is to work with deep-cycle lead-acid batteries, which are common in the recreational vehicle industry. Deep-cycle batteries are intended to have high charge/discharge cycles [3], meaning that they are intended to be depleted as much as possible before being charged to full capacity. By allowing the batteries to discharge to just above the engine starting threshold, we can extend the lifetime of the batteries. Our design is intended to switch batteries which allows us to maintain the health of the batteries by changing the discharge depth of each battery. There will be three physical switches that will allow the user to override the controller in various ways for convenience, such as starting the vehicle, or bypassing the system we are implementing.

Since an engine is cumbersome, unsafe, and expensive to work with, a testbench is needed to verify our designs functionality. Due to the dangers of using lead-acid batteries in the context of this course, the project will function as a proof of concept for our design application by using small alkaline batteries. The design could then later be adapted to work with other battery choices. This will alleviate some of the associated dangers to complete this project for the course safely with the idea that we will later be able to scale it to work with lead-acid batteries. In addition to being safer for us to design around, the design will save costs by needing to implement less safety measures into our design.

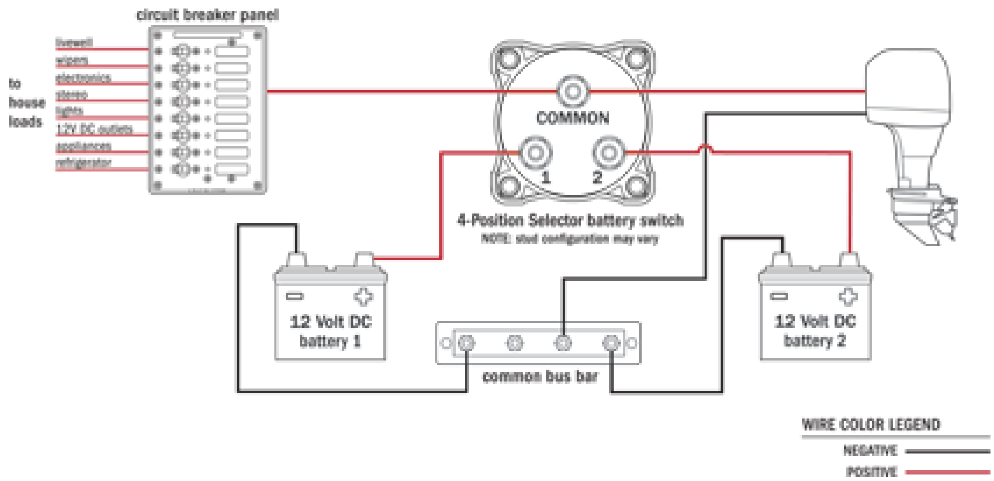

Fig. 1. Common Recreational Vehicle Power Circuit [4]

1.3 High Level Requirements

- The system must be able to cut all power delivered to recreational devices when the 12V battery banks reach charge levels of 10V one battery, and 8V on the other battery.
- The test bench should be able to simulate power drawn from recreational devices and a motor running using two 12V alkaline battery banks. These branches should be able to draw 500mA over 20 minutes to simulate recreational use, and 1.5A over periods of up to 5 seconds to simulate motor start conditions.
- Power consumption of the controller itself must stay below 2W of power

2 Design

2.1 Block Diagram

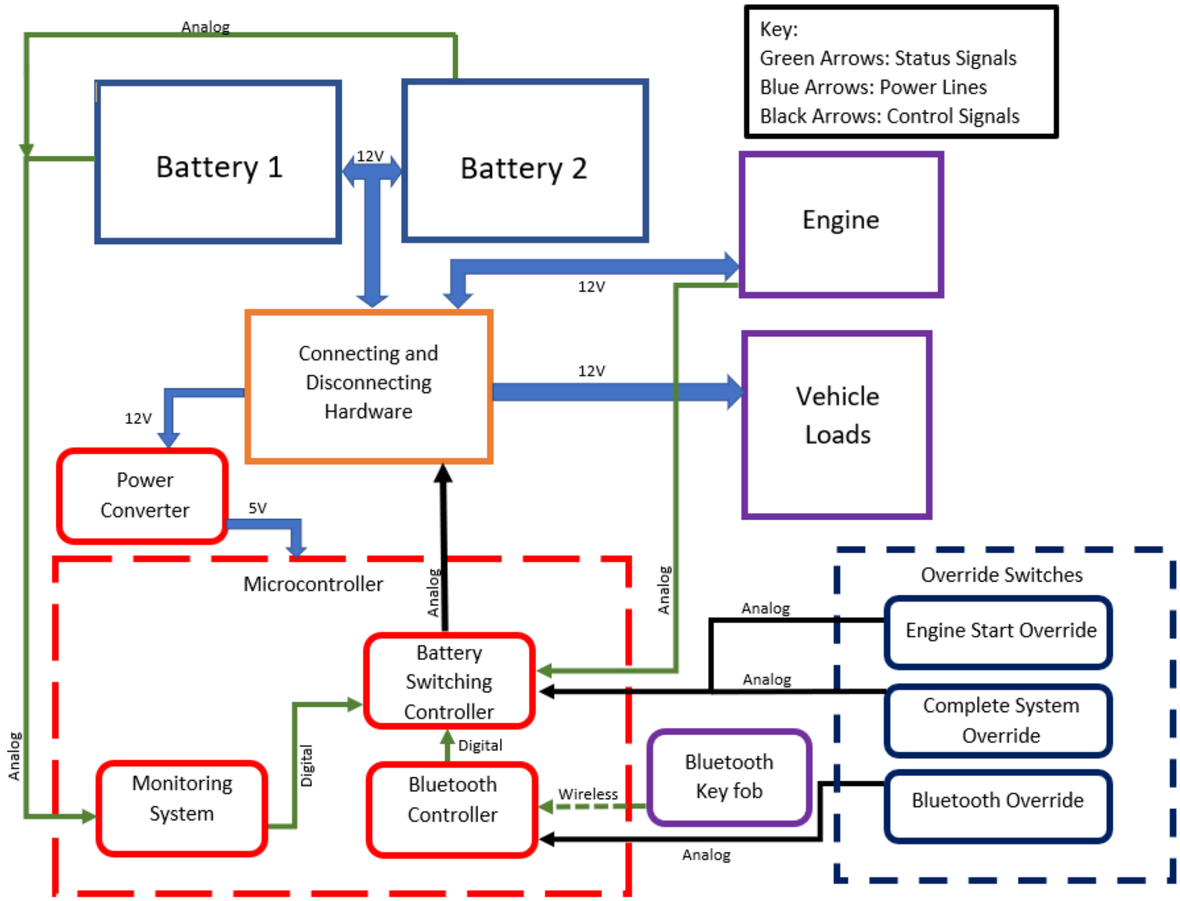

Fig. 2. Block Diagram

Descriptions of Subcomponents found in Fig. 2:

2.1.1 Microcontroller:

2.1.1.1 Monitoring System: Keeps track of battery voltages

2.1.1.2 Battery Switching Controller: Receives signals from other components, makes decisions on system output

2.1.1.3 Bluetooth Controller: Monitors status of Bluetooth switch and keyfob app input

2.1.2 Override Switches:

2.1.2.1 Engine Start Override: Activated Override / Timer

2.1.2.2 Complete System Override: Completely turns off the system, or tells the device to act as though the system is not there

2.1.2.3 Bluetooth Override: In case of lost keyfob app, allows the bluetooth functionality to be disabled

2.2 Physical Diagram

2.2.1 External Physical Design

Physically, the outside of the device is just a plain black box. On one side wall are three wires that come from each of the two batteries and ground. The opposite side contains the output wire from the device that goes to the engine and other vehicle loads. On the top of the device is a heat sink that is used to conduct heat away from the internal mosfets. Finally, the override switches are on the front of the device for easy access by the end user. All of these features can be seen in Fig 2.1.

Fig. 2.1 External Physical Design

2.2.2 Internal Physical Design

The internal physical design will consist of the following components. The Microcontroller assembly will be composed of an ATmega328 microprocessor with capacitors and resistors specified for proper operation (See Fig. 6). There will also be a 5V voltage regulator with capacitors added for stability. These assemblies will be mounted away from two NMOS transistors that are responsible for connecting and disconnecting the load to reduce the effects of heating on those assemblies. The two NMOS transistors will have heat sinks extending out of the enclosure attached to them to allow for heat to dissipate to the environment. On one internal wall of the enclosure, a Bluetooth receiver module will be mounted. On another wall of the enclosure, the three system override controls will be mounted.

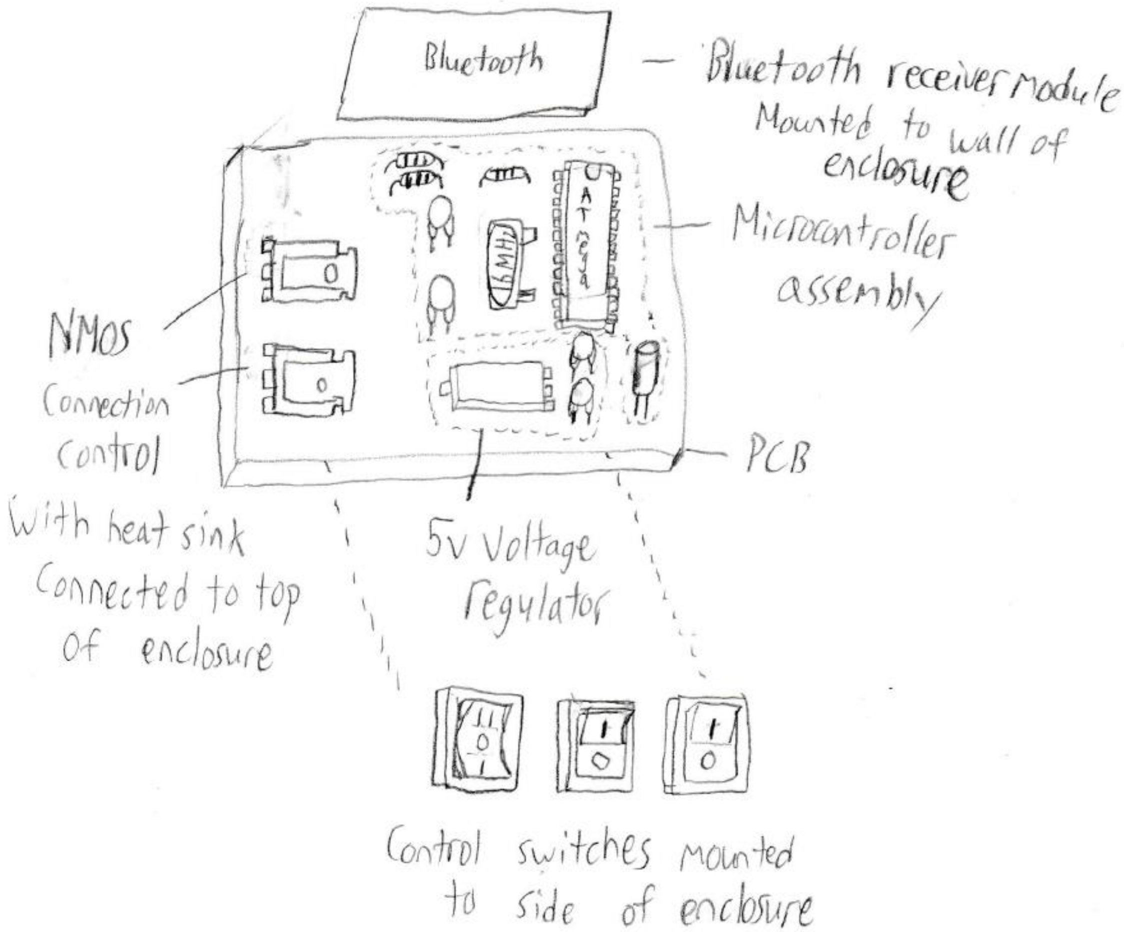

Fig. 2.2 Internal Physical Design

2.3 Subsystems

2.3.1 Power Converter

The microcontroller requires a 5V rail to operate. Thus, there needs to be a voltage regulator that has a fixed output of 5V. The regulator must also be able to stay constant regardless of voltage drops on the battery nearing 5V. So, to ensure that the 5V remains constant the regulator has a **low dropout voltage (500mV)**[5] allowing the regulator to perform correctly as low as a battery voltage of 5.5V. This is enough headroom for this application as the system's shut off will be designed to be 6-7V on the batteries. This voltage regulator is the LM2940CT-5.0 as shown in Fig. 3. It will also require two capacitors at both the input and output pins of 0.47µF (tantalum) and 22µF (electrolytic), respectively and shown in Fig. 4.

<table>
<tr><th>Requirement</th><th>Verification</th></tr>
<tr><td>A. Outputs 4.5-5.5V to the microcontroller at input voltages ranging from 6-13V.
B. Capacitors are correctly valued at 0.43-0.51μF and 0.18-0.26μF.</td><td>A. Verify voltage output with a multimeter (FLUKE 115).
1. Switch the dial to measure DC voltage on the multimeter.
2. Connect the test probes to the multimeter such that the black test probe is connected to the COM port on the multimeter and the red test probe is connected to the V/Ω/Hz port.
3. Place the COM/black test probe of the voltmeter at the ground of the battery terminal.
4. Place the red probe to the 5V side of the voltage regulator.
5. Verify on the screen of the multimeter that DC voltage is stepped down to 4.5-5.5V.
6. Continue to check this screen as voltages vary from the battery.
7. (optional) if in the lab, hook a DC voltage supply and vary the voltages ranging from 6-13V on the input pin of the voltage regulator.

B. Verify capacitors are at correct values using a multimeter (FLUKE 115).
1. Switch the dial to measure capacitance in the range of 100nF.
2. Connect the test probes to the multimeter such that the black test probe is connected to the COM port on the multimeter and the red test probe is connected to the V/Ω/Hz port.
3. Place the COM/black test probe on the terminal with the shortest leg if it is an electrolytic or any leg if it is a tantalum.
4. Place the red probe on the other leg of the capacitor.
5. Verify on the screen of the multimeter that the capacitors meet the specified requirements.</td></tr>
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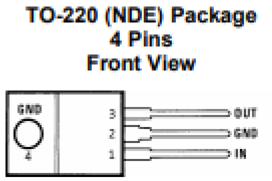

Fig. 3. The LM2940CT-5.0 packaging [9].

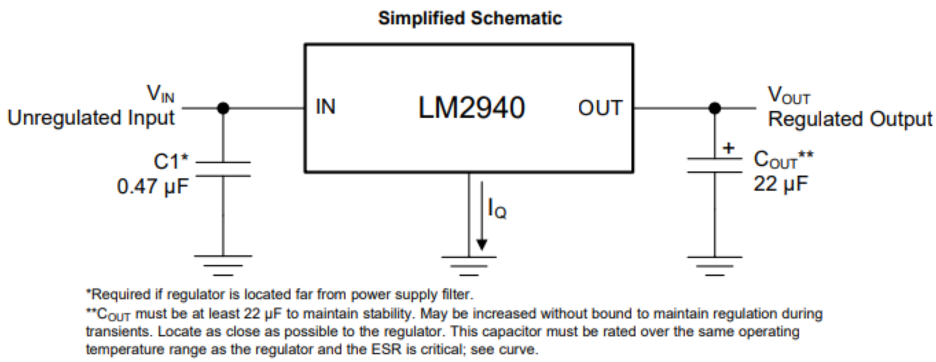

Fig. 4. Typical arrangement for a voltage regulator circuit [9].

2.3.2 Microcontroller

For this project to succeed, there needs to be a microcontroller to receive voltage levels from the battery and use that information to send out signals that turn on and turn off the batteries. It must be able to also take in inputs from numerous switches that the user will be able to control (see section 2.3.3 Override Switches). This can be accomplished using an ATMEGA328 as seen in Fig. 5. It will be coded using the Arduino IDE and debugged on a breadboard using the Arduino board as a way to code the ATMEGA[6]. The required parts to make this work are: a 16 MHz crystal, 10kΩ resistor, 2 22pFtantalum capacitors, and a 10µF electrolytic capacitor. The proper circuit can be seen in Fig. 6. Once the design has been properly debugged, then it will be soldered onto a printed circuit board for the final design.

Requirement	Verification
A. Microcontroller polls voltage levels from the batteries every 20-30 seconds. B. Microcontroller sends out digital signals 4.5-5.5V until a voltage criteria*, switch criteria, or bluetooth criteria is met. C. Components such as the resistor, capacitors, and the crystal must be tested.	A. This can be checked in the Arduino IDE in the control window on the breadboard before installing it to the PCB. 1. Open the Arduino IDE software 2. Make the necessary connections to the Arduino for modifications as seen in Fig. 7. 3. Make sure the code is uploaded to the ATMEGA through the Arduino board. 4. On the breadboard, place a wire connection to PIN 9 on the ATMEGA. 5. Grab any battery or voltage source with a known voltage value. 6. Touch the wire connected to PIN 9 on the ATMEGA to the positive terminal of the battery. 7. Connect the negative terminal of the battery to the same GND as the ATMEGA or PIN 27. 8. Look at the Arduino IDE control window and see if the voltages on the screen match the voltage source and are appearing in 20-30 second intervals. B. This can be checked in the Arduino IDE control window and with the ATMEGA on the breadboard. 1. Open the Arduino IDE software. 2. Make the necessary connections to the Arduino for modifications as seen in Fig. 7. 3. Make sure the code is uploaded to the ATMEGA through the Arduino board. 4. On the Arduino, place wires on PINs 26 and 25 5. Get a multimeter (FLUKE 115) and turn the setting to read out voltage. ALos, make sure the black and red probes

	are plugged into the correct ports on the multimeter. 6. Place the red probe on the PIN 26 wire and the black probe to GND. 7. Make sure the override switch is turned off. 8. The multimeter should read 4.5-5.5V. 9. Turn the override switch off. 10. The multimeter should now read 0V. 11. Do steps 6-10, but place the red probe on PIN 25. 12. Turn the override switch off. 13. Place the red probe of the multimeter on PIN 26, again. 14. Take the Bluetooth keyfob app on one's phone (described in sec. 2.3.3 Bluetooth Control) and walk 30-50 feet away from the Bluetooth module. 15. Press the off button on the app.. 16. Go back to the multimeter. It should read 0V. 17. Repeat steps 13-16, but place the red probe of the multimeter on PIN 25. 18. Using a 1k potentiometer, connect 1 pin to a 12V battery. Connect another pin to GND. 19. Connect PIN 9 of the ATMEGA to the third pin of the potentiometer. 20. Place the multimeter's red probe on the same pin as the ATMEGA's PIN 9. 21. Turn the potentiometer until the voltage reading is lower than 8V. 22. Check PIN 26 of the ATMEGA by placing the red probe there. It should read 0V. 23. Place the probe back on the potentiometer. 24. Turn the potentiometer until the voltage is above 8V. 25. Check PIN 26 of the ATMEGA by placing the red

	probe there. It should now read 4.5-5.5V. 26. Turn the potentiometer back down to below 8V. 27. Put the red probe on PIN 25. 28. Using a different potentiometer, repeat steps 19-25, but the voltage level is now 10V and the ATMEGA PIN to probe is PIN25. C. Testing components is very similar to that described in verification B of sec. 2.3.1. The difference is testing the crystal oscillator. 1. Obtain a multimeter. 2. Connect the probes as described in earlier verifications. 3. Turn the multimeter dial to the “Hz” option. 4. Have the ATMEGA connected properly as shown in Fig. 6. 5. Place one probe to one side of the crystal and the other probe to the other side. 6. It should read 16MHz.

*Voltage criteria is the determined voltage that is set within the code of the ATMEGA. This means, for our system, when 8V is ‘seen’ by the microcontroller the signal for that battery will turn off and disallow current to pass through the MOSFET that is controlling that battery. This happens when the other battery meets a voltage level of 10V as well.

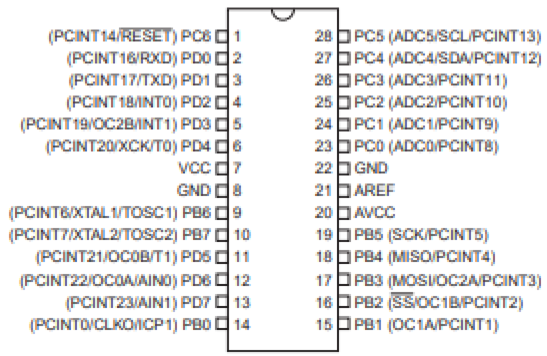

Fig. 5. The ATMEGA328 Packaging [7].

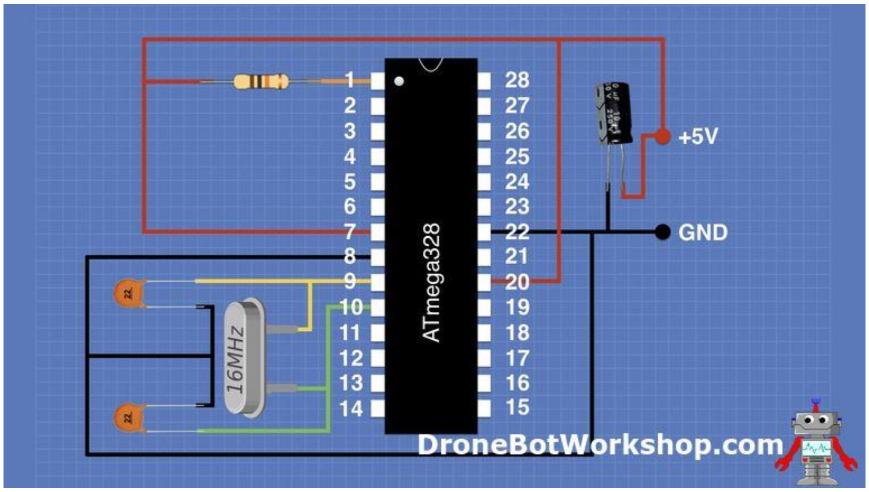

Fig. 6. Proper design for the ATMEGA [6].

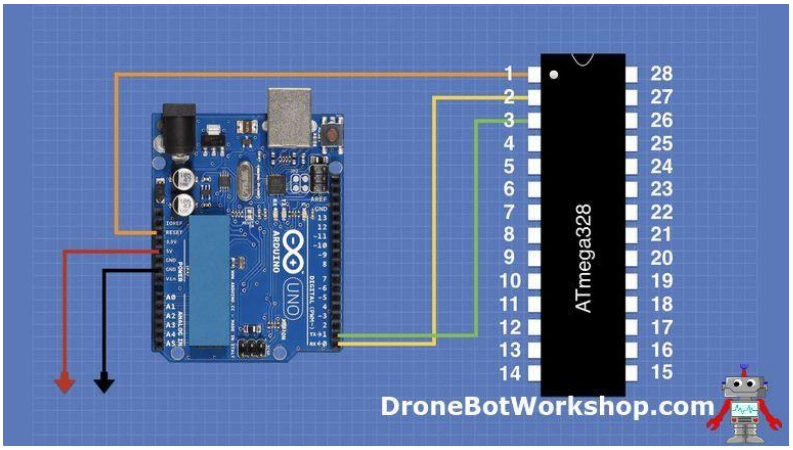

Fig. 7. Proper setup for programming the ATMEGA [6].

2.3.3 Bluetooth Control

The Bluetooth control will receive a signal from a keyfob app designed for mobile phones. The Bluetooth control will output a signal to the microcontroller to disconnect or connect the batteries determined by the user's application on his phone. The nRF51822 Bluetooth Low Energy Module - MDBT40-256RV3 is the part that will be included for Bluetooth control as seen in Fig. 8. It requires flashing of the module with Bluetooth firmware.

Requirement	Verification
A. Must be able to receive signals from a mobile app to shut off batteries from 30-50ft away.	A. Testing this requires a multimeter. 1. Attach probes to GND and to the 12V rail of the batteries. 2. Walk 30-50 feet away. 3. Press the "OFF" button. 4. Go and check the multimeter. It should read 0V.

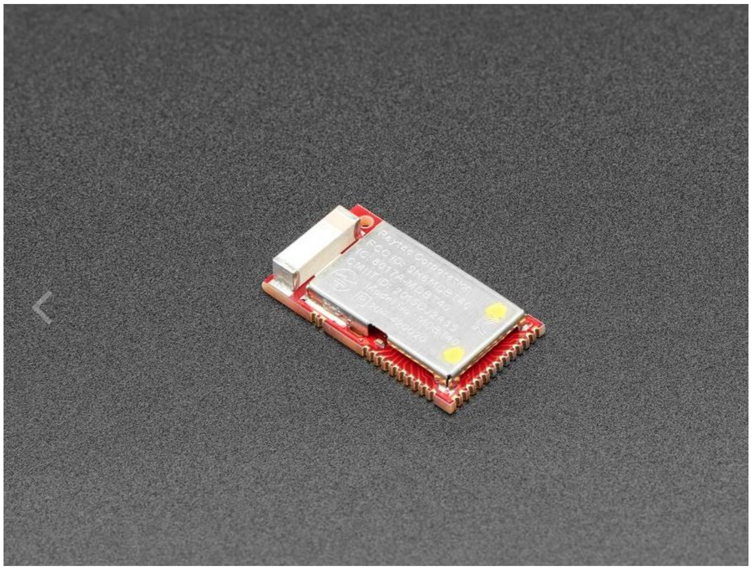

Fig. 8. Bluetooth module [8].

2.3.4 Connecting/Disconnecting Hardware

The design calls for high power MOSFETs to handle the switching of the batteries. This will ensure low power consumption during which the batteries are on. The chosen MOSFETs are the IRFP3206PBF as pictured in Fig. 9.

Requirement	Verification
1. These MOSFETs should be able to switch each individual battery given a control signal from the microcontroller. Should use less than 500mW of power.	A. To check for a working, low power MOSFET, grab a multimeter. 1. Switch the multimeter to read current. 2. During an off state for a battery, place the probes in series with the drain of the MOSFET. 3. It should have reasonably low current on the order of microamps. 4. Have the condition where a battery is connected to the 12V rail. 5. Measure the current again on the drain of the MOSFET. 6. It should read in milliamps. 7. Now, switch the multimeter to read voltage. 8. Check the voltage between drain and source. 9. The voltage should be on the order of millivolts.

Fig. 9. MOSFET used in design [9].

2.3.5 Override Switches

2.3.5.1 Engine Start Override

The engine start override switch will send a control signal to the battery connection hardware to connect both batteries to the load temporarily to allow starting of the engine. If the engine is not started during a short period of time, the batteries are disconnected again to conserve charge. The design calls for the 1825910-6 switch to ensure operation.

Requirement	Verification

1. Both batteries will be connected upon activating the engine override switch.
2. After a period 10-20s after activation, if the engine is not started, both batteries will be disconnected.
	A. Measure voltage and current on the load side after activating the switch to confirm the control signal functionality.
	    1. This can be done using a multimeter.
	    2. After activation, place probes on each battery rail in series to check for a current.
	    3. There should be a current coming out of both batteries.
	B. Activate the switch, wait 10-20s, then measure voltage and current on the load side to verify the disconnection of the batteries.
	    1. Using a multimeter, check the 12V rail.
	    2. It should read 0V after disconnection.
	C. After 20-30 seconds with the engine started, verify that the batteries do not disconnect.
	    1. Place probes on the 12V rail.
	    2. It should not be 0V.

Fig. 10. Switch used for Engine Start Override [10].

2.3.5.2 Complete System Override
The complete system override uses a single pole, double throw switch as seen in Fig. 11 to control power to the system. There will be three states: System-operating, system-disabled, and battery disconnect. The system operating state will be the default state in which the intelligent battery control is operational. The system disabled state will connect both batteries at once and disable disconnection control signals. The battery disconnect state will disconnect both batteries from the load, and disable connection control signals.

Requirement	Verification
1. The three states that the complete system override can take all functions as specified.	A. In the system-operating state, test all connection/disconnection control signals to verify their functionality. 1. This should not hamper the original control signals provided by the microcontroller. 2. Go through standard procedures described in the verification process for the microcontroller. B. In the system-disabled state, test all disconnection signals to verify disabled state. 1. Check connections from the microcontroller with a multimeter. 2. They should be activating the MOSFETs regardless of state. C. In the battery disconnect state, test voltage at the load to ensure

	batteries have been disconnected. 1. Check with a multimeter that the batteries are not supplying a voltage.

Fig. 11. A single pole double throw switch [11].

2.3.5.3 Bluetooth Override

The Bluetooth override switch will disable the Bluetooth signal measuring control. The system will continue to operate without taking Bluetooth signal strength into account for connection/disconnection controls. We will be using the switch as shown in Fig. 12.

Requirement	Verification
1. When the Bluetooth override switch is activated, the system will ignore any Bluetooth inputs from the app.	A. Activate the bluetooth override switch, then check the functionality of all control signals to verify that the Bluetooth signal does not impact operation. 1. Run through the standard verification for the microprocessor with the switch off.

Fig. 12. Switch [12].

2.4 Tolerance Analysis

An important part of our design where tolerance is critical is the output of the 5V voltage regulator that drives the ATmega328 microprocessor. The ATmega328 microprocessor can accept a range of voltages from 1.8V min to 5.5V max. The reason this part is critical is because the maximum voltage that can be read from the analog to digital conversion pins (ADC) on the ATmega328 can only accept a voltage reading of VCC + 0.5V [7]. Our battery voltages that we are monitoring are intended to be within the range of 8V to 12V. To ensure proper functionality of the ATmega328 controls, we must keep the output voltage of the regulator within a very narrow range while also implementing a voltage divider to step down the battery voltage to a level that can be accepted by the ADC converter. Using two resistors, we obtain the formula for a voltage divider:

$$V_{divider} = V_{battery}\left({}^{R_2}\!\big/_{R_1 + R_2} \right)$$

Eq. 1 Voltage Divider

Our design must ensure that this divided voltage stays within an upper bound of VCC + 0.5V, with VCC being produced by the 5V voltage regulator. To meet tolerance requirements for our design, the voltage regulator must output a constant 5V voltage signal +/- 10% (4.5V to 5.5V). The voltage divider will incur additional power dissipation that must be kept under 1 watt total for the microcontroller block of our design. Since only the voltage is being measured for the control logic in the microprocessor, we will be able to use high impedance resistors to drive current down to negligible levels.

2.5 Contingency Plan

In the case of COVID-19 precautions by the university making in-person lab equipment unavailable, the course of action for this project would remain mostly unaltered. It was agreed upon that there is a location where all individuals can convene to work on the project with self provided equipment. Some techniques for the test bench, or debugging methods may have to be altered due to the lack of equipment found in the lab. For example, an oscilloscope may not be available to test for momentary signal spikes or collect waveforms. While the project verification methods may be subject to change by these precautions, the overall requirements and goals for this project should not be altered in a significant manner.

3 Cost and Schedule

3.1 Cost Analysis

Reports from job recruitment sites list the average annual salary of an entry-level electrical engineer in the United states to be from $55,000 [13] to $75,000 [14]. Using these sources as a basis, we will define an entry-level electrical engineer salary to be $65,000, or $31.25/hour.

Our development costs for this design are estimated as follows: Assuming 7 hours of work weekly for 3 entry-level engineers over the course of 7 weeks at an hourly rate of $31.25/hour, we obtain the following labor cost equation:

$$Cost_{labor} = 7_{hours} \cdot 3_{workers} \cdot 7_{weeks} \cdot 31.25_{\$/hour} = \$4{,}593.75$$

Eq. 2 Cost of Labor

The cost breakdown for each product made is summed in this table:

Item:	Cost:
ATMEGA328	$1.90
22pF capacitor x 2	$0.34
LM2940CT	$1.53
10kΩ resistor	$0.10
0.47µF capacitor	$0.57
22µF capacitor	$0.15

Switch x 3	$3.00
Bluetooth module	$10.00
High Power MOSFET x 2	$3.00

3.2 Schedule

Week of:	Chris (ONL) Task:	Jed Task:	Joey Task:
10/5	Go through Design Review feedback, modify designs for device and test bench	-Order parts that have been approved -Research Bluetooth interface	Go through Design Review feedback, modify designs for device and test bench
10/12	-Review PCB design -Order final parts -Develop final device Schematic	Create preliminary app needed for bluetooth application	Design PCB and order
10/19	Design case for the device (Black Box), 3D print prototype and assemble	Build the device internals	Build the device internals
10/26	Write code to upload to board for device operation	Debug Bluetooth functions	Assemble Test Bench
11/2	-Based on feedback, make sure the device is meeting our specified stipulations. -Order replacement parts	Debug device, make alterations to code, physical design, etc.	Debug test bench,, make alterations to physical design, etc.

11/9	-Analyze power data and feedback -Based on device behavior, make sure the device is meeting our specified stipulations.	Debug device, make alterations to code, physical design etc.	Debug device, make alterations to code, physical design etc.
11/16	Begin Final Paper	Demonstration Prep/ Work out final bugs in system	Demonstration Prep/ Work out final bugs in test bench
11/23	Final Paper	Create Final Presentation	Begin Final Paper
11/30	Final Paper	Final Presentation last minute details / Check	Final Paper
12/7	Final Paper	Final Paper	Final Paper

4 Ethics and Safety

This device has the potential to be dangerous as there will be high currents being passed through the upscaled design. The proof of concept design presented here will have much smaller current values, which will mitigate many of the potential hazards. All of the hazards found in the small scale are multiplied in the full scale. Despite the lower constraints, there is still the chance for burns associated with current passing through devices to cause harm. To minimize bodily risk, when working with the 12V side of the device and test bench, which is where the majority of the power dissipation takes place, it is imperative to ensure the device is off and to let it cool down before servicing its parts. If parts must be serviced immediately, insulated gloves must be worn at a minimum. Although no PPE is expressly required in this situation [15], it would make the technician servicing the unit safer if by chance an accidental short was to occur. Additionally, added insurance can be implemented by fusing the device to prevent short circuits from occurring. This would be a crucial last step in ensuring an explosion does not happen.

If the design is to be manufactured for automobiles or boats, then the design will need to follow guidelines specified by organizations such as the International Organization for Standardization (ISO) [16] and the United States Coast Guard (USCG) [17]. These are important to IEEE as these standards have established the safety concerns needed for everyday use. They verify that the device meets specific stipulations, such that it is not harmful for human use. On boats, this means that no sparks can be generated by electrical components. Information on this is found in the USCG section 183.410[18]. On the automotive side of things, the device would be primarily by ISO 10483-2, which discusses intelligent power switches for road vehicles [19]. This standard discusses only the electrical aspects of the device. Additionally, it would have to pass stipulations found in various other ISO standards based on its environment, and mechanical considerations. Examples of these are, but not limited to, vibration, mechanical shock, temperature and humidity cycling, and impact testing.

After receiving warning information regarding the intended application of lead acid batteries to simulate the system, a design change was made to use alkaline batteries in their place. By putting eight AA batteries in series, the desired voltage level is reached in a safer manner. The lead acid batteries would have been filled with sulfuric acid, which is a highly corrosive substance that is harmful to humans[20]. Precautions would have been taken to ensure the safe handling of the batteries to lessen the exposure risk, but it was agreed that it was not something that should be put to chance. Additionally, if the batteries were charged improperly, they could explode, sending shrapnel and sulfuric acid into the air [21]. On top of these worries, there would also be the risk of a sudden discharge event triggering a Hydrogen (H_2) gas emission[22]. H_2 gas can be explosive in the air. These issues can be seen as a concern according to IEEE standards I-7 [23]. To respond to these issues, working to make the system flawless is the top priority so that this risk is minimized.

Using the alkaline batteries in place of the original lead acid batteries should allow for the minimization of many of these risks, but forces a change when it comes to testing the charging capabilities of the system. More or less, since alkaline batteries cannot be charged safely, it is impossible for this function to be demoed. They can however, be slowly discharged safely by our test bench. Here we plan on taking the necessary steps to ensure that safe current levels are maintained throughout the process.

5 References

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