Autonomous Dog Entertainment

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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 analog and digital inputs from the modules that have external inputs, such as buttons and sensors, and uses the information to send data to the motors module. Furthermore, internally, the control powers and commands a display and speaker for use by the dog and owner. Furthermore, the microcontroller provides a PWM gate driver to the IR sensor network. The motor drive takes power and PWM inputs, which it then uses to operate the two rear-wheel motors through a current safety module. The current safety module sends digital data to the microcontoller that is used to determine if the motors need to be shut off.

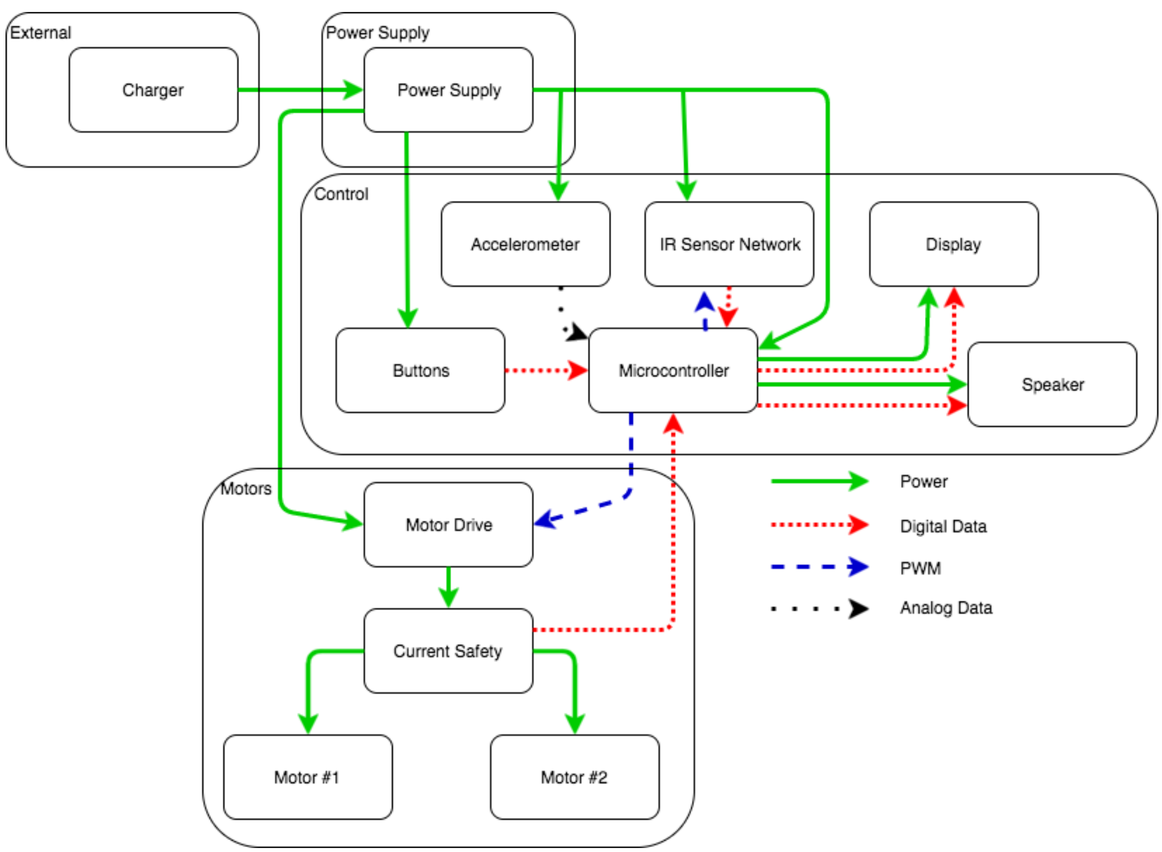

Figure 1: Block Diagram

2.2 Physical Design

The physical design of our device will be durable such that it can continue to operate if dropped in any orientation. This will be achieved by the use of hemispherical shaped wheels (Figure 2). The shape of the wheels will allow the device to be dropped on its side without it staying flat on its side, making the cart immobile. The location of the sensors are shown in red in Figures 3 and 4. Each sensor was chosen to be in the center on each side in order to better detect obstacles in the path of the vehicle. The display and buttons were placed in the front in order to minimize the potential risk for damage. The dog is least likely to bite on the front face due to the length and placement of the wheels. Furthermore, the wheels extend forward in order to act as a buffer between the display and objects. The back has a short cord with a latch that forms a hangmans noose around whichever toy the owner decides to attach to the back. Measurements in Figures 3 and 4 show the minimum dimensions required. Minimum width is 8 inches, minimum height is 4 inches, and minimum length is 9 inches. The wheels have been chosen to have a diameter of 6 inches so that the diameter of the wheels is larger than the height of the device.

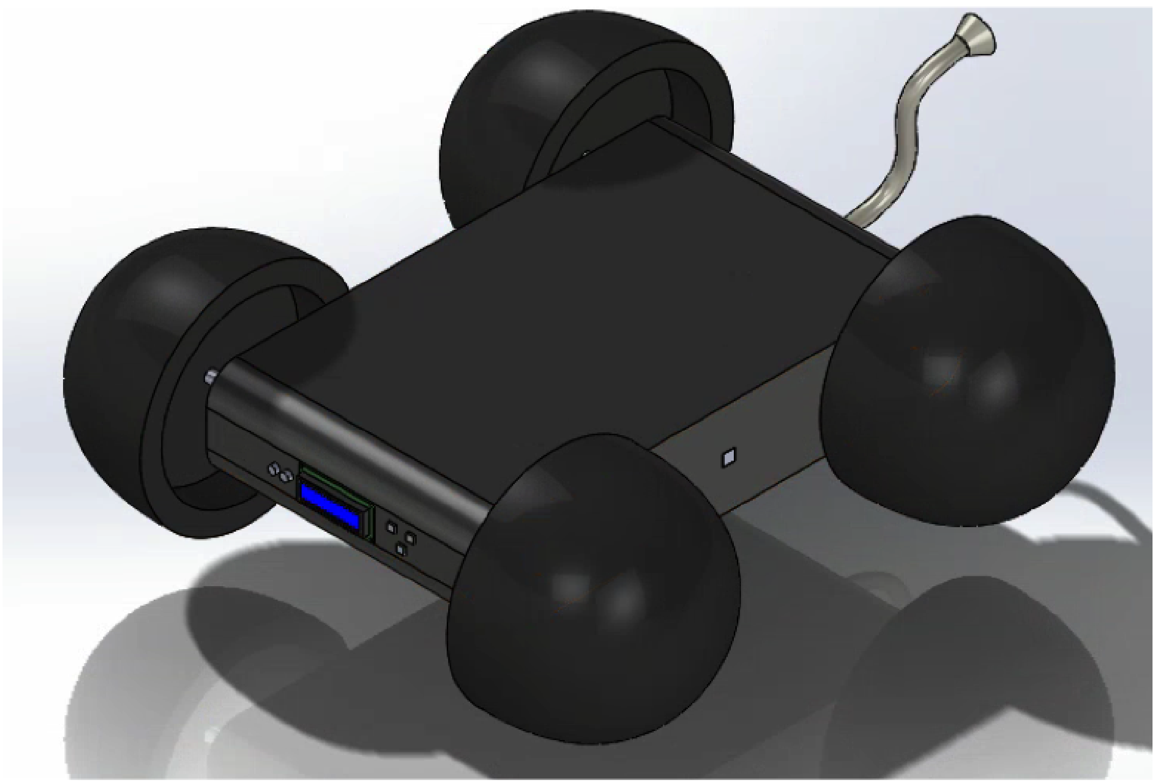

Figure 2: Concept Drawing of Design

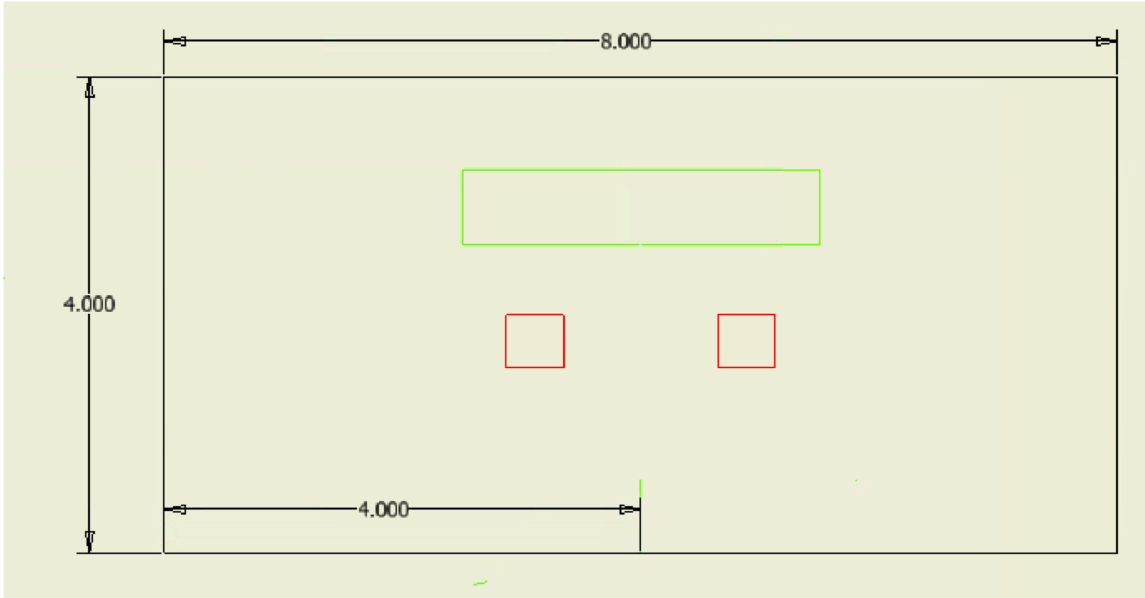

Figure 3: Front View (Measurements in Inches)

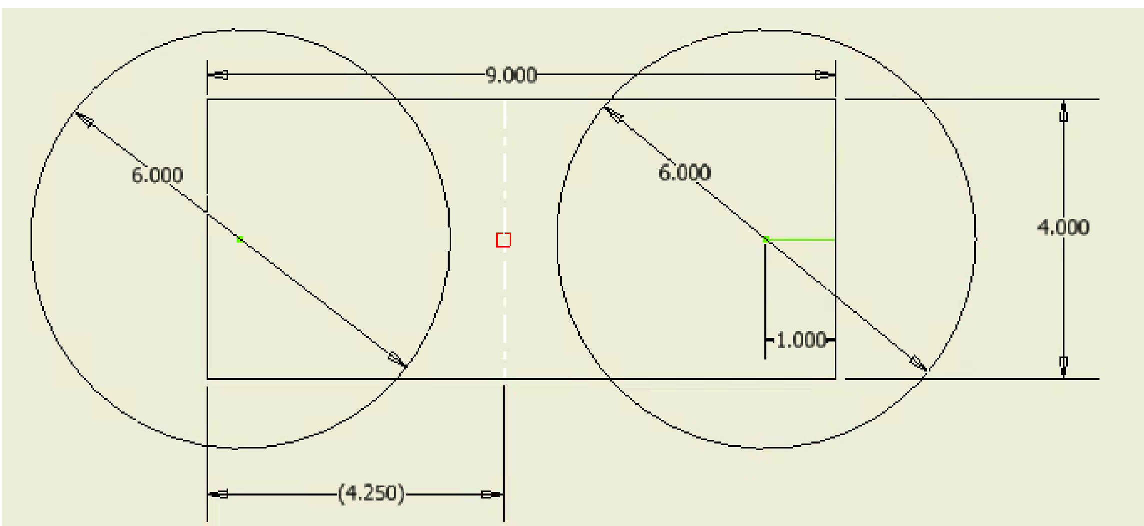

Figure 4: Side View (Measurements in Inches)

2.3 Block Descriptions

2.3.1 Charger

This block is used to recharge the battery that will be used as the power source. This block will convert a standard 120VAC wall outlet input into a DC source that will be able to charge the 12V sealed lead-acid battery.

2.3.2 Power Supply

The power source will be used to power each of the components of the device. A rechargeable 12V sealed lead acid battery will be used to power the device. The battery will have a rating of 5 Ah in order to allow the device to function in the active state for 20 minutes after being in the idle state for a period of time. A DC-DC converter will be used to step down the battery voltage to the 5V for the microcontroller and the motor drive. Linear regulator will be used to step down the voltage to 3.3V to supply the hex display. Furthermore, potentiometers will be used to adjust the voltage being supplied to the IR receivers, and therefore will be used to control the range.

2.3.3 Buttons

The design utilizes three buttons in total. One button is the power button, which is used to tell the system to start operating. The power button is between the battery and the powered devices. The device remains active as along as the power button is pressed down. The other two buttons connect from the power supply to pins on the microcontroller and are used for increasing time on the timer.They are only on while pressed and provide digital data to microcontroller I/O pins. One button is for adding additional hours while the other is for incrementing the timer by ten-minute intervals. The maximum time allowed on the timer is 11:50 and after another button press time will reset to zero hours.

2.3.4 Accelerometer

The accelerometer will be powered by the power supply and provide analog data to the first microcontroller. The data provided will be equivalent to the orientation of the x, y, and z-axis in order to determine if the device is flipped or wedged against an object. Furthermore, the microcontroller will have two digital connections that will relay signals representing orientation and being wedged on its side.

2.3.5 IR Sensor Network

There are four IR emitters in the sensor network that are mounted with two on the front and one on each side of the device. They are accompanied by three IR receivers that are located at the front and on both sides of the device. The IR emitters will be driven at a frequency of 38 kHz through the use of MOSFETS that will recieve gate signals from the microcontroller. Furthermore, the IR sensors will have a range of at least a half meter. If there is an object that becomes present in front of the vehicle, the sensor will send a digital high signal. Then, based on the signals being returned from the sensors on each side, the vehicle will turn, switch directions, or stop.

2.3.6 Display

The display consists of a hexadecimal display as well as two LEDs. The hexadecimal display is a four-digit clock display that shows the amount of time that is left on the timer that counts down to device activation. The hexadecimal display receives digital data from the microcontroller. On the other hand, the LEDs are used to indicate that the device is fully charged and that the device is low on battery, below 25% of its full charge. The LEDs are controlled by separate circuits that determine the voltage level of the battery. An op-amp is used to determine if the voltage of the battery is above the set threshold voltage value to turn on the full battery LED. A second op-amp is used to determine if the voltage level of the battery is below 25% of its full charge, which will turn on the low battery LED. The full battery LED circuit is located between the battery and power switch so that the LED will indicate a full charge without the device being on.

2.3.7 Speaker

The speaker is connected to the microcontroller and emits a sound whenever it receives a digital high signal from the microcontroller. The speaker will operate at a frequency range of 40 kHz as this is within the acceptable range for gaining a dog's attention[3]. Furthermore, due to the low power needs of the speaker, it will be powered by the microcontroller. We chose to use an ultrasonic range finder because it emits sound at the desired frequency. The cost for the range finder was less than transmitters that were found on the internet.

2.3.8 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. We chose to use two microcontrollers because a single ATmega328 did not have the amount of I/O pins we needed for our design. While there are larger microcontrollers with more I/O pins, than the ATmega328, they are more expensive than two ATmega328 microcontrollers. 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, device wedged, 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.

2.3.9 Current Safety

The current safety module will have a current limiter in series with each motor that will limit the current to a threshold that is below the maximum output current level of the motor drive. Furthermore, a small resistance will be placed in series with each motor. For both motors, a voltage comparator will be implemented using voltage dividers and operational amplifiers to determine the voltage level between the resistor and motor. The comparator outputs are then connected to the inputs of a NAND gate that sends a digital signal to the microcontoller. If the voltage is lower than the reference voltage, the motor has stalled and caused a current spike. This will lead to the NAND gate sending a signal to the microcontroller to turn off the motors.

2.3.10 Motor Drive

The motor drive consists of a dual H-bridge motor driver that regulates the power to the motor by using a PWM digital signal that is provided by the microcontroller. Furthermore, the motor drive utilizes signals from the microcontroller to determine whether the motor receives power to operate in forward or reverse. The output of the motor drive is power that travels throught the current safety module to the motors.

2.3.11 Motor 1

The two motors will be placed in the rear of the cart and will turn the left and right rear wheels. They are controlled using an H-bridge motor driver that provides power to the motors in a manner that can operate the motor in forward or reverse. The motors being used will be gear motors in order to increase torque without drawing too much power.

2.3.12 Motor 2

The two motors will be placed in the rear of the cart and will turn the left and right rear wheels. They are controlled using an H-bridge motor driver that provides power to the motors in a manner that can operate the motor in forward or reverse. The motors being used will be gear motors in order to increase torque without drawing too much power.

2.4 Circuit Schematics

2.4.1 Microcontroller Circuit

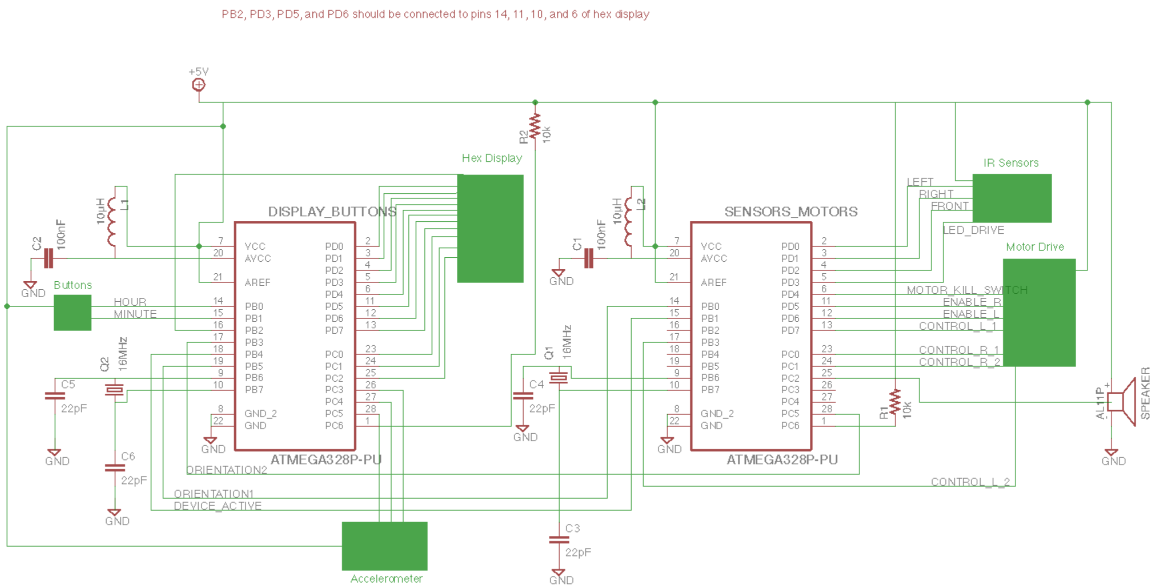

Figure 5: Microcontroller Circuit[4][5][6]

2.4.2 Accelerometer Circuit

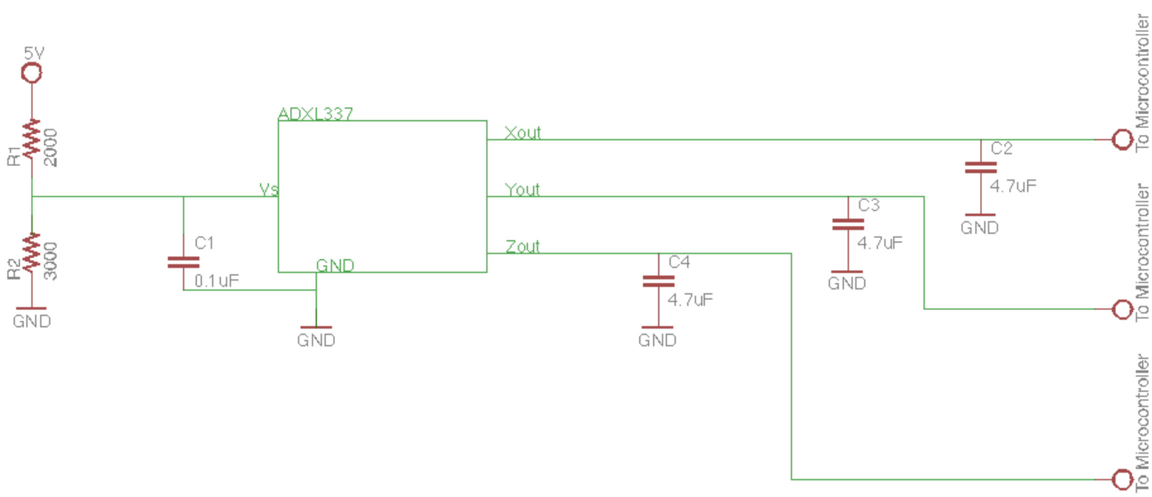

Figure 6: Accelerometer Circuit[7]

2.4.3 IR Sensor Network Circuit

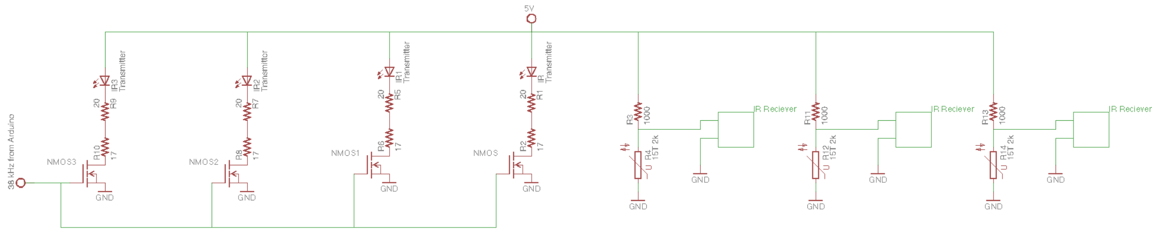

Figure 7: IR Sensor Network Circuit[8][9]

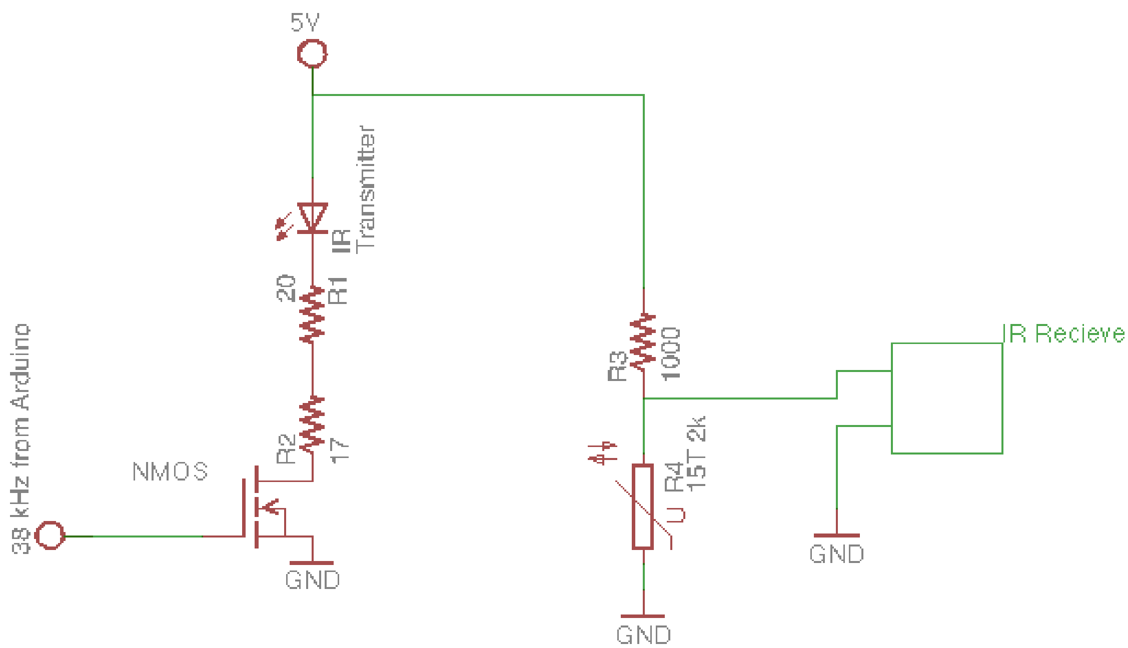

Figure 8: Individual Transmitter and Reciever Circuit[8][9]

2.4.4 Hexadecimal Display Circuit

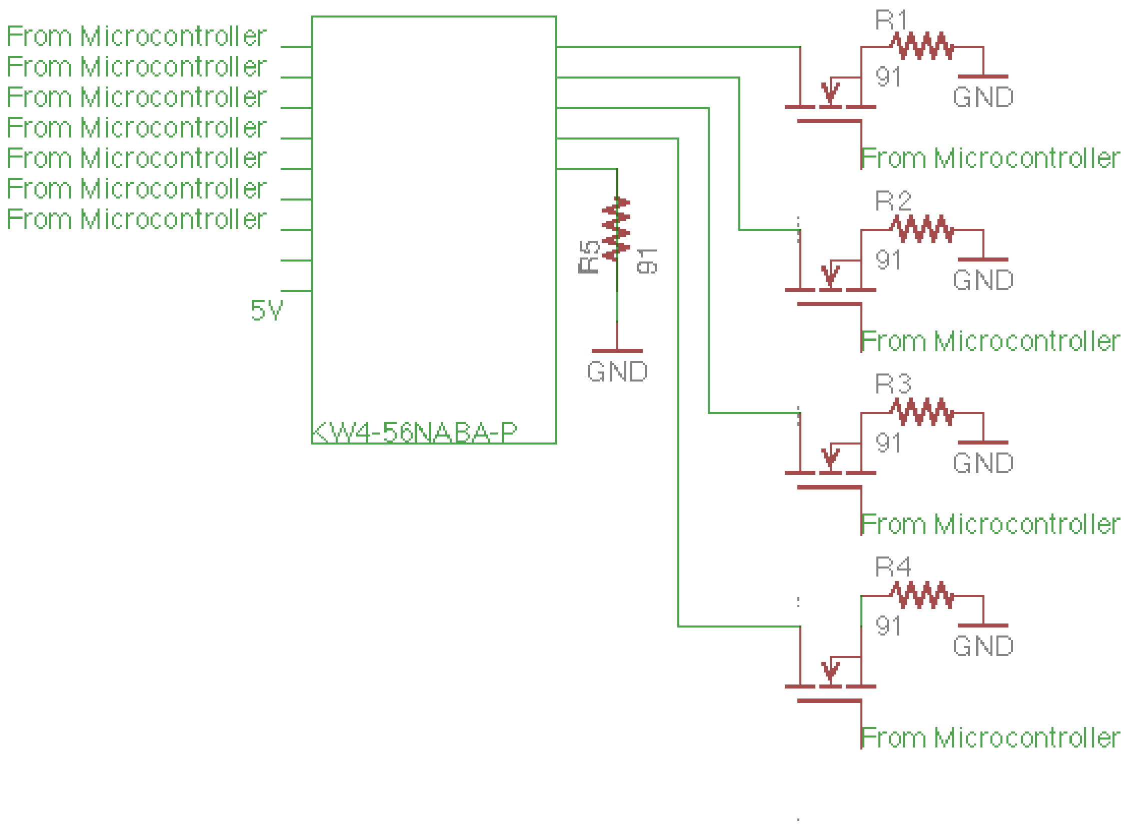

Figure 9: Hexadecimal Display Circuit[10]

2.4.5 Charger Circuit

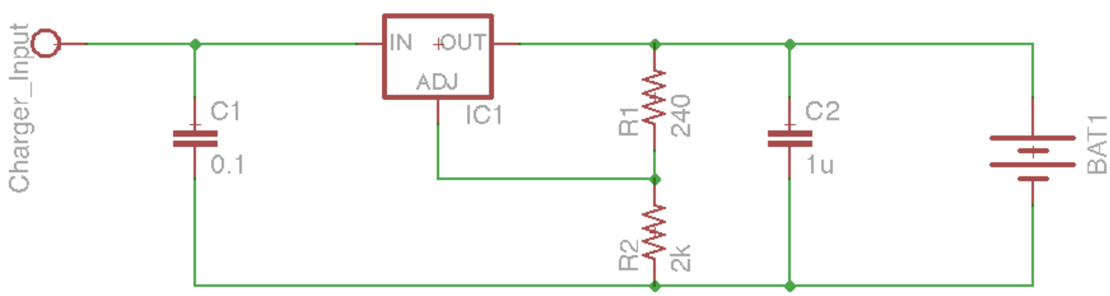

Figure 10: Battery Charging Circuit[11][12][13]

2.4.6 Power Supply Circuit

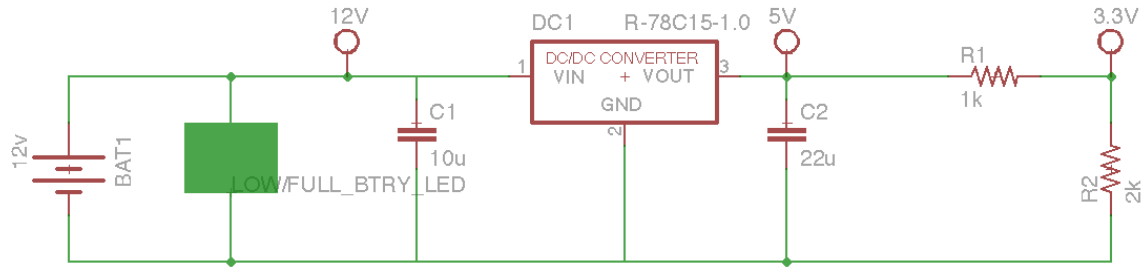

Figure 11: Power Supply Circuit[14]

2.4.7 LED Display Circuit

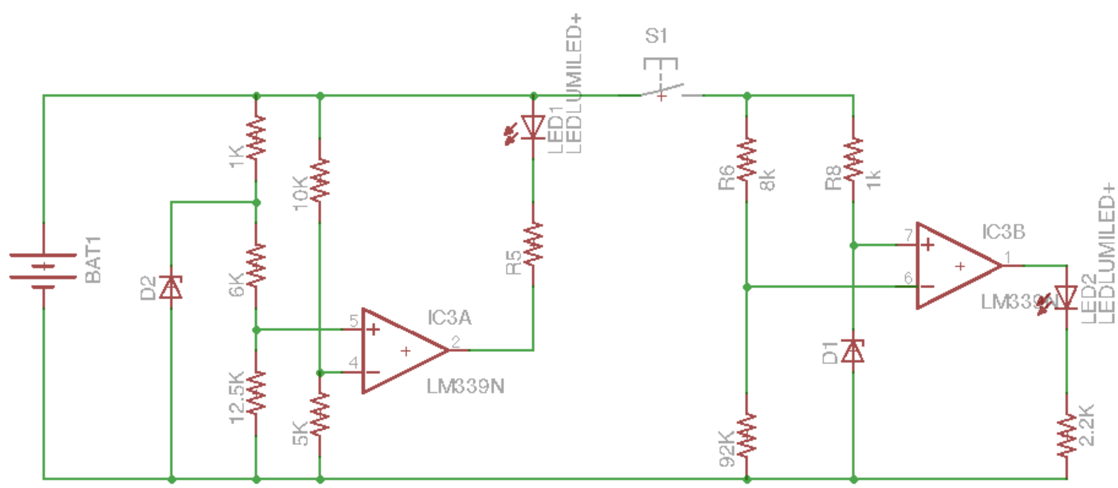

Figure 12: Low Voltage and High Voltage LED Indicators Circuit[15][16]

2.4.8 Motor Drive Circuit

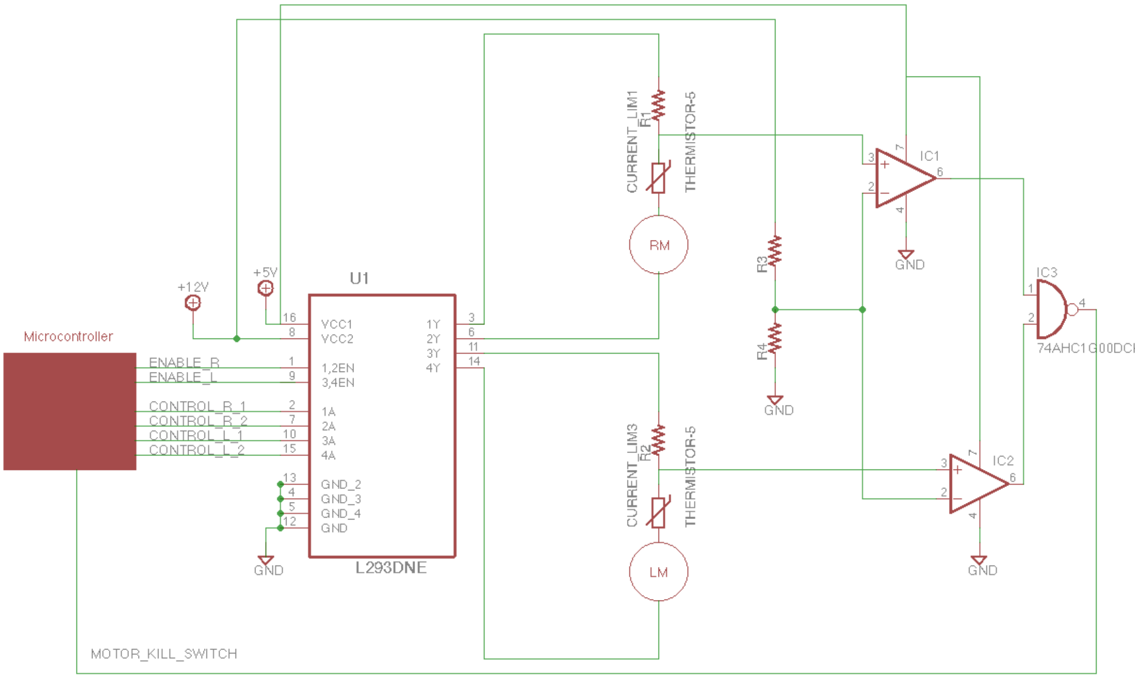

Figure 13: Motor Drive Circuit[17]

2.5 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.

Torque Calculations:

$$m_{case} \approx 1.5lbs[18]; m_{toy} \approx 0.5lbs; m_{motor} \approx 1lbs; m_{motor} \approx 1lbs; m_{bettery} \approx 4lbs;$$

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

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

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

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

$$Datasheet \Rightarrow 4Nm \approx 3rpm[19]$$

$$v_{\text{minimum}} = 2 * \pi * r_{wheel} * rpm = 2 * \pi * 0.25ft * 3rpm \Rightarrow 4.71\frac{\text{ft}}{\text{minute}}$$

Power Supply Resistor Calculations:

$$3.3V = \frac{R_2}{R_1 + R_2} * 5V$$

$$\frac{R_2}{R_1 + R_2} = 0.66 \Rightarrow R_1 = 1k\Omega; R_2 = 2k\Omega$$

Charging Circuit Resistor Calculations:

$$V_{out} = (\frac{R_2}{R_1} + 1) * V_{REF} \Rightarrow V_{REF} = 1.25V$$

$$\frac{12}{1.25} = (\frac{R_2}{R_1} + 1) \Rightarrow R_1 = 240\Omega; R_2 = 2.1k\Omega$$

IR Emitter Resistor Calculations:

$$V_R = V_S - V_F = 5 - 1.35 = 3.65$$

$$R_{total} = \frac{V_R}{I_F} = \frac{3.65}{0.1} = 36.5\Omega \approx 20\Omega + 17\Omega$$

Calculation of Maximum Variable Resistance needed for IR Reciever:

$$V_{IN} = \frac{R_{\text{var}}}{100 + R_{\text{var}}} * V_S \Rightarrow 4.75 = \frac{R_{\text{var}}}{100 + R_{\text{var}}} * 5 \Rightarrow R_{\text{var}} = 1900\Omega$$

Hexadecimal Display Resistor Calculations:

$$V_R = V_S - V_F = 5 - 3.2 = 1.8$$
$$R = \frac{V_R}{I_F} = \frac{1.8}{0.02} = 90\Omega$$

Battery Life in Idle Mode Calculation:

$$I_{active} * h_{active} = 2.565A * 0.33h = 0.85Ah$$

$$5Ah - 0.85Ah = 4.15Ah$$

$$4.15Ah = 0.22A * h_{idle} \Rightarrow h_{idle} = 18.86 hours$$

Skid Distance to Stop:

$$d = \frac{0.5v^2}{\mu g}$$
$$d = \frac{0.5(4.71)^2}{(0.9)(32.2)} = 0.38ft = 4.6in$$

2.6 Simulations

2.6.1 Full Battery Indicator

This simulation is to determine that the LED indicating full battery is on when the voltage battery is above a certain threshold indicating a full charge. The LED is shown in blue and the voltage of the battery is shown in green. 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 low meaning that the LED is turned off. 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 has gone high meaning the LED is now on.

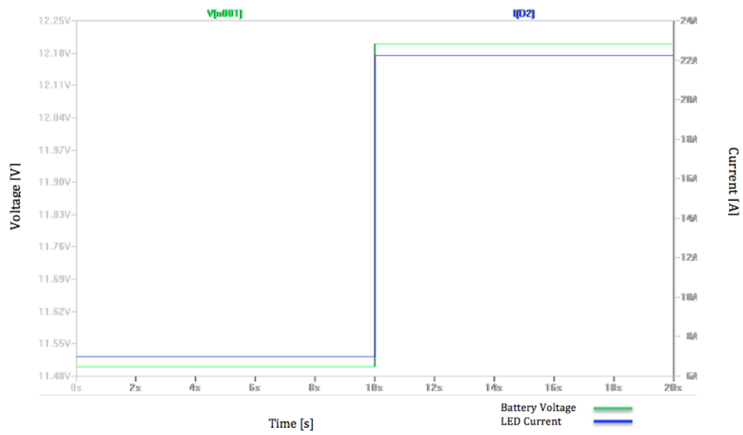

Figure 14: LED Full Battery Life Indicator Simulation

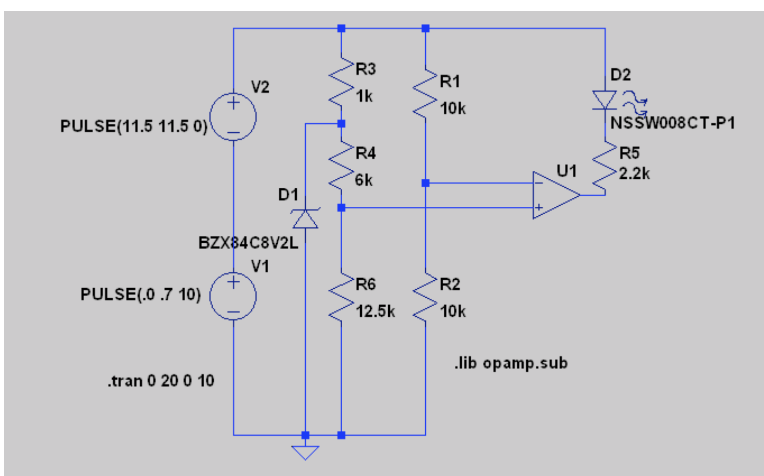

Figure 15: LED Full Battery Life Indicator Circuit

2.6.2 Low Battery Indicator

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. The LED current is shown in blue and the voltage of the battery is shown in green. 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.

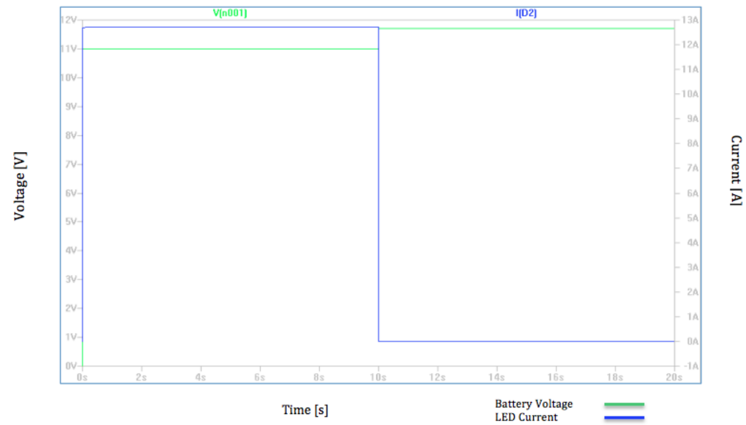

Figure 16: LED Low Battery Life Indicator Simulation

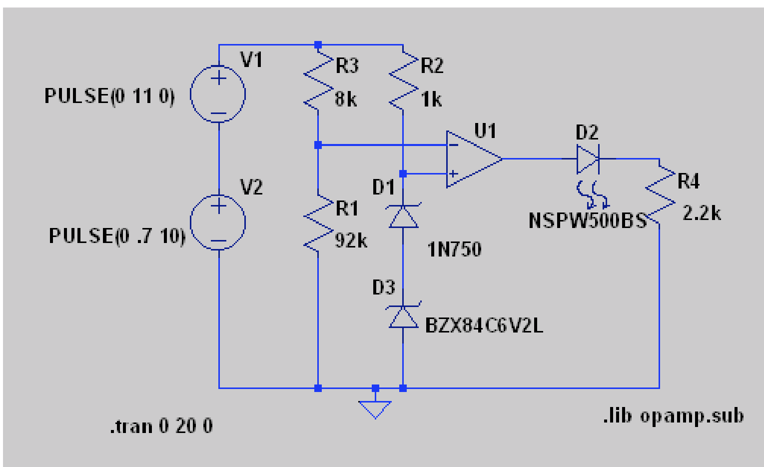

Figure 17: LED Low Battery Life Indicator Circuit

2.7 Software

The software components are split between two microcontrollers. Controller 1 handles user input, activation time, displays, and accelerometer data. It communicates with Controller 2, which handles motor control, IR sensor data, and speaker output, through two digital signals that determine when the device should go into active mode and the orientation of the device.

2.7.1 Time Input Flowchart

Upon power up, the system takes user input from the minute and hour buttons. Hours and minutes are updated with each button press and displayed on the hexadecimal display. Once the user is finished pushing buttons, the system waits the desired time then enters active mode.

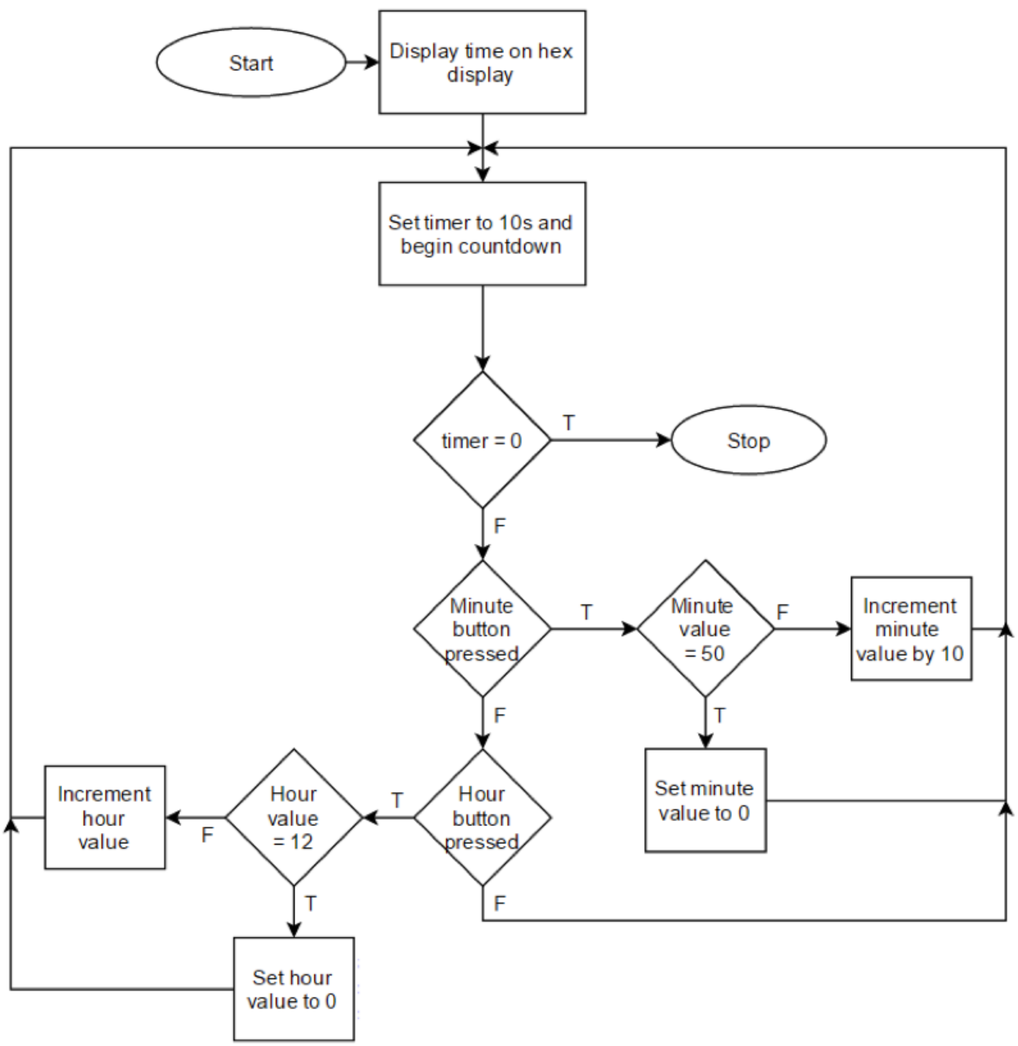

Figure 18: Time Input Flowchart

2.7.2 Movement Control Flowchart

While in active mode, the system implements the Movement Control process detailed below. During this process, the sensors are checked, and if the path ahead is free of obstacles, the device moves forward. If an object is detected in the path ahead, the device turns either right or left depending on which side sensor does not detect any objects. The device continues to turn until the front sensor detects a free path. If all sensors detect objects, then the device turns to the right for 5 seconds and then turns to the left for 5 seconds. This is in order to retrace the path the device used before. It also may continue to engage the dog even if the device senses it is blocked on all sides. Once the device has spent 20 minutes in active mode, it will stop and become idle again.

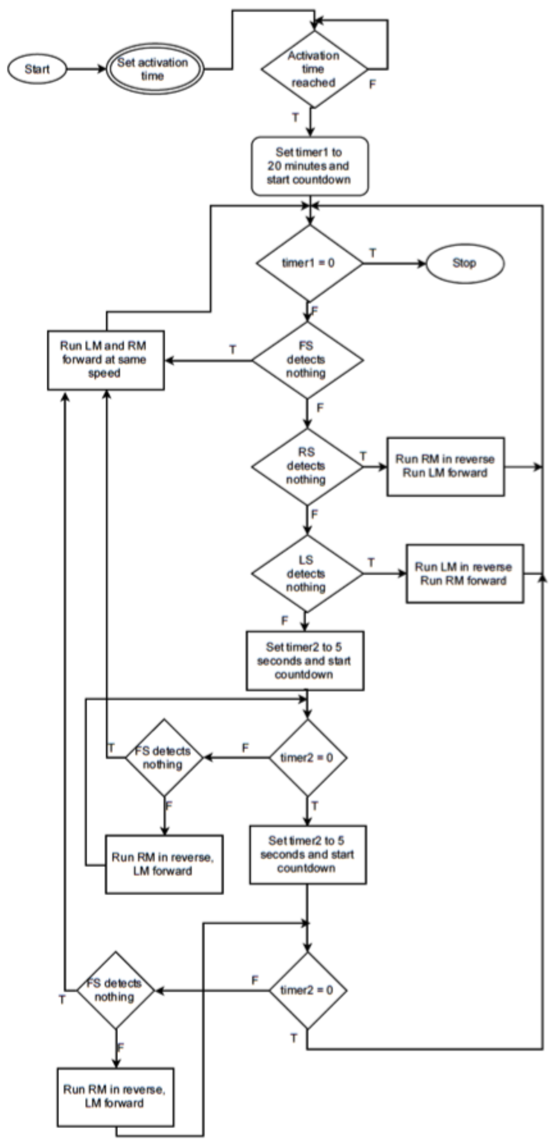

Figure 19: Movement Control Flowchart

2.7.3 Interrupts

Two digital inputs are used as interrupts in our design. The motor kill interrupt will be raised if the motors begin drawing too much current. Its function is to stop running the motors and check every 5 seconds if they are not stalled. The accelerometer interrupt is raised by Microcontroller 1 when it detects that the device has been flipped over. The interrupt swaps which pwm signals correspond to going forward and backward.

3 Requirements and Verifications

3.1 Charger

Requirement	Verification	Points
1) Must charge battery with a maximum charge current of 1.5 A	1) Measure output current of charger while battery is charging checking current never exceeds 1.5A.	0

3.2 Power Supply

Requirement	Verification	Points
1) Must be able to provide power such that the device can operate in active state for 20 minutes	1) Connect device to active load and have device run for 20 minutes. Then measure the charge left on the battery	5
2) Provide step down voltage of 5V within a tolerance of +/- 2%	2) Use multimeter to measure that module outputs voltage within range 4.9V - 5.1V.	
3) Provide output voltage of 12V with a tolerance of 5%	3) Use multimeter to measure that module outputs voltage within range 12.6V - 11.4V.	
4) Provide step down voltage of 3.3 V within a tolerance of +/- 5%	4) Use multimeter to measure that module outputs voltage within range 3.46V - 3.13V.	

3.3 Buttons

Requirement	Verification	Points
1) Power Button should turn on the device	1) Press power button and measure each module is powered with correct supply voltage	0
2) Minute and hour buttons should provide digital high signal of a minimum of 3V to microcontroller while pressed	2) Press button and measure output voltage with multimeter verifying voltage is at least 3V.	
3) Minute and hour buttons should provide digital low signal of 1V or lower to microcontroller while not pressed	3) Leave button unpressed and measure output voltage with multimeter verifying voltage is at at maximum 1V.	

3.4 Accelerometer

Requirement	Verification	Points
1) The z-axis of the accelerometer outputs distinct differences between being upward and downward.	1) Connect the accelerometer circuit to the microcontoller and display the data being provided by the accelerometer when the device is facing both upward and downward. Check to make sure that the microcontroller is able to distinguish a difference.	5
2) The x or y-axis output a distinct difference if either axis is at an angle of greater than 30°.	2) Connect the accelerometer circuit to the microcontoller and display the data being provided by the accelerometer when the device is at an x or y angle of greater than 30°. Check to make sure that the microcontroller is able to distinguish a difference between being at approximately 0° and the new angle.	

3.5 IR Sensor Network

Requirement	Verification	Points
1) The gate operates at a frequency of 38 kHz +/- 10%. 2) The IR reciever is able to detect objects up to at least 0.5 meters away. 3) The sensor is able to observe objects within 40 degrees of the center of the receiver. 4) The IR reciever outputs a digital high value when an object is detected.	1) Measure the gate signal of the MOSFET on an oscilloscope while a function generator inputs a 38 kHz square wave and measure the frequency. 2) Use a multimeter to measure the output voltage of the IR reciever as an object is moved to positions of 0.25, 0.5, 1, and 2 meters from the direct center of the reciever. 3) Use a multimeter to measure the output voltage of the IR reciever as an object is moved to positions of 15, 30, 40, and 60 degrees from the direct center of the reciever. 4) Use a multimeter to measure the output voltage of the reciever when an object is 6 inches in front of the sensor.	10

3.6 Display

Requirement	Verification	Points
1) The correct value of the timer is displayed on the screen 95% of the time. 2) The full charge LED turns on whenever the battery charge is above 95%. 3) If the battery voltage level drops below 25%, the LED turns on.	1) Use a microcontroller to run a timer for 30 seconds and check that the correct value is displayed for at least 27 seconds. 2) Use a multimeter and DC voltage supply to determine the level of battery life at which the LED turns on. 3) Use a multimeter and DC voltage supply to determine the level of battery life at which the LED turns on.	5

3.7 Speaker

Requirement	Verification	Points
1) The speaker emits a 40 kHz +/- 10% sound when given a trigger signal.	1) Place an object in front of the transmitter. Use a multimeter to measure the voltage of the reciever output as an input voltage is applied.	0

3.8 Microcontroller

Requirement	Verification	Points
1) For at least 16 pins configured as digital output pins, voltage for digital output HIGH is at least 3V and Voltage for digital output LOW is at most 1V	1) Load program that outputs HIGH to 15 digital I/O pins on chip. Measure output voltage of each pin to ensure each outputs at least 3V. Load program that outputs LOW to 15 digital I/O pins. Measure output voltage of each pin to ensure each outputs at most 1V	10
2) Excluding the pins from requirement 1, for at least 7 pins configured as digital input pins, voltage input of 3V or higher is read as digital HIGH, and Voltage input of 1V or lower is read as digital LOW	2) Load program that sets 7 digital I/O pins to input and displays their value on a console. Input 3V to each input pin. Check console to ensure all inputs register as HIGH. Input 1V to same 7 I/O pins. Check console to ensure all inputs register as LOW.	
3) Analog voltage input between 0V and 5V to analog configured pin, excluding pins from previous requirements, is correctly mapped to integer value from 0 to 1023.	3) Connect analog pin 28 to a variable voltage source. Load program that sets pin 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.	
4) At least 4 pins, excluding pins from previous requirements, configured for pulse width modulation, output square wave with arbitrary duty cycle	4) Connect pin 5 to oscilloscope. Load program that configures pin 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	
5) The microcontroller must be able to output at least a 38 kHz signal with a 50% duty cycle.	5) Connect pin 5 to oscilloscope. Load program that configures pin 5 as digital output and outputs signal at 38 kHz with 50% duty cycle. Using oscilloscope, ensure specified signal has been output correctly.	

3.9 Current Safety

Requirement	Verification	Points
1) The current limiter limits the current at a value below 2 A. 2) The comparators output a digital high value if their respective motor current is above 1.8 A. 3) The module outputs a digital high value if either motor current is above 1.8 A.	1) Place a resistor and power source in series with the current limiter and increase the voltage until the current is over 2 A. Use a multimeter to measure that the module outputs less than 2 A. 2) Use a multimeter to measure the voltage of the comparator outputs when the current limiter is saturated due to a motor stall. Use a multimeter to also measure the current through the current limiter. 3) Stall the motor individually and together. Use multimeters to measure the current across the current limiter as well as the voltage at the output of the NAND gate.	10

3.10 Motor Drive

Requirement	Verification	Points
1) H-bridge motor driver can be configured to drive 2 motors in both forward and reverse 2) The motor drive is able to provide current that is equal to or greater than the current limiter current value of less than or equal to 2 A.	1) Connect motor in recommended configuration for bidirectional motor control. Provide a HIGH signal to one input and a LOW signal to the other. Check which direction motor turns. Swap HIGH and LOW inputs. Check that motor turns in opposite direction. 2) Use the multimeter to provide an input current of 2 A to current limiter. Check that current through limiter is 2 A or less.	5

3.11 Motor 1

Requirement	Verification	Points
1) Motor can provide at least 10 rpm for a torque of 1.9 Nm or greater.	1) Connect a 3in (7.62cm) radius wheel to the motor. Attach a string to the wheel and connect a 25kg weight to the other end of the string. Power the motor and make sure that the weight is continuously lifted upwards. Check that the wheel is rotated at least 10 times in one minute.	0

3.12 Motor 2

Requirement	Verification	Points
1) Motor can provide at least 10 rpm for a torque of 1.9 Nm or greater.	1) Connect a 3in (7.62cm) radius wheel to the motor. Attach a string to the wheel and connect a 25kg weight to the other end of the string. Power the motor and make sure that the weight is continuously lifted upwards. Check that the wheel is rotated at least 10 times in one minute.	0

4 Tolerance Analysis

A major requirement for our device is that it can avoid obstacles. In order to do this, it must meet two requirements: 1) It must be able to detect an open space wide enough for the device to drive through. 2) When an object is detected, there must be enough distance between the object and the device to allow the device to stop without hitting the object.

Requirement 1 depends upon the physical dimensions of the device as well as the specifications of the IR sensor network. In our design, two IR emitters and one sensor are placed in the front of the device as shown in the figure below. The IR emitters have a maximum angle of 17 degrees on either side[8], and the IR sensor has a detection angle of 45 degrees on either side[9]. In order to ensure that any open path detected by the sensors will be wide enough for the device, the light from the emitters must reach at least a width equivalent to the width of the device including wheels. Likewise, the sensor must be able to receive light from that same width. In the case of the emitters, this requires a range of at least 18 inches or 0.46 meters, which is well under their maximum range of 2 meters[8]. The sensors required minimum range is 7.5 inches, or 0.19m, which is also below the sensors maximum range of 2 meters[9]. The sensor and emitters are easily capable of fulfilling requirement 1 even allowing for more than a 70% error.

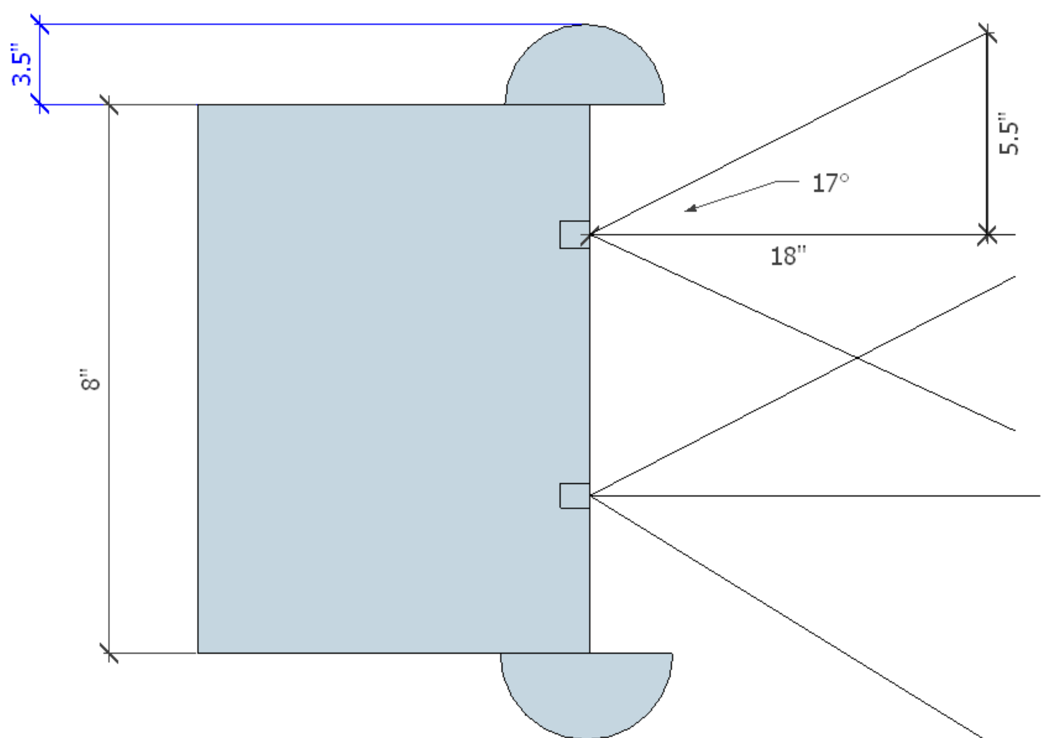

Figure 20: Emitter Range

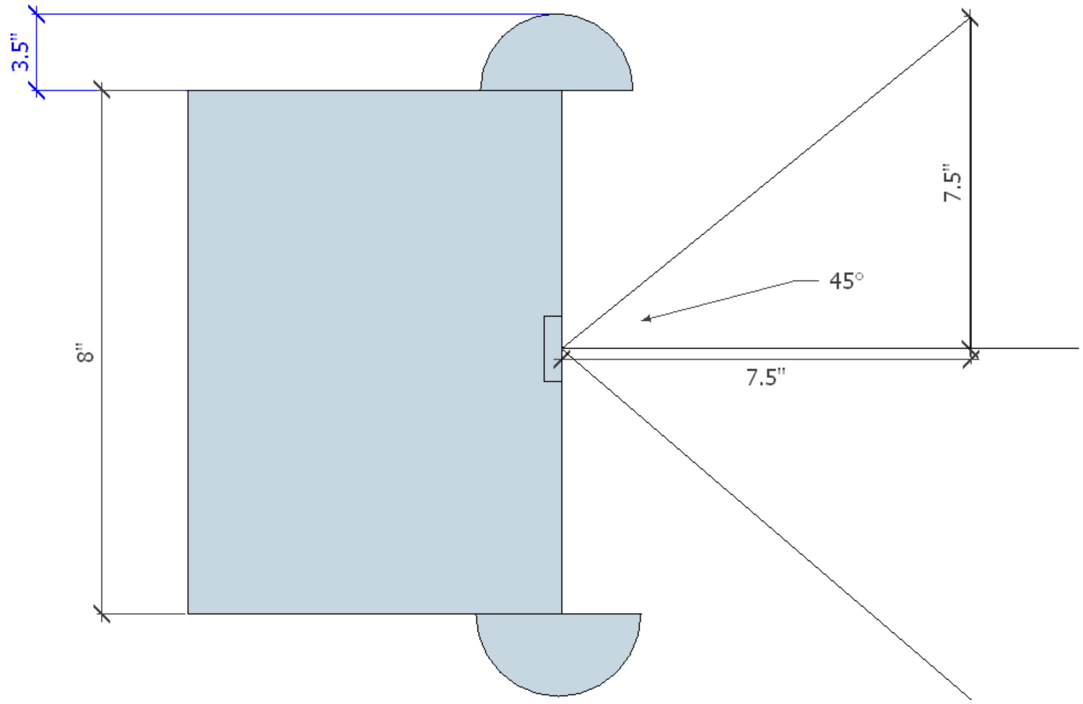

Figure 21: Reciever Range

Requirement 2 depends upon the microcontrollers, IR sensor network, and friction of the wheels. The IR emitters run at a frequency of 38kHz, causing a delay in detection of up to 26.3 microseconds. From the Movement Control flow chart, we can see there are no more than 5 actions taken between each check of the front sensor. Assuming each block in the flow chart takes on average about 7 microseconds to complete, this creates a maximum of 35 microseconds before the microcontroller checks the front sensor. Checking the sensor and stopping the motor if an object is present requires an additional 7 microseconds for a total of 42 microseconds. This along with the detection time yields a total delay of 68.3 microseconds. In this amount of time, assuming a velocity of 4.71 feet per second, the distance the device will travel is 5.3610-6 feet. This distance is small enough to be negligible even if the code is a hundred times less efficient.

Another factor that needs to be addressed is the distance the device may skid. Using the equation[20]

$$d = \frac{0.5v^2}{\mu g}$$

where d is skid distance, v is velocity just before stopping, is the coefficient of friction of the wheels, and g is acceleration due to gravity, we found that the distance the device will skid on a smooth floor is

$$d = \frac{0.5(4.71)^2}{(0.9)(32.2)} = 0.38ft = 4.6in$$

This is far enough below the required minimum range of 7.5 inches already established for requirement 1 allowing for over 60% error in coefficient of friction or an increase in velocity of over 25%.

From this tolerance analysis, we were able to conclude that the minimum range of the front IR sensor and emitters depends most heavily upon the width of the device. The sensor and emitters should not have any problems meeting our minimum range requirements. We realize that the device would be less likely to run into objects if the maximum range for the sensor were used, but this would greatly limit the mobility of the device. For this reason, we must carefully calibrate the sensor network so that it is above the minimum range but also still allows the device to move around an enclosed space such as a living room.

5 Cost and Schedule

5.1 Cost

5.1.1 Parts List

Manufacturer	Part No.	Cost ($)	Number of Parts	Total Cost ($)
Analog Devices	ADXL337	4.46	1	4.46
Vishay Semiconductor	TSAL6200	0.57	4	2.28
Micro Commercial Co	2SK3018	0.35	8	2.80
Vishay Semiconductor	TSSP58038	0.95	3	2.85
Luckylight	KW4-56NABA-P	5.95	1	5.95
Texas Instruments	LM741CN	0.66	4	2.64
SparkFun	HC-SR04	3.95	1	3.95
EPCOS	B57236S500M	1.08	2	2.16
Microchip Technology	ATMEGA328P-PU	2.14	2	4.28
ECS Inc.	ECS-160-18-4XEN	0.66	1	0.66
Volgen	LABC14-12V	25.28	1	25.28
Tensility	50-00533	1.60	1	1.60
CUI Inc	V7805-1500R	9.85	1	9.85
Texas Instruments	LM317MDCYR	0.85	1	0.85
BB Battery	BP5-12-T2	27.14	1	27.14
Adafruit	1440	1.50	1	1.50
E Switch	KS-03Q-02	0.53	2	1.06
Vex Robotics	217-2585	22.99	2	45.98
On Shore Technology Inc.	ED32DT	0.40	2	0.80
Texas Instruments	SN754410	2.43	1	2.43
Cytron	SPG50-180K	17.63	2	35.26
Vishay Semiconductor	SB030-E3/54	0.44	8	3.52
AndyMark	AM-0144	9.00	2	18.00
ECEShop	Resistors	0	N/A	N/A
ECEShop	Capacitors	0	N/A	N/A
ECEShop	LEDs	0	N/A	N/A
ECEShop	Diodes	0	N/A	N/A
			Total Part Cost ($):	205.30

5.1.2 Labor Costs

People	Hourly Rate	Hours Worked	Total Labor Costs (Multiplier = 2.5)
Robert	\$30.00	80	\$6,000
Mary	\$30.00	80	\$6,000
Aimee	\$30.00	80	\$6,000
Machine Shop	\$50.00	23	\$2,875
		Overall Labor Cost:	\$20,875

5.1.3 Grand Total

Grand Total = Parts Costs + Labor Costs = \$205.30 + \$20,875 = \$21,080.30

5.2 Schedule

Week	Aimee	Robert	Mary
6-Mar	Finalize parts for Power supply, charger, buttons, display, speaker and Motors modules. Order Parts	Finalize specifications for physical design. Get specifications to Machine Shop.	Finalize parts for Sensor Network, Accelerometer, Motor Driver, Microcontroller, and current safety modules.Order Parts
13-Mar	Design Battery PCB. Design Microcontroller_1 PCB	Design Microcontroller_2 PCB.	Develop Code to control timer display.
20-Mar	Order Battery PCB and Microcontroller_1 PCB	Order Microcontroller_2 PCB	Test Timer Display code with Hex display.
27-Mar	Assemble and test Battery PCB. Assemble and test Microcontroller _1PCB. Redesign any PCB revisions	Assemble and test Microcontroller_2 PCB. Get any revisions to machine on physical design to machine shop. Redesign any PCB revisions.	Develop Code to control Sensor Network and Accelerometer
3-Apr	Integrate Battery PCB and Microcontroller_1 PCB.	Reorder PCB revisions if necessary. Test sensor network with code.	Develop Code for Motor Control.
10-Apr	Integrate PCBs together.	Physically assemble all components within device.	Integrate all portions of code together.
17-Apr	Acquire data for final demo	Acquire data for final demo	Acquire data for final demo
24-Apr	Prepare Final Presentation	Prepare final Presentation	Prepare Final Presentation

6 Ethics and Safety

Our project adheres to the IEEE code of ethics[21]. 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[22].
- 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[22].
- 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[22][23].
- The parts that contain chemicals are stored within a container that will be subject to a use and abuse test[23].

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.
- Attach a toy that does not have long strands of material that can get caught in the wheel.

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[24] 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***.

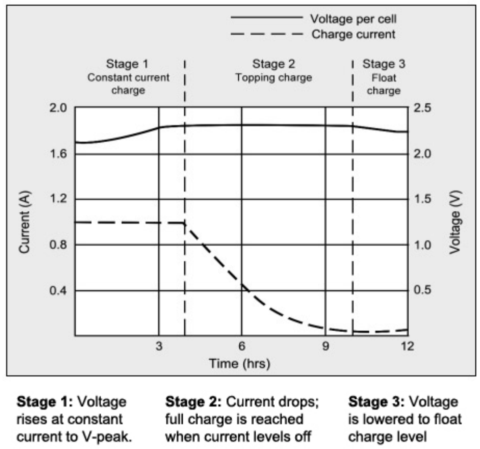

Fig. 1: The Generic Charging Characteristic of a Lead Acid Battery. Source.

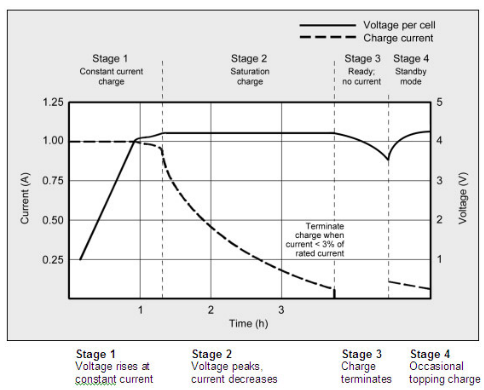

Fig. 2: The Generic Charging Characteristic of a Lithium Battery. Source.

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.

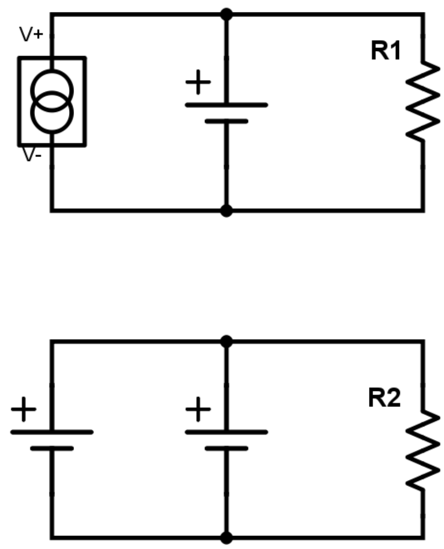

Fig. 3: Top: the proper way to think of charing your battery. Below: a risky way to do so.

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
Print Name

2/21/17
Date

Signature

2/21/17
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

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