Autonomous Dog Entertainment

By

Mary Abbott

Aimee Rogala

Robert Scheuneman

Mock Design Review for ECE 445, Senior Design, Spring 2017

TA: Luke Wendt

21 February 2017

Project No. 16

Contents

1 Introduction

1.1 Objective

Dogs are often left at home alone for periods of time when their owner needs to leave the house. According to the American Humane Society, this can cause a dog to become anxious or bored while left alone. This can lead to the dog acting out and chewing on the furniture or causing some other damage throughout the house[1].

Our goal is to develop a device that will provide a stimulating source of entertainment for the dog while its owner is out of the house. Furthermore, it will keep the dog's attention for the length of its attention span in order to keep it from becoming bored or anxious. We want to create a device that will drag one of the dog's toys around the house in order to stimulate the dog's interest and provide entertainment. The device will be able to navigate throughout the house by using IR sensors on the vehicle in order to avoid obstacles. The navigation will be autonomous and require no user control. The device will be durable such that it is not damaged by the dog playing with the device and must be safe for a dog to play with. Finally, the device will be able to move around for 20 minutes so that it will keep the dog's attention for its full 15 minute attention span[2].

1.2 Background

Most current dog toys on the market rely on human interaction to stimulate the dog's attention. This makes them ineffective when humans are not around to play with the dog. Some dogs are still willing to play with toys without human interaction, but this often involves throwing or flinging the toy with potentially destructive results. Our system will not require human interaction and will minimize harm to its surroundings by actively avoiding obstacles.

Some dog owners choose to send their dog to doggy daycare or hire someone to walk the dog during the day. This method, while effective in entertaining the dog, can be costly. Some dog owners cannot afford to spend $20-$40 a day on entertainment for their dog. Our goal is to provide a more affordable way for dogs to be entertained when their owners are unable to play with them.

1.3 High-level Requirements

- The device will be able to detect and avoid items of furniture that are obstructing its path at least 80% of the time.
- The device operates in a manner that could attract a dog for a duration of 20 minutes.
- The device can continue to operate effectively when dropped on any side.

2 Design

2.1 Block Diagram

The block diagram shows that there are four main modules to our device: External, Power Supply, Control, and Motors. The external portion of the device contains a charger that is used to recharge the power supply, battery, within the device. The power supply contains a battery as well as converters and voltage regulators to allow for multiple voltage supply levels to various parts of the control and motors. The control utilizes power to operate various parts that are used for the internal operation of the device. The control collects inputs from the environment, such as button clicks and potential obstacles, and uses the information to send data to the motors module. Furthermore, internally, the control operates a display and speaker for use by the dog and owner. The motor drive takes power and data inputs, which it then uses to operate the two rear-wheel motors through a current safety module. The current safety module sends data to the microcontoller that is used to determine if the motors need to be shut off.

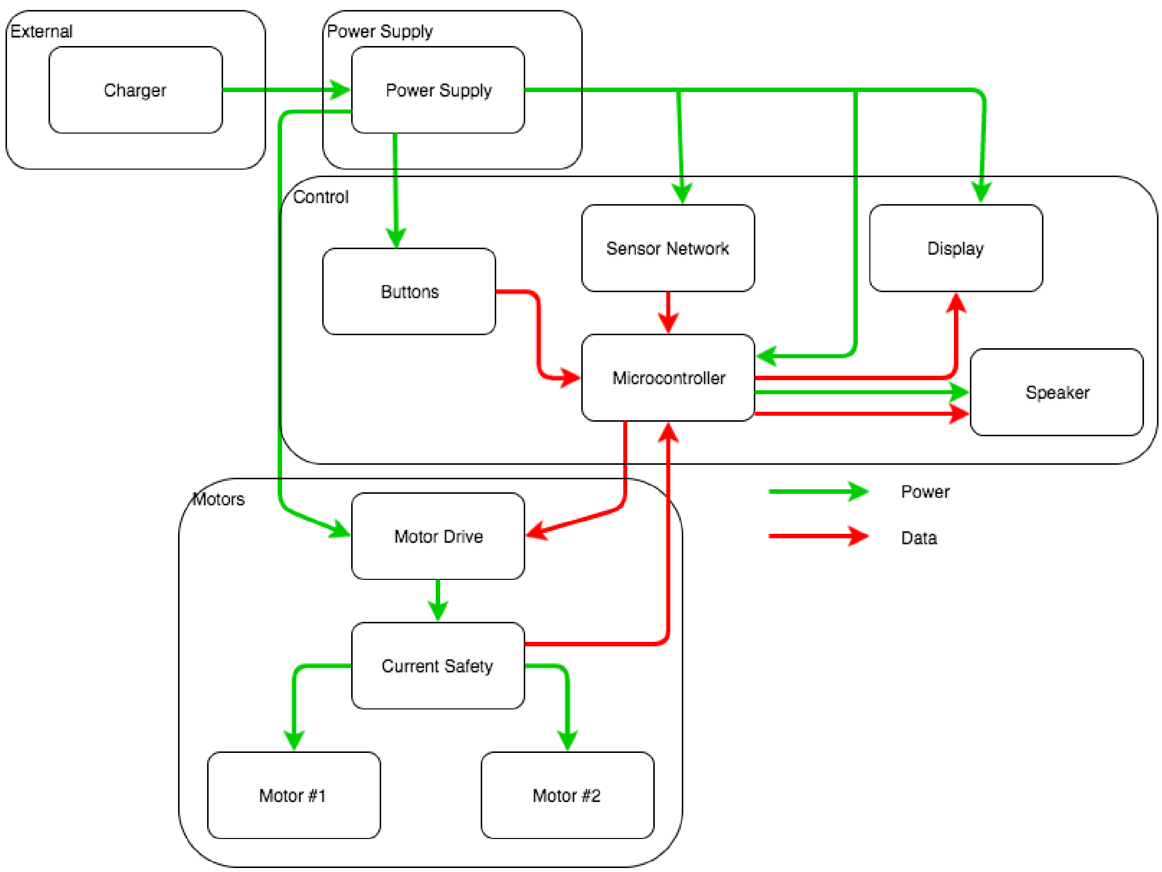

Figure 1: Block Diagram

2.2 Block Descriptions

2.2.1 Microcontroller

The microcontroller module is the central hub of the system where all the data goes through. This module consists of two ATmega328 microcontrollers. Both are powered from the DC-DC converter. The first AtMega328 takes digital inputs from the buttons, which is used to determine the time until the device will activate, and analog inputs from the accelerometer used to determine the orientation of the device. Using this data it determines if the device is active based on the counter and determines the orientation of the device. It then outputs the current time of the counter to the HEX display and sends digital signals orientation and device active to the second ATmega328. The second ATmega328 microcontroller takes digital signals orientation and device active as well as digital signals from the IR sensors placed throughout the body of the device. Based on the input data it will output digital enable signal to the motor drive as well as PWM signals to each of the motors.

2.3 Circuit Schematics

2.3.1 Microcontroller Circuit

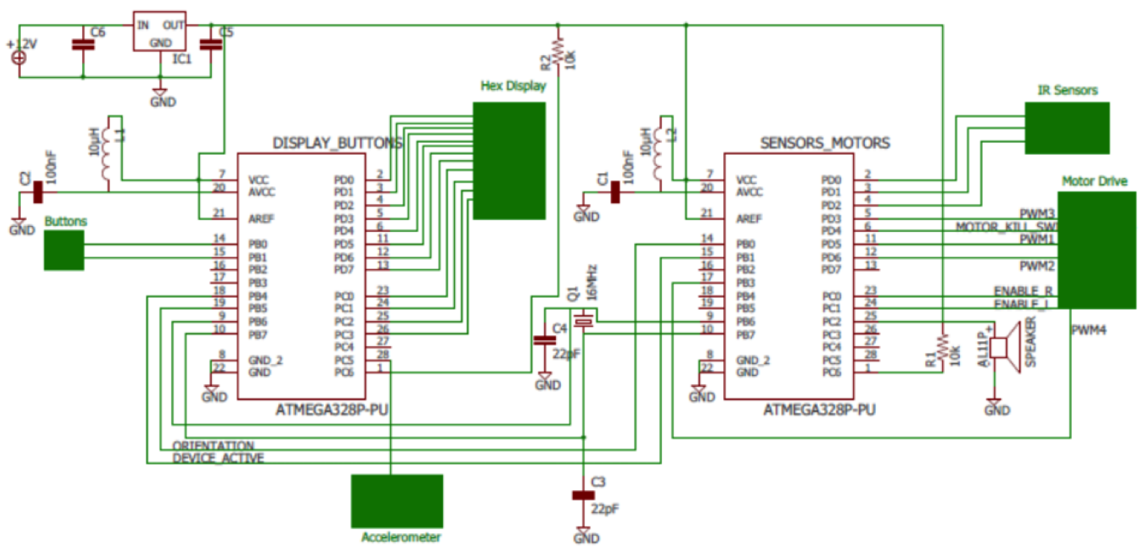

Figure 2: Microcontroller Circuit[3][4][5]

2.4 Calculations

The torque calculations assume that the current to the motor is not being regulated by a PWM signal through the motor drive. The solution is a minimum speed because there will be two motors operating and the weight will be distributed across four wheels. Due to these variations, the actual speed will be greater than the listed value without regulation. The calculation is to show that our motor has enough torque to move the device, even if all of the weight was placed on one motor.

$$m_{case} \approx 1.5lbs; m_{toy} \approx 0.5lbs; m_{motor} \approx 1lb; m_{motor} \approx 1lb; m_{battery} \approx 4lbs$$

$$m_{omniwheel} \approx 0.9lbs; m_{omniwheel} \approx 0.9lbs; m_{wheel} \approx 1lb; m_{wheel} \approx 1lb; m_{electronics} \approx 1.2lbs$$

$$\sum m = m_{total} = 12lbs \approx 5.443kg$$

$$r_{wheel} = 3in = 0.25ft = 0.0762m$$

$$\tau = F * r = g * m_{total} * r_{wheel} = 9.81 * 5.443 * 0.0762 = 4.069Nm$$

$$Datasheet \Rightarrow 4Nm \approx 3rpm$$

$$v_{\min} = 2 * \pi * r_{wheel} * rpm = 2 * \pi * 0.25ft * 3rpm \Rightarrow v_{\min} = 4.71 \, {}^{ft}\!/_{\min}$$

Figure 3: Torque Calculations[6]

2.5 Simulations

This simulation is to determine that the LED to indicate low battery is only on when voltage on the battery is below a certain threshold. Current going into the LED is shown in green and the voltage of the battery is shown in blue. The initial value of the battery voltage is 11.5V, which indicates that the charge on the battery is low. It can be seen that the current through the LED is high meaning that the LED is turned on. At time 10s the voltage of the battery is at it full charge of 12V. It can be seen that the current through the diode is now zero meaning the LED is off.

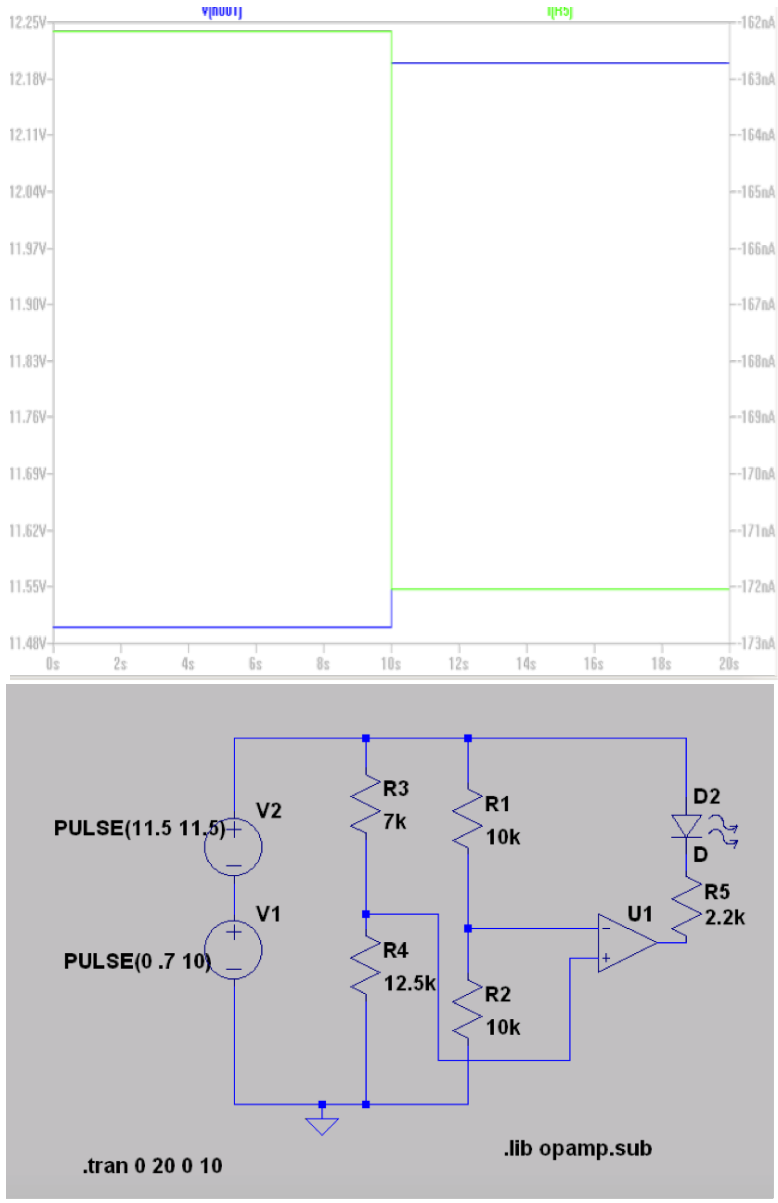

Figure 4: LED Battery Life Indicator Circuit and Simulation

2.6 Software Flowcharts

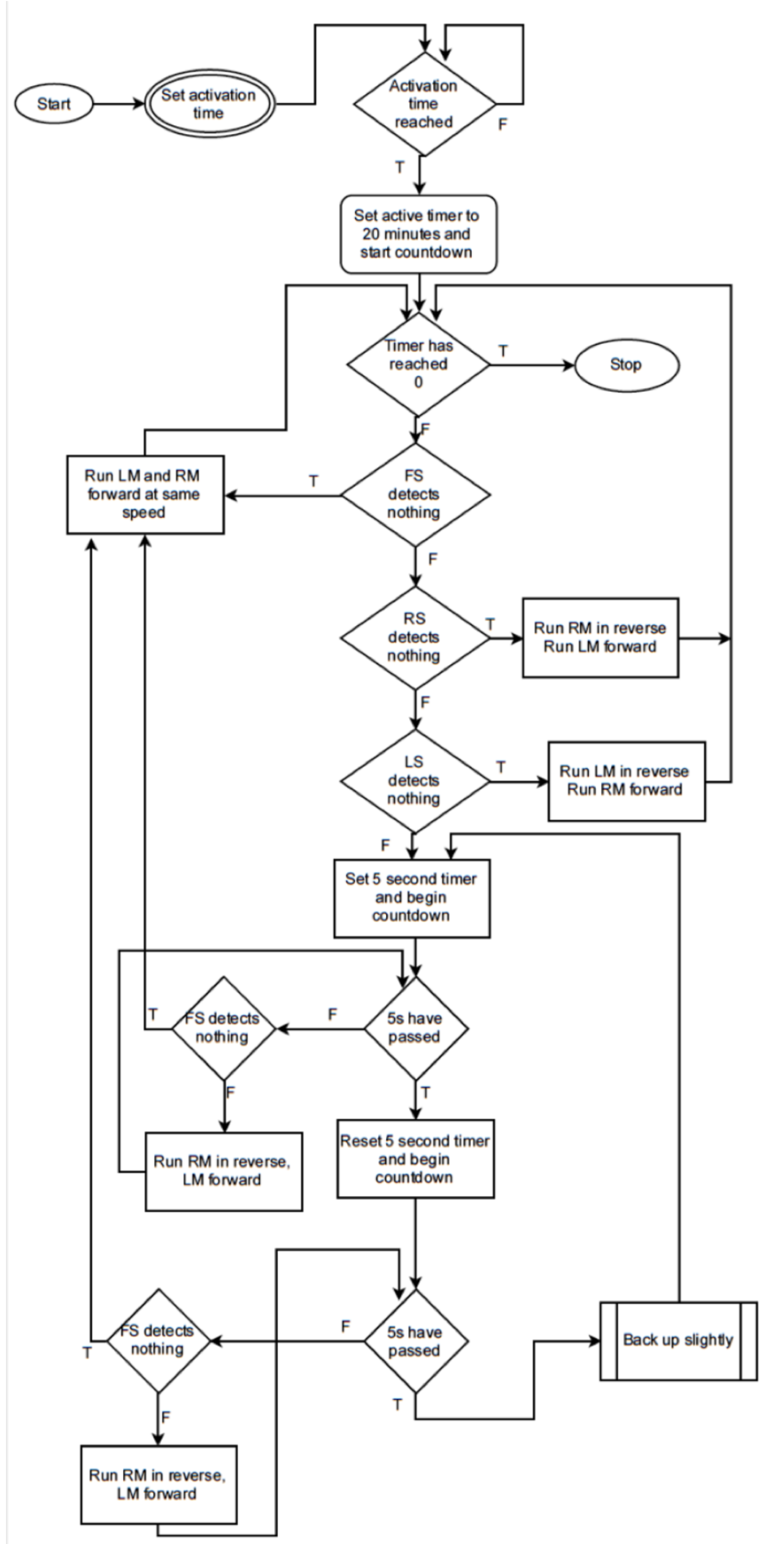

Figure 5: Software Flowchart

3 Requirements and Verifications

3.1 Microcontroller

Requirements	Verifications
1) Voltage for digital output HIGH is at least 3V	1) Load program that outputs HIGH to all digital I/O pins on chip Measure output voltage of each pin to ensure each outputs at least 3V
2) Voltage for digital output LOW is at most 1V	2) Load program that outputs LOW to all digital I/O pins Measure output voltage of each pin to ensure each outputs at most 1V
3) Voltage input of 3V or higher is read as digital HIGH	3) Load program that sets all digital I/O pins to input and displays their value on a console Input 3V to all I/O pins Check console to ensure all inputs register as HIGH
4) Voltage input of 1V or lower is read as digital LOW	4) Load program that sets all digital I/O pins to input and displays their value on a console Input 1V to all I/O pins Check console to ensure all inputs register as LOW
5) Analog voltage input between 0V and 5V to pin 28 is correctly mapped to integer value from 0 to 1023	5) Connect pin 28 to a variable voltage source Load program that sets pin 28 to analog input and displays on a console the integer value corresponding to the voltage input to that pin Sweep voltage input from 0V to 5V and check console to ensure correct mapping
6) Pins 5, 11, 12, and 17, configured for pulse width modulation, output square wave with arbitrary duty cycle	6) Connect pin 5 to oscilloscope Load program that configures pin 5 to output PWM signal and sets duty cycle to 25%, 50%, and 75%, holding those values for 5 seconds each Using oscilloscope, ensure that a square wave with the correct duty cycle was output during each 5 second period Repeat for pins 11, 12, and 17

4 Ethics and Safety

Our project adheres to the IEEE code of ethics[7]. The following rules were especially taken into consideration during the course of this project. The first rule was taken into account because the project has some potential health and safety issues that we have addressed and disclosed for future users to view. An example is the potential for the dog to bite through the casing over time. Furthermore, the third rule is adhhered to as there are limitations to the capabilities of our project, such as the casing being subject to wear and tear that causes circuitry exposure after a large amount of use. We have been upfront about any potential limitations. We have also adhered to the fifth rule and attempted to maintain a project that was within the scope of our combined abilities,which included limiting the capabilities of the device in order to make it a trustworthy device. Besides that, there are several safety steps that we have taken to minimize damage to the operator, property, and pets. Some safety considerations include:

- The motors and other electrical devices are located inside of a hard plastic casing so that the dog can safely bite the device without harming itself. We avoided the use of foam or sponges as they have been proven to be potentially harmful[8].
- The display is on the front and behind a layer of transparent polycarbonate to decrease the likelihood of the dog causing damage to it.
- The buttons are indented in a layer of transparent polycarbonate to decrease the likelihood of the dog causing damage to them.
- The device is water resistant so that it will not be damaged by slobber or spills.
- The torque of the motors is enough to allow for the cart to move without causing harm to the dog.
- The torque of the motors and sensor ranges are enough to allow for the device to turn without damaging potential obstacles.
- The size of the cart is large enough that the dog wont be able to lift the cart for an extended period of time and can be utilized by large dogs[8].
- The wheels are semi-spherical so that the device cant land on its side.
- The battery is able to be oriented in any direction, except inverted, which is avoided by placing the battery on its side so that it is never continuously inverted.
- The battery is a lead-acid, leak-free so that dogs and humans are not exposed to toxic chemicals.
- The cord used for attaching the toy is short in order to avoid tangling around the dog or furniture.
- The parts of the toy that are accesible to the dog are large enough to avoid a potential choking hazard[8][9].
- The parts that contain chemicals are stored within a container that will be subject to a use and abuse test[9].

Furthermore, there are several steps that users can take in order to ensure the maximum level of safety while operating the device. These steps include:

- Only plugging the charger into a 60 Hz, 120 VAC outlet.
- Removing the charger once the battery indicates a full charge.
- Checking the device on a semi-regular basis to ensure that wear and tear has not exposed circuitry.
- Don't submerge the device in a body of liquid.
- Use on floors that are made of wood, carpet (excluding shag carpet), or tile.
- Use the device on a ground floor and/or in an area that does not have access to stairs.
- Use in a room that does not have fragile and/or expensive items that the dog could potentially knock over.

Finally, before any lab work takes place, the team will be certified in lab safety protocols as well as electrical safety protocols. Furthermore, we have read and signed the Battery Safety Sheet[10] and attached it to this document.

Safe Practice for Lead Acid and Lithium Batteries

Document Prepared By: Spring 2016 Course Staff
ECE 445: Senior Design Project Laboratory
Last Revised: April 13, 2016

I. Introduction

Hello senior designers! If you are reading this document, you are probably planning on designing a project using some form of battery! Batteries are a great way to store energy for later use in portable devices or backup systems. One often overlooked problem with batteries is that they are dangerous. Additionally, different batteries are dangerous for different reasons. In this document, we will challenge students to justify why they need a battery, introduce dangers inherent to all batteries, explain the dangers that are unique to two common types of batteries (lead-acid batteries and lithium batteries), present some suggestions for charging batteries, and end with a discussion of the ECE 445 procedures for minimizing the risks of projects involving batteries.

II. Do You Need a Battery?

Due to the danger, the course staff would like to stress that students should ***avoid batteries if at all possible and use the very nice voltage supplies that are provided at every single lab bench***.

III. Dangers Inherent to all Batteries

To prevent runaway current, your batteries must always be stored in a secure location with the terminals covered by insulating material to ensure that there is absolutely no way that a short circuit can present itself. Both of these battery chemistries are capable of delivering unbelievably high currents ($>$5000A) and will overheat and possibly ignite (lead acid via ignition of evaporating hydrogen and lithium via decomposing cathode and eventual exposure to oxygen) if they become too hot. Additionally, proper ventilation should be allowed such that any gas can dissipate itself. If your circuit requires a battery, you must be able to demonstrate that your circuit will not have any conditions where a failure results in a short circuit.

IV. Unique Dangers of Lead Acid, SLA, Gel Mat, etc. Batteries

Lead acid batteries are the same types of batteries in your car. They are very high capacity and capable of outputting tremendous amounts of current at a reasonably low voltage. As the name implies, they are full of lead (bad) and acid (also bad). What's worse, the acid inside of a non-SLA or non-Gel Mat battery is in a liquid form and these batteries have valves to allow vapors to evaporate from the battery, meaning they pose a severe risk of spewing acid everywhere (VERY bad). For these reasons, if your project involves a lead-acid battery of any type, you will be *REQUIRED* to find the Material Safety Data Sheet (MSDS) and data sheet for your battery before you can acquire the battery and you must keep this documentation with you at all times in the laboratory. If possible, it is advised that students purchase a battery with protection against chemical spills (SLA is typically the most effective for student projects relating safety and cost) in order to minimize the risk of chemical leakage occurring.

V. Unique Dangers of Lithium-Ion, Lithium Iron Phosphate, etc. Batteries

Lithium batteries are the type of batteries found in your mobile phones and laptops. They are generally smaller and lighter than comparable capacity lead acid batteries, but they are also *substantially more flammable*. Unlike the lead acid battery where cell damage typically translates to reduced capacity, cell damage in a lithium battery translates to *a particularly nasty chemical fire*. Lithium Iron Phosphate batteries tend to be somewhat more fire resistant on account of different cathode material; however, they are still extremely flammable. For this reason, if you elect to use a lithium battery in any capacity, you will be required to complete additional fire safety and fire extinguisher training before proceeding with the course. Additionally, you will be required to incorporate some circuit to prevent your battery cell voltage from decaying below 3.0 $\frac{V}{cell}$ (2.5 $\frac{V}{cell}$ for $LiFePO_4$) or exceeding 4.2 $\frac{V}{cell}$ (3.65 $\frac{V}{cell}$ for $LiFePO_4$). Any charge or discharge tests must be performed while the battery is inside of one of the specially design lithium safety bags and any protection or charging circuits must be approved by your TA **AND** one of the power-centric TAs before they are so much as tested on a breadboard. These procedures are in place in order to protect you, others, and the brand new ECEB from being reduced to a smoldering pile of ashes. ***IF YOUR BATTERY BEGINS TO SWELL, FEEL HOT OR MAKE FUNNY NOISES: disconnect the battery IMMEDIATELY and place it in a battery bag FAR AWAY FROM FLAMMABLE STUFF. You should then report the issue to your TA and a power-centric TA IMMEDIATELY either in person or via a phone CALL to dispose of the battery as soon as possible.***

Swollen Battery = Time Bomb

There are several ways to damage a lithium cell. They include:

- Over charge
- Over discharge
- Over current (charge or discharge)
- Excessive heat
- Internal or external short circuit
- Mechanical abuse

Always check the battery specifications before purchasing or using them!
To minimize the risk associated with lithium batteries, the following precautions should be followed:

- Written work instructions and checklists should be generated for testing procedures
- Remove jewelry that may accidentally short circuit the terminals
- All dented batteries should be disposed of immediately (Contact your TA AND Casey Smith (217)-300-3722; cjsmith0@illinois.edu))
- Cover all metal work surfaces with insulating material
- Batteries should be transported in non-conductive carrying trays
- Always ensure the the open circuit voltage is within the acceptable range for your battery

VI. Charging Lead-Acid Chemistry Batteries

Charging a lead-acid battery is a non-trivial task. The course staff strongly suggest that if you must build a charger, you use some kind of integrated circuit (IC) solution. Additionally, you must familiarize yourself with the battery's charge characteristic and maximum charging current. Lead-acid batteries are inherently safer than lithium chemistry batteries. While an overcharge or overdischarge will cause extreme damage to your battery, the damage will be limited to internal calcification of the plates, reducing your capacity to a fraction of what it originally was. For this reason, ***the course staff strongly suggests that you use a lead-acid type battery if your project requires a battery and is not weight or size sensitive***.

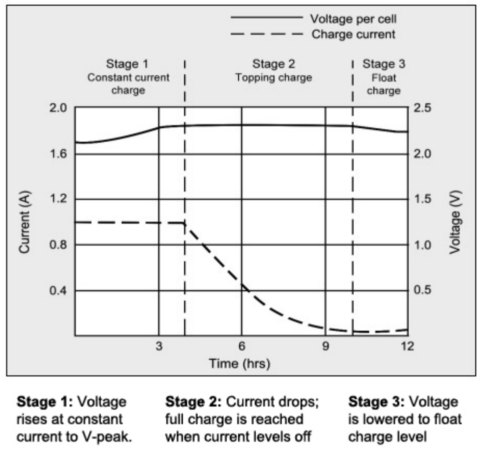

Fig. 1: The Generic Charging Characteristic of a Lead Acid Battery. Source.

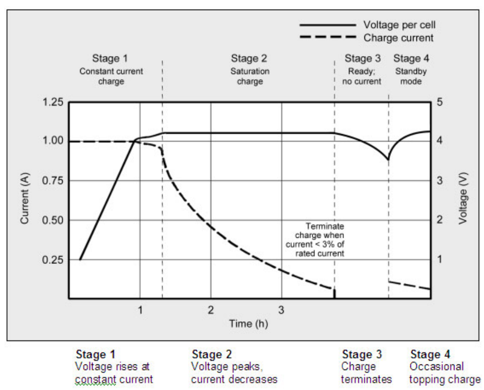

Fig. 2: The Generic Charging Characteristic of a Lithium Battery. Source.

VII. Charging Lithium Batteries

Charging a lithium battery is also a non-trivial task. The course staff continue to strongly suggest that if you must build a charger, you use some kind of IC solution. You must also familiarize yourself with the charge characteristic and maximum charge current. *Any circuitry you design that involves a lithium battery must be approved by your TA* ***AND*** *one of the power-centric TAs before they are so much as tested on a breadboard.* As an addition, it is important to note that batteries, which we can model as ideal voltage sources, charge with ideal current sources. Having an ideal current source and voltage source in parallel with the load is fine! Problems arise if we instead have two voltage sources in parallel. Any mismatch in the voltage will break KVL, which leads to a sudden rush of current from one source to the other in order to try and balance the voltages. This is a very unstable and hazardous methodology, therefore we always charge our batteries with current driving sources.

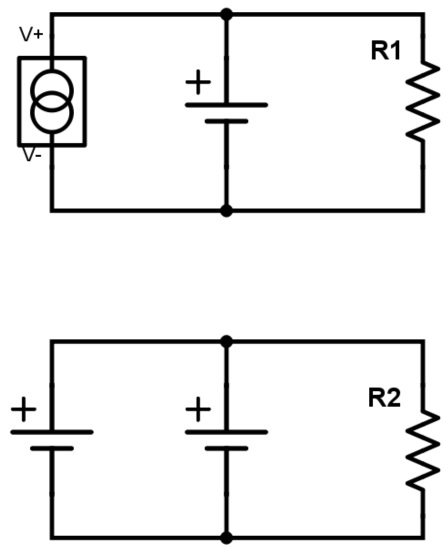

Fig. 3: Top: the proper way to think of charing your battery. Below: a risky way to do so.

VIII. Charging Suggestions and Testing Requirements

If possible, we strongly suggest purchasing and incorporating a fully featured charging suite if your project requires batteries. Those must meet rigorous safety standards in order to be sold in the USA. If this is not possible for any reason (your project is cost sensitive because it is for the developing world, you are using solar panels to charge a battery, etc.), we strongly suggest using an integrated circuit solution. As a last resort, you may attempt to design your own charging circuit. Regardless of the route you choose to take, due to the inherent danger of charging these batteries, everything must be approved by your TA and one of the power-centric TAs before you even bring your design to the breadboard. Once your charging design has been approved, its functionality must be validated to your TA in a demonstration before the battery is connected to the system. Initial testing of the charging circuit with the battery connected should be done in the senior design lab with a TA present and proper protective and emergency equipment easily accessible.

TABLE I: A Short Table of Suggested Charging ICs. (Google is Your Friend)

Chemistry	Suggestions
1S-2S Lithium	MAX1551/5, LM317 (see datasheet)
3S+ Lithium	LT1505, LT1512, LM317 (see datasheet)
Lead Acid	LM317 (see datasheet), LTC4020, LT3652

IX. ECE 445 Procedures

1) Justify to the course staff that your project requires a battery.
2) Determine the appropriate chemistry for your project. Spill-resistant lead acid is vastly preferred.
3) Obtain safety documents:
   a) If you are using a lead-acid battery: obtain the MSDS and battery data sheet.
   b) If you are using a lithium battery: obtain additional fire safety and fire extinguisher training
4) In this order:
   a) If your project allows for it: search for a commercially available charger.
   b) Search for ICs that will perform the entire charge algorithm for you.
   c) AS A LAST RESORT: Design your own charging circuit.
5) Simulate your circuit in SPICE, even if you plan to use a charging IC.
6) Have your TA and a power-centric TA review and approve your design.
7) Build your design on a breadboard and validate functionality to your TA before attaching a battery.
8) If using a lithium battery, place it in one of the lithium battery bags whenever charging or discharging the battery.
9) To be done only in the senior design lab with a TA present and with protective and emergency equipment easily accessible: connect a battery to your circuit.
10) If your circuit behaves correctly, congratulations! You are done. If not, close is NOT close enough and you will have to return to Step 4.

If a problem occurs in your circuit:

1) Shut off power
2) Locate problem before power is restored
3) If circuit breaker is tripped, report to ece-eshop-repairs@illinois.edu to reset
4) If help is needed, contact Casey Smith ((217)-300-3722; cjsmith0@illinois.edu) or the electronics shop for assistance
5) If the situation is an emergency, **call 911**

A. Emergency Procedures

- If a lead acid battery spills: use the Battery Acid Spill Kit located in the back of the lab to clean the spill. Contact Casey Smith and your TA immediately.
- If a lithium battery explodes, **call 911** and evacuate the area.
- If a lithium battery ignites, **call 911** and extinguish it with either of the fire extinguishers located in the lab. They are both rated to extinguish electrical fires and should be at your bench whenever you are actively working with your batteries. Contact Casey Smith and your TA immediately.
- If a lithium battery swells, feels hot to the touch, or makes funny noises but does not ignite, keep the battery in the bag and contact Casey Smith and your TA immediately. The battery cannot be left unattended until it has been properly disposed of.

By signing below, you acknowledge that you have read this document and agree to follow the ECE 445 Course Staff's guidance regarding high capacity batteries and will complete all necessary safety training and adhere to the guidelines set forth in this document as well as additional guidelines as the course staff deems necessary.

ROBERT SCHEUNEMAN — 2/21/17

Print Name — Date

2/21/17

Signature — Date

TABLE II: History of Revision

Revision	Date	Authors	Log
A	3/19/2016	Lenz	Creation
B	3/28/2016	O'Kane	Additonal Information, General Revision
C	3/29/2016	SP16 Staff	Collaborative Revisions
D	4/7/2016	Salz	General Revision

References

[1] "Separation anxiety," 2016, American Humane Society, accessed February 2017. [Online]. Available: http://www.americanhumane.org/fact-sheet/separation-anxiety/

[2] "Dogs attention span," 2009, Capital Canine Services, accessed February 2017. [Online]. Available: http://capitolk9.blogspot.com/2009/04/dogs-attention-span.html

[3] R. Nugent, C. Maw, and D. A. Mellis, "Building an arduino on a breadboard," Arduino, accessed February 2017. [Online]. Available: https://www.arduino.cc/en/Main/Standalone

[4] "From arduino to a microcontroller on a breadboard," Arduino, accessed February 2017. [Online]. Available: https://www.arduino.cc/en/Tutorial/ArduinoToBreadboard

[5] *ATmega328/P: Datasheet Complete*, Atmel, 2016, accessed February 2017. [Online]. Available: http://www.atmel.com/Images/Atmel-42735-8-bit-AVR-Microcontroller-ATmega328-328P_Datasheet.pdf

[6] "Asm weight calculator," Aerospace Specification Metals Inc., accessed February 2017. [Online]. Available: http://asm.matweb.com/tools/weight-calculator.asp

[7] "Ieee code of ethics," 2016, IEEE.org, accessed February 2017. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html

[8] "Everyone wants their pets to be safe from harm." 2016, SafeMade Pet Products, accessed February 2017. [Online]. Available: http://www.safemadepet.com/what_is_safe.html

[9] "Cfr 1199.1 - children's toys and child care articles: Phthalate-containing inaccessible component parts." Legal Information Institute, accessed February 2017. [Online]. Available: https://www.law.cornell.edu/cfr/text/16/1199.1

[10] S. . Staff, "Safe practice for lead acid and lithium batteries," ECE 445, accessed February 2017. [Online]. Available: https://courses.engr.illinois.edu/ece445/documents/GeneralBatterySafety.pdf