AUTONOMOUS PET TOY

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Abstract

The contents of this report include motivation for the project, discussion of design decisions, results of the design, and a conclusion outlining future work. The device is an autonomous pet toy that runs inside the house while the owner is out during a typical workday. The device is completely stand alone and therefore has its own power supply, sensing and control modules, which allow the cart to navigate the house throughout the day while entertaining and exercising the pet.

The results of this project are described in detail below, but at a high level the individual components were met with much success. Integration of the final design was nearly complete with slight troubleshooting of tolerance values and improvements on resolution of the sensor modules. Lessons learned throughout this semester allowed each student involved in this project to walk away with more confidence in design work and applying concepts taught in class.

Contents

1. Introduction

1.1 Purpose and Functionality

Owners often feel remorse leaving their pets at home for long periods of time because they get bored, get anxious, cause destruction to items around the house, and do not get enough exercise throughout the day. This is a widespread problem according to Daily Mail [1] because pet owners must leave work on average for 8 hours on Monday through Friday for work and they do not want to come home to an unhappy pet or a mess.

A solution to this problem is an autonomous, bone-shaped cart to entertain and exercise the pet throughout the day. A rechargeable battery and power converter serves as the power supply for the cart. The control system reads in signals from eight custom active infrared sensors and a gyroscope and then makes decisions on how to navigate the cart based on these signals. The cart will be able to drive in either upright or flipped orientation to make the toy more durable and prevent it from becoming stuck if it gets picked up by the dog or goes down stairs. Owners will have the ability to record messages for the dog through a microphone before they leave for work. The cart will then play a sound (doorbell or recorded messages) from a custom speaker/amplifier system, then wait to detect movement before it begins to run. To simulate the game of chase, the toy will run away from the dog, avoiding walls and objects according to the input signals from the IR sensors for 10 seconds. After 10 seconds it will wait to detect the dog approaching again and repeat the sequence.

In this report, an overview of the design decisions, requirements, and results will be discussed for each component of the project. Each individual component successfully met the requirements except for the motors. Although the final integration of the project had a few shortcomings, which will be discussed in the conclusion along with lessons learned.

1.2 Subsystem Overview

As shown in Figure 1.1 below, this system consists of eight modules to be described throughout the report.

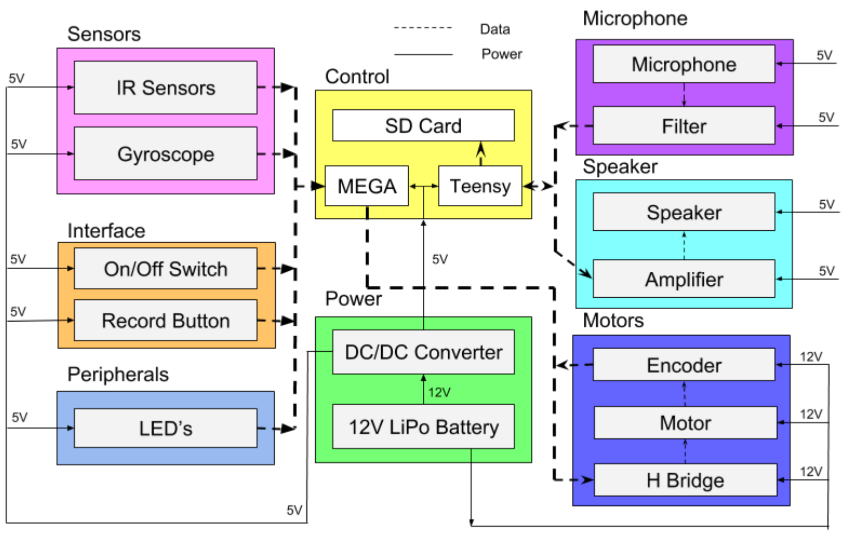

Figure 1.1: System Block Diagram

The power block will provide energy to each component on the cart from one rechargeable battery run through a converter. The control section determines the operation of the speaker and motor blocks depending on inputs from the sensors and the switch. Input from the sensors determines where the cart needs to go. The motor drive consists of an H bridge and encoder to propel the cart while the speaker will output sound to attract the dog. The LEDs stay on, while the power switch can be used to conserve power while the cart is not needed. Finally, the microphone is an added feature that allows the owner to record messages for their dog to be played throughout the day.

1.3 Physical Design

The physical design of the project is shown in the form of CAD Drawings in Figure 1.2 below. These CAD drawings were sent to the Maker Lab at University of Illinois Urbana-Champaign to be 3D Printed.

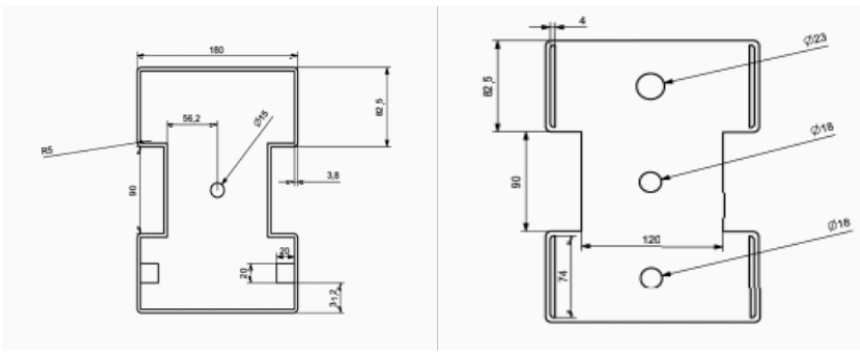

Figure 1.2: Physical Design CAD Diagram

The final project is shown in Figure 1.3 below. The design purposefully resembles a Block I, and the colors were chosen to represent the University of Illinois at Urbana-Champaign.

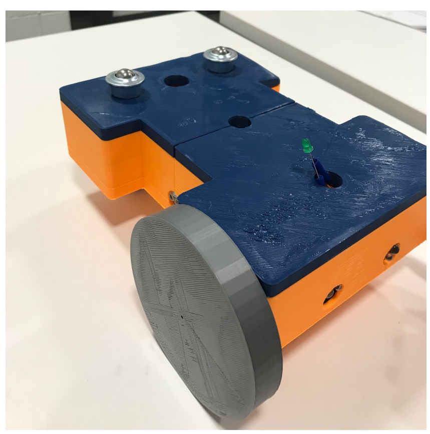

Figure 1.3: Final project design

The cart runs off of rear wheels and has bearing wheels in the front that allows the cart to turn left and right. The bearing wheels are on both the top and bottom of the chassis to allow for the cart to run in both the upright and flipped states.

The following chapter will discuss each of the individual subsystem design decisions and verification.

2. Design

The following sections of this chapter will discuss details for each block of the system including design decisions, issues that arose, corrective actions, and overall results.

2.1 Power Module

2.1.1 LiPo Battery

A LiPo battery will be supply the entire system with power. However, the battery will be at 12V whereas all of the electronically components are at 5V. The LiPo battery must be able to power the sensors, motors, LED's and microcontroller. The main power draw will come from operating the motors, which pull around 1400 mA. All together using a 4500 mAh LiPo battery will give us around 2 hours of active driving operation, while the car can last even longer as it is not always driving.

2.1.2 DC/DC Converter

In order to power the peripherals as well as the microcontrollers a DC/DC buck converter was designed and built to step a 12 V source down to 5 V. We chose to use a buck converter over a voltage regulator for a more efficient power system as well as more control over the output voltage. The converter receives a PWM signal from the ATmega328, which will go to the gate driver circuit shown in Figure 2.1. The only other input to the converter is the 12 V coming from the battery.

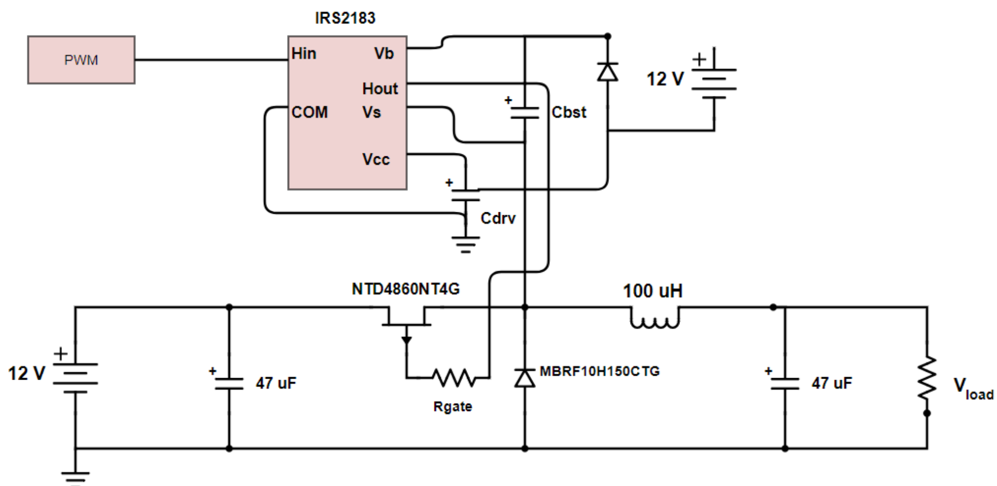

Figure 2.1: Buck Converter Schematic

To operate the buck converter the first required component is the duty cycle. Bucking the voltage to 5 V from 12 V requires a duty cycle of 46.3% using Equation 2.1.

$$D = \frac{V_{out}}{V_{in}} \tag{2.1}$$

For finding the inductance we needed the maximum ripple voltage as well as the operating frequency. A typical buck converter frequency is 20 kHz and a ripple current is 0.4 A. Using these values in Equation 2.2 the inductance were calculated as 91.15 μH.

$$L = \frac{V_2(V_1 - V_2)}{\Delta I_L f_s V_1} \tag{2.2}$$

Using the same frequency and ripple current the capacitance can be found using Equation 2.3. For this converter a voltage ripple of 10% is required which translates to 0.5 V. This results in a capacitance of 26 μF.

$$C = \frac{\delta I_L}{8 f_s \Delta V_2} \tag{2.3}$$

The gate driver circuit was pulled from the ECE469 Lab Manual [22] and will allow the converter to run from a PWM signal from the ATmega328. The ATmega cannot output enough current to the MOSFET in the converter, so the gate drive will boost that current to run the MOSFET instead.

After working with the ATmega it was discovered it cannot output a PWM at 20 kHz exactly, but can output at 31 kHz. With this change all of the components are oversized now so the ripple should not be a problem, but the power dissipation in the MOSFET will increase.

Using available components in the lab two 47 μF were chosen as the input and output capacitors and a 100 μH inductor since it was the easiest to find online.

2.2 Control Module

The control module is separated by two different microcontrollers each with different cores to allow for different usages. The first microcontroller, Atmega328, was used to control the entire functionality of the car these includes: driving the wheels, the buck converter, gyroscope, IR sensors, LED and switch. The second microcontroller, Teensy 3.5, was used primarily for the control of the speaker, microphone and connection to the SD card.

2.2.1 ATmega 328 Microcontroller

The Atmega328 operates within our circuit with an 18 Mhz crystal on an 8-bit AVR core that allows for connection to eight different IR sensors. Six of these IR sensors were producing analog signals and required to be routed into the analog pins on the microcontroller. Two of the IR sensors were digital signals and could be placed on any of the GPIO pins. The buck and motor required special PWM pins and their respective timers needed to be modified in the code to output the correct frequency of 31 kHz and 7.9 kHz respectively. The triple-axis gyroscope operates on I2C protocol that unfortunately requires two of the same pins the analog IR sensors needed so an analog multiplexer was required to switch between the two devices when taking measurements. The LED and switch were placed on GPIO and used accordingly in the state machine.

2.2.2 Teensy 3.6 Microcontroller with SD Card

The Teensy 3.5 is an ARM core running off of a 120 MHz crystal on the board. The Teensy board has an integrated SD card, which it can directly access do the Direct Memory Access (DMA) feature of the microcontroller. DMA allows the user to directly access the memory regardless of the current process being implemented by the processor. So during operating, it can be powering the speaker or the microphone depending on the current state of the machine and still be either writing or reading from the SD card.

2.3 Microphone Module

To combat anxiety and make the toy more soothing to the dog throughout the day, the owner will have the option to record a message. The microphone [7] will be turned on by a peripheral placed near the on-off switch. This will turn on the microphone and the pre-amp circuit, which will then record 10-second message. This message will be saved on an SD card module connected to the microcontroller.

The schematic found in Figure 2.2 below shows the final microphone circuit, which includes an operation amplifier LF353 to boost the signal as well as capacitors and resistors, which act as high and low pass filters for the signal.

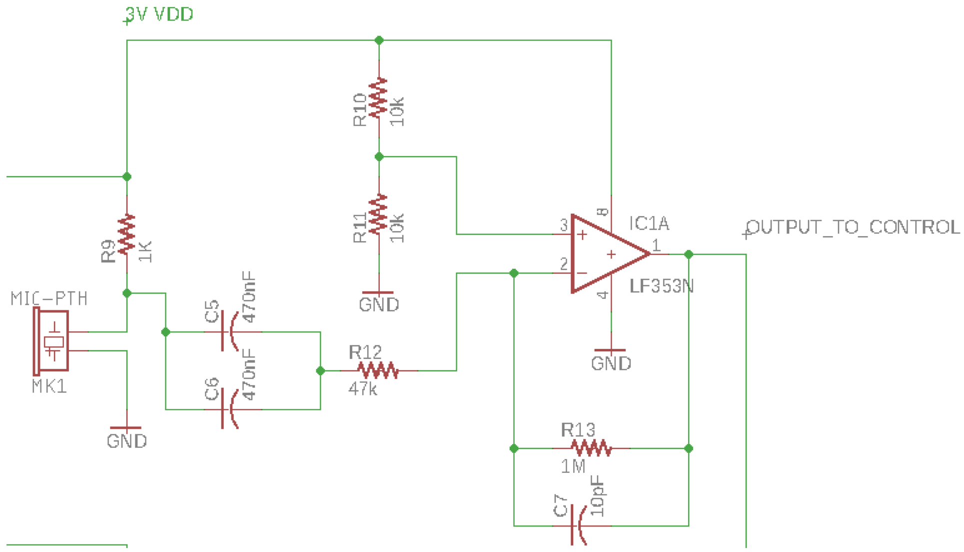

Figure 2.2: Microphone Schematic

2.4 Speaker Module

A .5W, 8-Ohm speaker with an LM386 Low Voltage Audio Power Amplifier [8] circuit of adjustable gain will be mounted to the cart to provide a tone or recorded message to attract the dog throughout the day. The input sound signal will be from the Teensy microcontroller and be preloaded tones or the recording from the microphone. Dogs have a slightly larger range of frequencies than humans, so the speaker must output sound within the range of 40Hz to 60,000Hz [9]. It is important that the speaker tone is loud enough for the dog to hear it from adjacent rooms because the tone is designed to initiate engagement of play so this functionality will be part of the verification testing.

The schematic for the speaker circuit is shown in Figure 2.3 below. The final schematic shows the audio amplifier with gain set by capacitor 8 and resistor 14. There are also high and low pass filters to create better sound quality before the signal is sent to the speaker to be played.

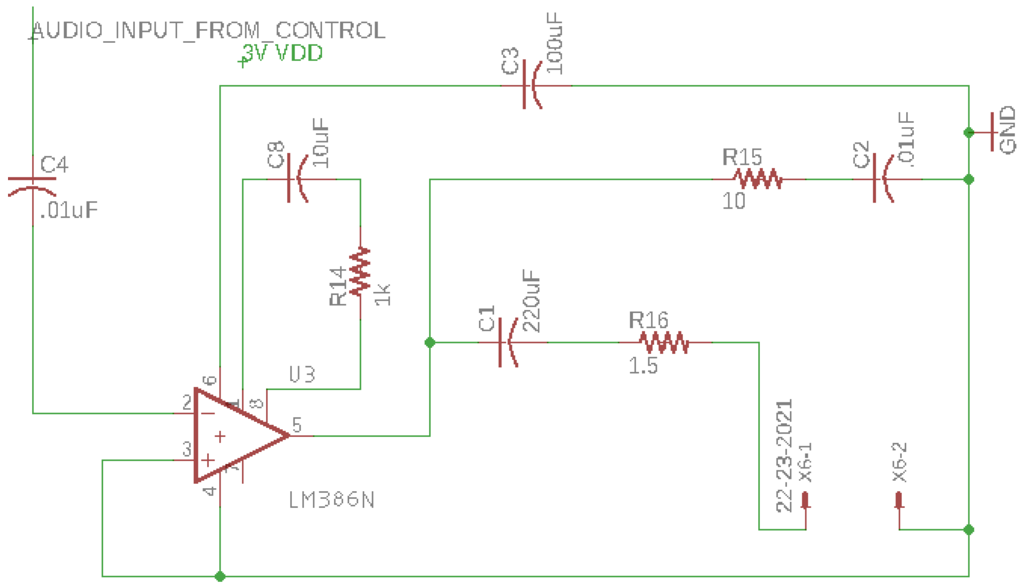

Figure2.3: Speaker Schematic

2.5 Motor Module

2.5.1 Motor Drive

The motor drive will be implemented with an H-bridge driver connected to two DC motors. The voltage applied will be determined by the control module, which will control the speed of each motor with PWM. The PWM signal will come from the microcontroller and the duty ratio will be determined by the input from the IR sensors. The H-bridge [10] is used as this allows for current to be pushed through the motor in either direction, allowing for forward and backwards movement. This two-direction motion also allows the car to operate while flipped. If the gyroscope detects a flipped car, the PWM signals from the microcontroller will be inverted and run the motors in the proper direction. The motor stall currents are rated at 0.8 A, but accounting for transients the H-bridge must stand up to 1 A and 12V. The motor drive circuit is shown in Figure 2.4.

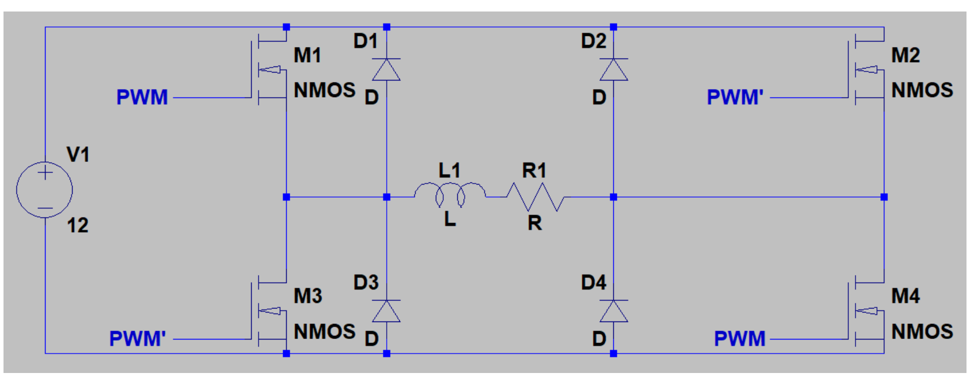

Figure 2.4: H-Bridge Circuit

After receiving the PCB’s for the H-bridge they were found to be incorrectly routed in some places. Due to time constraints we shifted to a simple DC motor drive which did take away the ability to move forwards or backwards. This new design is shown in Figure 2.5. Here we used a low side driver configuration since it is much easier to connect and use than the high side driver.

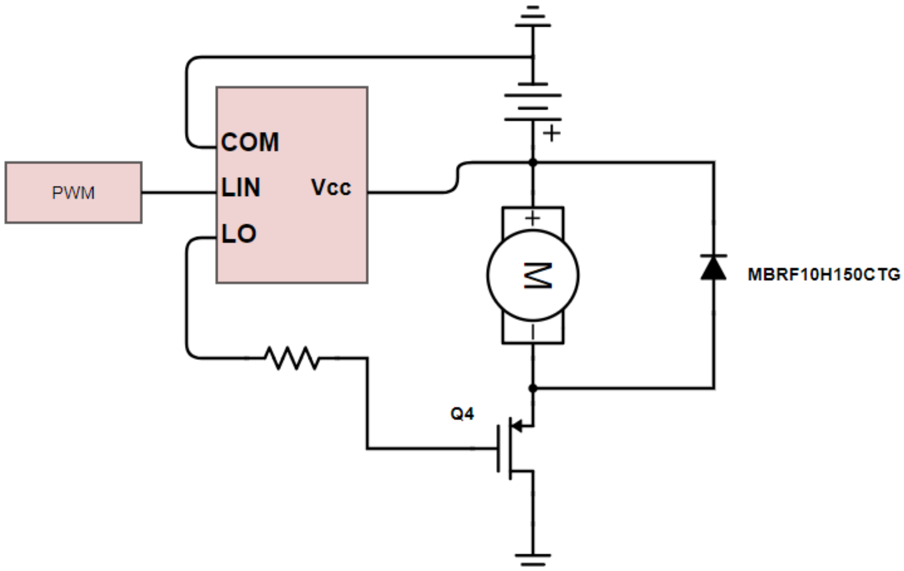

Figure 2.5: DC Motor Drive Circuit

2.5.2 Motor

Using two 12 V motors powered from the H-bridge, the motors [11] must be able to operate the vehicle over any household terrain, from tile to carpet, with the same speeds. In order to do this they must be able to push a 2.667 kg load at 2 m/s. This requires a total torque of 0.436 Nm over the two motors. Two motors will be used as rear wheel drive in order for the vehicle to turn, as it has no steering component for the front wheels. Both motors will be brushless DC motors to simplify forward and backward movement. Also attached to the motors are encoders [12], which read 12 counts per revolution. If these do not detect spinning while the motors are being provided voltage, the control system will know that the motors are stalled and to stop applying current.

The average dog can run approximately 8.5 m/s at a full sprint [13], so moving around inside would be about 2 m/s. This was the speed chosen for the car, but will be refined with more testing. Accelerating at 2.667 m/s^2, it would take 0.75 seconds to reach full speed from Equation 2.4.

$$a = \frac{v_o}{t} \tag{2.4}$$

Knowing the weights of each part the approximate weight of the car will be 2.7 kg. To get this acceleration with this weight, 7.264 N if force is needed (by using Equation 2.5).

$$F = ma \tag{2.5}$$

Using 6 cm radius wheels and multiplying by a factor of 1.2 to account for friction in Equation 2.6, this would require a torque of 0.436 N-m, which the two motors can achieve.

$$\tau = Fr(1.2) \tag{2.6}$$

2.6 Sensor Module

2.6.1 Active IR Sensor

Eight Active IR sensors will be used to detect objects in the path of the cart and around it. Using the circuit shown in Figure 2.6 below, an IR LED Emitter [15] will be constantly emitting a stream of light. This light will reflect off of objects and be collected by the photodiode (IR Receiver) [16]. When a signal is detected, it will be sent through a LM358 amplifier [17] that is being used as a comparator with the threshold voltage set by the potentiometer. The output voltage of the amplifier is sent to the microcontroller to make decisions about which direction to move the car to avoid the walls. When the output is low, that means the photodiode is not receiving enough IR light to allow current to flow. When the output of the amplifier is high, the photodiode must be receiving enough light reflected off an object to create a higher voltage than the threshold.

In order to avoid colliding with a wall, the motor must turn away in time even going at full speed. Using Equation 2.7 and a friction coefficient of 0.85 the radius the car can turn at is 0.48m. The friction coefficient was pulled from a generic rubber wheel [18] and then 15% was added to account for other types of wheels. This is also assuming no braking will occur.

$$r = \frac{v_o^2}{\mu_s g} \tag{2.7}$$

According to this calculation, the threshold distance will be set to 50 cm to give the cart enough time to turn away from the wall during its run state.

The schematic for the IR circuit is shown in Figure 2.6 below. The left side of the circuit is the IR LED and current limiting resistor, then the photodiode that collects 950 nm light and a resistor to determine the output voltage range. The raw voltage output is sent to the microcontroller as an analog input that will be read in to decide if motion was detected and which direction for the motor to turn.

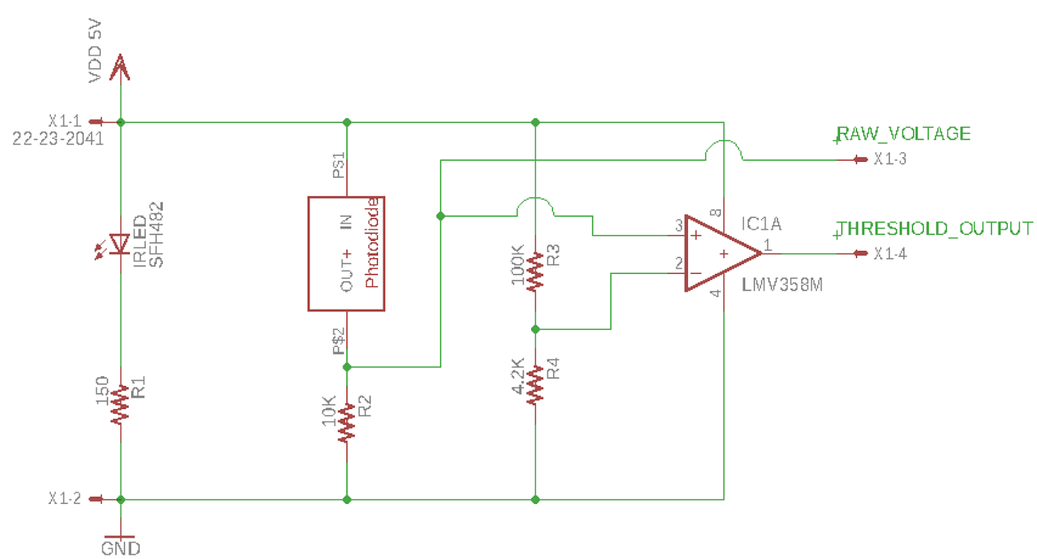

Figure 2.6: IR Sensor Schematic

The right side of the circuit creates a digital input to the microcontroller that is used to check which orientation the cart is in. The two resistors act as a voltage divider set to 0.2 V because that is a typical value reading less than 10 cm, which would signify the IR is pointing toward the ground. This 0.2 V voltage divider output is sent through an op amp, which compares the raw voltage output from the photodiode to the 0.2 V to decide if the IR sensor is pointing towards the ground or the ceiling.

2.6.2 Gyroscope

The triple-axis gyroscope is used to help in two different situations. The first being when the car is on an incline and could possibly has an issue with stalling the motors. We use it to determine the incline and if it is not changing and the encoders on the motor read no movement than we stop the function of the car. Also, dogs are prone to get excited with toys and we did not want the toy to lose functionality if the dog happens to flip it when the user is not home the gyroscope will allow the circuit to know when the car is flipped and it will then turn the motors the opposite direction and take the readings as if it was flipped. This car can do this from the H-bridge motor drives.

The gyroscope will be designed to sense three axis rotation and output a digital signal with a sensitivity of 8.75 mdps/digit. The gyroscope has three separate dps modes (245, 500, or 2000 dps), but only the 245 dps mode will be used in our design because it is not critical to have exact degree of rotation but instead to detect ranges.

Control for different degree readings will be decided as follows:
330-30 Degrees - Cart is in upright driving position
30-150 Degrees - Cart is stuck and wheels should not run
150-210 Degrees - Cart is in upside driving position
210- 330 Degrees - Cart is stuck and wheels should not be run

2.7 Peripherals Module

2.7.1 LED Status Light

The LED status light signifies when the car is in the recording state. It will turn on when the record button is pressed.

2.7.2 Record Button

If the button is pressed the car will then stop and allow for the user to record a personal message to be played for the dog.

2.8 Software

The microcontroller will be used to carry out the algorithm described in the flowchart shown in Figure 2.7 below. The top of the flowchart describes the stop condition of the toy where lights, and sounds from the speaker will be played to attract the dog to the toy. In this state the owner can also record a message through the microphone by pressing the record message button and storing the signal in the Micro SD card.

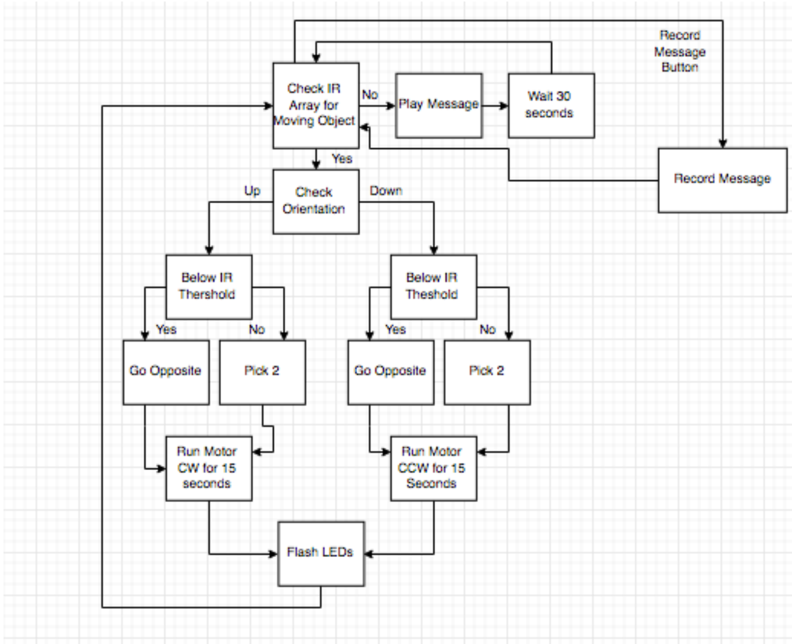

Figure 2.7: Software Block Diagram

Motion is detected by comparing the stored values from the eight IR sensors from the previous second with the current IR sensor values being read into the microcontroller. If a change in any of these values is detected it must mean there was movement in the area around the toy which can be attributed to the dog approaching the toy. At this point, the algorithm launches into its run state.

In the run state the microcontroller will first check the orientation being read from the gyroscope to determine if it is in upright or flipped orientation. The car then reads in values from each of the eight IR sensors around the car and chooses the two lowest values, corresponding to the direction with the farthest distance to the wall and sends PWM signals to the wheels to move the car in that direction. At the end of these 15 seconds, the car will pause again and return to its stopped state so that the dog in engages in a game of chase.

3. Verification

3.1 Power Module

3.1.1 LiPo Battery

To perform our battery tests the batter was connected to an electronic load box with the output current held at 2 A, approximately the expected output current when the motors are in operation. With this we kept track of the voltage and current of the battery every fifteen minutes. We observed values below out expected output with the battery only providing 11.4 V to begin with. From Table 3.1 it can be seen that the voltage does not stay constant at 12 V as advertised on the battery. Some voltage drop is expected over time but not this large of a difference. This led us to believe our battery was defective but for short operations it was sufficient.

Figure 3.1: Battery Output Characteristics

Time (min)	Voltage (V)	Current (A)
0	11.4	1.97
15	10.95	1.97
30	10.53	1.97
45	10.23	1.97
60	10.04	1.97
75	9.84	1.97
90	8.63	1.97

3.1.2 DC/DC Converter

To ensure the buck converter would operate correctly it was first tested on a breadboard, then transferred over to the PCB. Using a DC power supply 12 V were connected to the input of the buck converter and a gate PWM signal sent from the ATmega. Using an oscilloscope the output voltage as well as the inductor current was measured. From Figure 3.1 the ripple voltage is 400 mV which is within the 10% requirement on output voltage and from Figure 3.2 the current ripple never drops to 0 A as required.

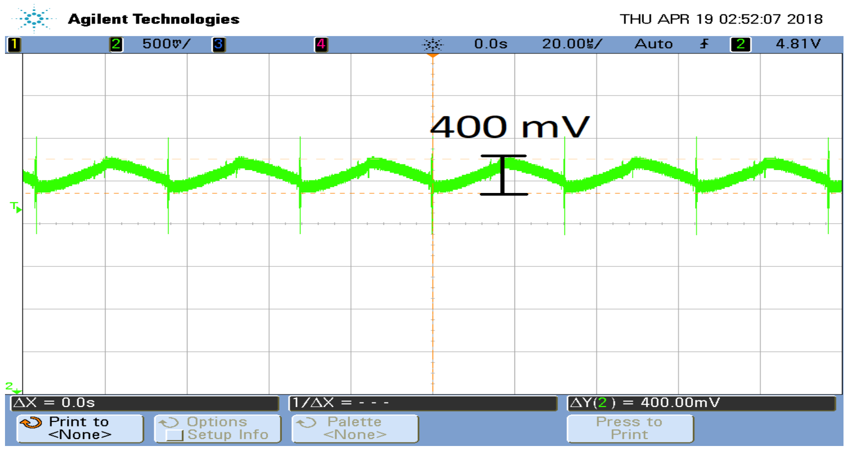

Figure 3.1: Buck Converter Ripple Voltage

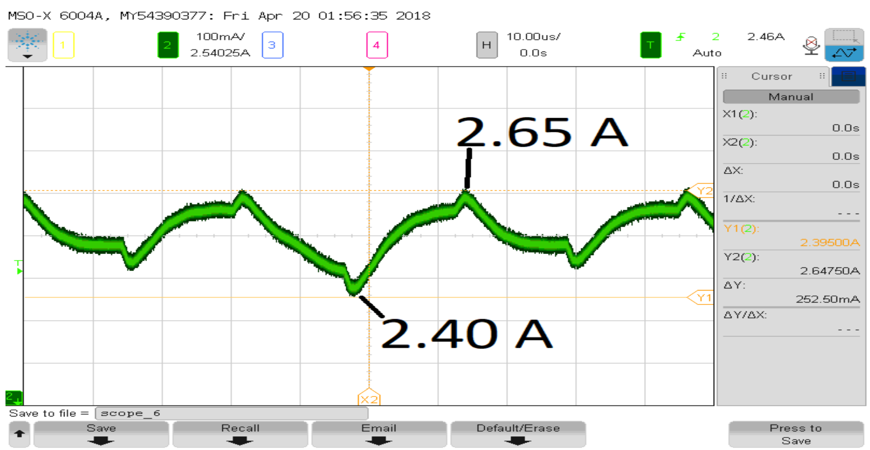

Figure 3.2: Buck Converter Output Current

The efficiency was also measured using digital multimeter attached to the load. The results were taken at various load resistances with the final load of the project being 1.6 Ω. Following the trend of the data, the efficiency of the converter will be above 70%.

Table 3.2: Buck Converter Efficiency Readings

Efficiency (%)	R_{Load}(Ω)	Duty Ratio (%)
66.8	20	26
68.3	18	28
83.2	16	30
71.3	14	32
73.6	12	34
73.5	10	38

76.4	8	41
79.0	6	42
79.1	4	43
76.1	2	46

3.2 Control Module

3.2.1 ATmega 328 Microcontroller

The atmega328 controlled the entire circuit and allowed for the switching between the different states and this is evident in the final demo when the car was properly moving the motors from the IR sensors and then playing the music/stopping the car during the stationary state.

The atmega328 PCB did not have the correct pin-out to the Buck converter PWM pins so the entire circuit needed to be perfboarded. The multiplexers were surface mounted and did not make in into the final design.

3.2.2 Teensy 3.5 Microcontroller

The teensy microcontroller was in charge of the audio by interfacing with the SD card and playing the pre-recorded audio files during the demo. The record function was programmed, however, the microphone circuit had a crucial bug that human voice could not be properly recorded.

3.3 Microphone Module

The requirements for this module were met as the final measured current was measured to be 0.16mA and the detection range was in the defined frequency range for voice. Final integration however was not completed because although the circuit was proven to respond to tapping of the microphone by detecting a change on the oscilloscope, voice could not be picked up through the microphone. The cause of this issue is the supply voltage for the operational amplifier was not high enough to boost the signal and therefore the signal was too small to measure voice. In the current schematic, the operational amplifier is supplier 3.3V and ground, where in typical configurations the operational amplifier would instead need a supply of +9V and -9V to amplify the signal.

3.4 Speaker Module

Each requirement for the speaker module was met, as it was able to play standard .wav files from the teensy microcontroller and was loud enough to be heard from 10m away or an adjacent room. Final integration for the speaker was also complete and was successful part of the demonstration where a song was to be played while motion was not detected so that the dog was attracted to the toy.

3.5 Motor Module

3.5.1 Motor Drive

For testing the motor drive circuit the output to the motors were probed with an oscilloscope as well as the output of the gate driver circuit. With the oscilloscope connected to the motors a clear PWM waveform and the oscilloscope connected to the gate driver also shows a clear PWM signal with a fall time of 4 ns and a rise time of 18 ns. When the motor is connected to the DC power supply, stalling the motor results in a stall current of 0.6 A so the motor driver can support this.

3.5.2 Motor

The motors could not be verified since they could not be adhered to the rotors of the motors.

3.6 Sensor Module

3.6.1 Active IR Sensor

Each of the requirements was met for the IR sensor regarding its resolution, threshold detection, current draw, and ability to capture IR light reflecting off both objects and skin. The results from the resolution test are shown in Figure 3.3 below.

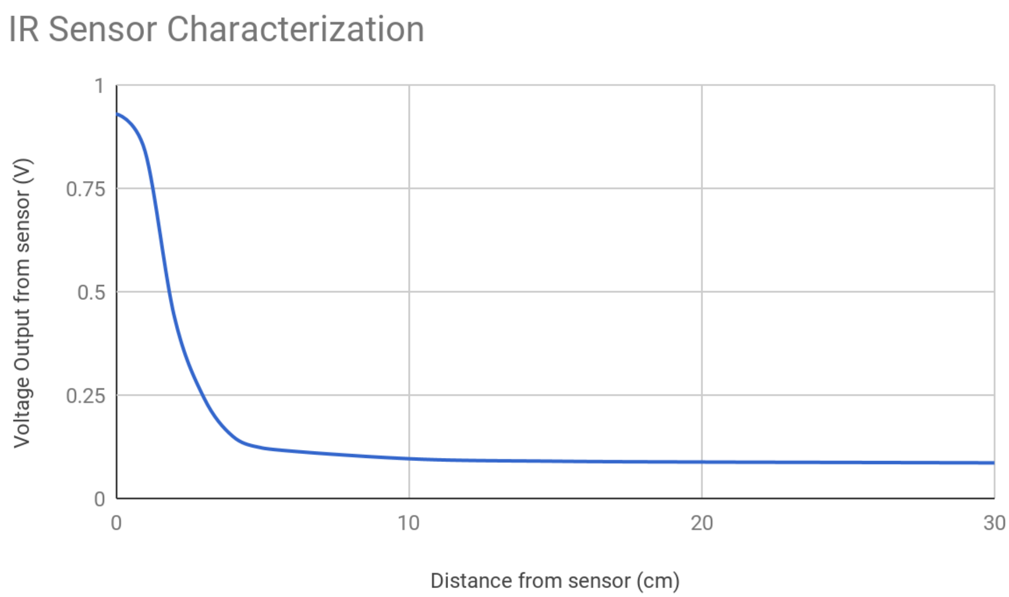

Figure 3.3: IR Sensor Characterization

It can be seen from the characterization curve that the Voltage Output is an exponential response where close to the sensor the resolution is much more defined than that at 10cm. The main shortcoming of the IR sensor component was its limited detection range. As mentioned previously, the goal detection range was 50 cm so that the cart had enough time to turn before hitting an obstacle. To attempt to boost the range, a few different photodiodes were tested. The final photodiode that was chosen had a clear lens that would increase sensitivity, but it was still not enough to gather a further detection range.

Future iterations could utilize an IR wavelength laser to increase the sensitivity because the light would have more intensity than the simple IR LEDs currently being used.

3.6.2 Gyroscope

The gyroscope worked correctly when it was put independently of the project as shown with the graph in Figure 3.4 below. The graph value is each value of the ADC of a single axis of the gyroscope. The ideal gyroscope would give roughly 85 values for every degree since the AVR core is a 8 bit microprocessor so the integers values range from 0-1024 from the ADC in the chip. The gyroscope was measured with a protractor and analyzed on the serial monitor. The gyroscope was not integrated into the final design.

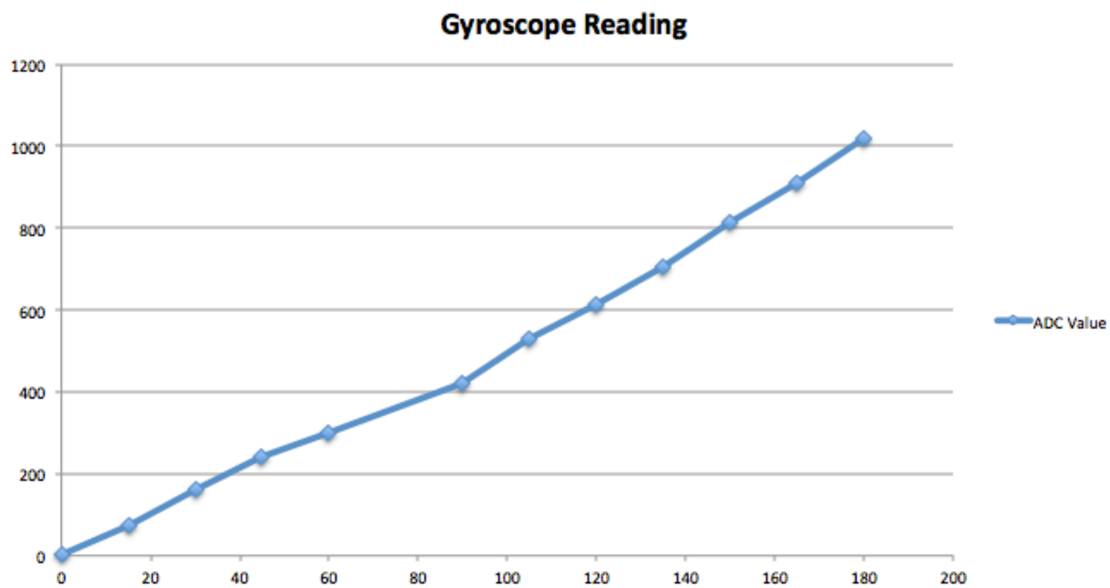

Figure 3.4: Gyroscope ADC Output vs. Angle of rotation

3.7 Peripherals Module

The peripherals module requirements were qualitative results based on user experience and do not have verification procedures or results.

3.8 Software Module

The software component was to create the state machine for the car to properly run and engage the dog. We worked to ensure the code was efficient as possible, because we wanted to cycle through as often as we can to get the most accurate readings on our sensors. The software was completely functional in the final demo; however, it did not include all of the sub functions that would have been added in later as we integrated more portions of the car.

4. Costs

4.1 Parts

Table 4.1: Parts Costs

Part	Manufacturer	Retail Cost ($)	Quantity	Actual Cost ($)
Infrared LED	Ledtech	0.25	8	2.00
Photodiode	VTP	0.41	8	3.28
Low Power Op Amp (LM358)	TI	0.36	8	0.15
Low Voltage Audio Op Amp (LM386)	TI	0.91	1	1.16
Speaker	PUI Audio	3.97	1	3.97
Gyroscope	STMicro	12.50	1	12.50
Battery	Jameco	49.95	1	49.95
Buck Converter Caps	Mouser	2.05	4	8.20
Inductor	Mouser	6.87	1	6.87
Buck Converter Diode	Mouser	0.86	7	6.02
MOSFET	Mouser	0.57	12	6.84
Motor	Pololu	17.95	2	35.90
Microphone	Challenge	0.95	1	0.95
Teensy 3.6 Microcontroller	Teensy	25.00	1	25.00
ATMega 328	ATMega	1.96	1	1.96
Stainless Steel Ball	Omnitrack	8.52	4	34.08
Total				**198.83**

4.2 Labor

The fixed labor costs for this project is based of the average University of Illinois Electrical Engineer Salary of $67,000 per year [20]. We assume an average of 10 hours of work are to be applied to this project each week. We also assume only 14 weeks of work on the project because a semester is 16 weeks and we are not including the first week of the semester and the week off of school for spring break.

$$3people * \$30hrs * 10\frac{hrs}{week} * 14\frac{weeks}{semester} * 2.5 = \$31{,}500 \quad (4.1)$$

4.3 Schedule

Table 4.2: Project Schedule

Week	*Matt*	*Tyler*	*Rachel*
2/18/18	Complete motor and power modules schematic design	Complete microphone and SD card schematic design	Complete control module with IR sensor circuits schematic design
2/25/18	Finalize CAD sizing and approximate battery power draw	Design Speaker, Filter and SD Card module PCB	Complete routing PCB and order breadboard parts
3/4/18	Test buck converter ratings	Test microphone ability	Test loudness of speaker and IR

	and h-bridge ratings, motors	and power consumption	resolution, and power consumptions
3/11/18	Assemble PCB and motors components	Write Preliminary Control Code	Begin Soldering and assembling PCB with speaker, amplifier and IR
3/18/18	Spring Break	Spring Break	Spring Break
3/25/18	Finish assembling power PCB	Finish Programming Code	Finish assembling control PCB
4/1/18	Begin power verification testing and begin first 3D print	Begin control verification testing	Begin IR and speaker verification testing
4/8/18	Finalize CAD and begin final 3D print	Finalize control code and final control verification	Continue IR Verification testing and begin speaker verification
4/15/18	Assembly of motor mount to 3D printed cart	Fit power and controls PCB into 3D printed chassis	Assemble lR modules and mounting on 3D printed cart
4/22/18	Final Demo Testing for speeds and battery life	Final Demo Testing for code corrections	Final Demo testing focusing on IR sensitivity and begin Final Presentation
4/29/18	Presentation and Begin Final Report	Practice Presentation and Begin Final Report	Finalize Presentation and Final Report Format

5. Conclusion

5.1 Accomplishments

Our team is proud to have designed each component of the project ourselves without relying on store bought modules for power conversion or sensing. The success of the electrical design in this project boosted confidence levels in our abilities to do design work and apply concepts learned in class to real world applications. Final functionality of the project was limited due to small issues with the mechanical design. The final integration could not be fully tested because the wheels were not securely fastened to the chassis and therefore driving was not possible.

Our team had many lessons learned and walks away from the project with more confidence in our ability to do technical design work and creatively use resources available to us. In future projects, there will be a strong emphasis on quality design work ahead of building so that less troubleshooting will arise when integration begins.

5.2 Uncertainties

Uncertainties in this project revolve mainly around the microphone and storage of recorded messages. This was an added feature to the project so it was continuously pushed aside to more important tasks throughout the semester and ultimately was not fully debugged for final integration. The proposed solution to this issue would be to supply the pre-amplifier with a higher magnitude and both positive and negative voltages to allow for a boost of the signal.

Saving this signal as a .wav file and storing in the Micro SD card on the Teensy microcontroller would simply utilize a library created by teensy to perform such a task, but without the fully functioning microphone module, we were never able to fulfill this requirement.

5.3 Ethical considerations

With the usage of electronics, there is always a possibility of danger. This device will be expected to play autonomously with dogs without any human supervision. We will design the toy to have a maximum speed that will be safe if the toy were to accidentally run into furniture or the pet. We will also house all of the electronics in a safe location within the chassis to avoid anything coming loose in possible collisions. The entire toy will be designed with care in regards to the chosen materials to ensure the toy is not conductive and will electrocute the pet.

The overall circuit design will be made with as low of current as possible to maintain safety for the owner’s pets. We will enclose the entire circuit in multiple layers to withstand chewing and slobber from pets. The utmost care must be given to this product to ensure people are comfortable leaving the toy alone with their pets. The overall project will follow the following IEEE Code of Ethics [21].

5.4 Future work

In order for the toy to become more waterproof we would have to find a coating that will seal any holes and cracks in the chassis. This will help protect the electrical components as well as the dog since there is less chance of something be shorted out. There is also Plexiglas that allows certain wavelengths of light to pass through, we could purchase that and cover the IR LEDs, which would help with the waterproofing. To help the durability of the toy we would collaborate with other students in mechanical engineering and material sciences engineering to develop a sturdy chassis that is much more compact.

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Appendix A Requirement and Verification Table

Table A.1: System Requirements and Verifications

LiPo Battery

Requirements	*Verification*	*Verification Completed?*
1. 4500 mAh battery can operate for 2 hours when the current draw is 2 A while in motion. 2. Battery stays at 12V with a 10% tolerance	1. Run the battery from full charge to no charge with a 20 W load at 2 A draw and measure the time. 2. Periodically measure the voltage of the battery	1. Yes 2. No

DC/DC Converter

Requirements	*Verification*	*Verification Completed?*
1. 5 V DC output to load with a 5% ripple voltage 2. Stays in CCM throughout operation 3. 70% Efficiency	1. Probe the output voltage with a voltmeter and oscilloscope to measure both average and ripple voltages. 2. Probe output current to ensure it never drops to 0 A. 3. Probe the input and output power to calculate efficiency	1. Yes 2. Yes 3. Yes

Microcontroller

Requirements	*Verification*	*Verification Completed?*
1. Communicate over SPI at 16kHz to the SD card 2. Communicate over analog/digital pins to the sensors modules 3. Communicate over PWM to the motor drives	1. Put example file on to the SD card from the microcontroller and then check that it is correct on an external computer 2. Pull data from the sensors modules and determine if the data is correct by probing its voltage and current 3. Probe the voltage PWM wave from to the motor drive to ensure the correct duty cycle and voltage.	1. Yes 2. Yes 3. Yes

MircoSD Card Module

Requirements	*Verification*	*Verification Completed?*
1. Receive 10 second message from the owner at 96 kilobits/second 2. Send 10 second message from the owner at 705.6 kilobits/second	1. Use the microphone module to create the analog signal into a digital signal resembling the voice a. Check to see if the signal has the correct sampling rate from an audio software b. Check that the files are the correct size 2. With the speaker module interfaced with the microcontroller, send the signal through the speaker and determine whether the correct file saved on the SD module	1. Yes 2. Yes

Microphone with Pre-Amp

Requirements	*Verification*	*Verification Completed?*

1. Detection range of 100Hz-10kHz 2. Maximum current draw of 2mA	1. Play .wav functions at a range of frequencies to be recorded on the SD card and compare the original signal to the new signal 2. Probe the microphone during usage with an ammeter in series with the microphone and filter circuit	1. Yes 2. Yes

Speaker with Amplifier

Requirements	*Verification*	*Verification Completed?*
1. Loudness of 40-70 dB 2. Frequency range between 440Hz - 20kHz 3. Current draw of less than 8 mA 4. Must be heard from 10 meters away. 5. Must be heard from adjacent room with open door.	1. A. Probe output of amplifier directly before speaker B. Measure output wave amplitude on oscilloscope in dB scale 2. A. Probe output of amplifier directly before speaker B. Measure output wave frequency on oscilloscope 3. A. Place probe of multimeter in series with the speaker to measure current flow 4. A. Play constant tone and measure if the tone can be heard from a distance of 10m. 5. A. Play constant tone and measure if the tone can be heard from an adjacent room with open door..	1. Yes 2. Yes 3. Yes 4. Yes 5. Yes

Motor Drive

Requirements	*Verification*	*Verification Completed?*
1. Transistors fall time at or below 4.3ns and rise time at or below 20.1ns 2. Transistors can support stall current of 0.8 A 3. PWM signal operates at 8kHz with a duty cycle between 30 and 90 percent	1. Probe the voltage over each transistor, measuring rise and fall times 2. Measure current through each transistor 3. Probe PWM signal coming from control model	1. Yes 2. Yes 3. Yes

Motor

Requirements	*Verification*	*Verification Completed?*
1. Motors can propel the car at 2 m/s 2. Accelerate the car to 2 m/s in 0.75 seconds . 3. Car can make a turn with a radius less than 0.48m at full speed	1. Measure out a 10 meter distance and time the travel time of the car. 2. Measure out 3 meters and measure if the car can go that distance from motionless in 2.6 sec 3. Measure out 0.48m from a wall and run the car towards it, seeing if it can turn away without colliding	1. No 2. No 3. No

Active IR Sensors

Requirements	*Verification*	*Verification Completed?*
1. Can detect objects at 10 cm threshold with an accuracy of 90% 2. Can detect objects within a +/- 5 cm accuracy 3. Can detect IR bounced off of walls 4. Can detect IR bounced off of dog 5. Each IR sensor must have current draw less than 50mA. For a total of less than 400 mA for all 8 sensors.	1. A. Hold sensor 10 cm from an object B. Probe output voltage of amplifier to determine if photodiode is receiving enough light to exceed threshold voltage C. Repeat 9 times and record success and failure percentage. 2. A. Hold sensor 35 cm from object and probe output. B. Move closer to the object 1 cm at a time until 5 cm and measure output at each cm. C. Hold sensor at 5 cm from object and probe output. D. Move farther from the object 1 cm at a time until 35 cm and measure output at each cm. 3. A. Hold Sensor 10 cm from wall B. Probe output voltage to determine if photodiode is receiving enough light to exceed threshold voltage 4. A. Hold Sensor 10 cm from wall B. Probe output voltage to determine if photodiode is receiving enough light to exceed threshold voltage 5. A. Place ammeter in series with IR sensor circuit to measure current draw while actively sensing wall B. Place ammeter in series with IR sensor circuit to measure current draw while not sensing wall C. Repeat for each IR circuit and total	1. Yes 2. Yes 3. Yes 4. Yes 5. Yes

Gyroscope

Requirements	*Verification*	*Verification Completed?*

1. Can detect angle or rotation within tolerance +/- 10 degrees 2. Must operate with current of 5 mA.	1. A. Measure the output signal of the gyroscope at 0 degree state. B. Using a protractor, rotate the gyroscope to +20 degrees and measure the output signal of the gyroscope to be within +10 to +30 degrees C. Using a protractor, rotate the gyroscope to -20 degrees and measure the output signal of the gyroscope to be within -10 to -30 degrees 2. A. Place an ammeter in series with the gyroscope under normal operating conditions. B. Observe the current while rotating the gyroscope for 2 minutes	1. Yes 2. Yes

LED Status Lights

Requirements	*Verification*	*Verification Completed?*
1. LED must be seen in dark room from 10m away at a current of 10mA	1. A. Turn on the LED while control is on. Turn off ambient lights. Observe the LED from 10m away and ensure clearly visible.	1. Yes

Record Buttons

Requirements	*Verification*	*Verification Completed?*
1. The switch must be easy to press	1. A. Press the button 10 times and be sure it can be pressed without strain	1. Yes

Software

Requirements	*Verification*	*Verification Completed?*
1. Algorithm must detect movement 2. Algorithm must build in randomness to provide variable entertain to the dog.	1. A. Place the toy in the stopped position.Move toward the toy and watch reaction as the motion is detected. 2. A. Place the toy in a determined spot in stopped position. Watch the toy run away from object and record direction and movements. B. Repeat the same experiment from the same determined spot and look for random change to create variability. C. Compare recorded routes to decide with random changes occurred.	1. Yes 2. Yes

Appendix B ATmega Microcontroller Code

```
void setup() {
  // put your setup code here, to run once:
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  pinMode(A2, INPUT);
  pinMode(A3, INPUT);
  pinMode(A4, INPUT);
  pinMode(A5, INPUT);
  TCCR2B = TCCR2B & B11111000 | B00000001;// for PWM frequency of 31372.55 D3 & D11
  TCCR0B = TCCR0B & B11111000 | B00000010; // for PWM frequency of 7812.50 Hz D5 & D6
  pinMode(3, OUTPUT); //BUCK
  pinMode(11, OUTPUT); //BUCK2
  pinMode(5, OUTPUT); //MOTOR LEFT
  pinMode(6, OUTPUT); //MOTOR RIGHT
  pinMode(12, INPUT); //DIGITAL IR
  pinMode(13, INPUT); //DIGITAL IR
  pinMode(2, OUTPUT); //COMM
  pinMode(4, OUTPUT); // LED
  Serial.begin(9600);}

void loop() {
  analogWrite(3, 128);
  analogWrite(5, 1);
  analogWrite(6, 1);
  bool orientation;
  bool direct;
  bool moving = MotionDetection();
  int LEFT = 128;
  int RIGHT = 128;
  Serial.print("here1");
  if (moving == true)
  {
    if (digitalRead(12) == HIGH)
    {Serial.print("orientation");
      orientation = true; }
    orientation = false;
    direct = GetMotorDirection();
    Serial.print(direct);
    if (direct = true)
    { LEFT = 150;
      Serial.print("left"); }
    else
    {RIGHT = 150;
      Serial.print("right"); }
    analogWrite(5, LEFT);
    analogWrite(6, RIGHT);
    delay(80000);}
  else
  {
    digitalWrite(2, HIGH);
    digitalWrite(4, HIGH);
    analogWrite(5, 1);
    analogWrite(6, 1);
    delay(80000);
    digitalWrite(4, LOW);
    digitalWrite(2, LOW);}
```

```
}

bool MotionDetection(){
  int value = 0;
  Serial.print("here2");
  int MDarray[6];
  int MDarray2[6];
  for (int i = 0; i <= 5; i++)
  { value = getIRvalue(i);
    Serial.print(value);
    MDarray[i] = value;}

  delay(8000);
  Serial.print("here3");
  for (int j = 0; j <= 5; j++)
  {value = getIRvalue(j);
    MDarray2[j] = value; }

  for (int k = 0; k <= 5; k++)
  {if (MDarray2[k] > (MDarray[k] + 10) || MDarray2[k] < (MDarray[k] - 10))
      return true; }
  return false;
  }

bool GetMotorDirection()
{ int value = 0;
  int highestone = 0;
  int highesttwo = 0;
  int sum = 0;
  int IRarray[6];
  for (int i = 0; i <= 5; i++)
  {value = getIRvalue(i);
    IRarray[i] = value; }

Serial.print("here4");
  for (int k = 0; k <= 4; k++)
  {
    if (IRarray[k] + IRarray[k + 1] > sum)
    {highestone = k;
      highesttwo = k + 1;
      sum = IRarray[k] + IRarray[k + 1];}
    if (IRarray[0] + IRarray[5] > sum)
    {highestone = 0;
      highesttwo = 6;
      sum = IRarray[0] + IRarray[5];}
    Serial.print("here5");
  }
  if (highestone + highesttwo < 4)
  {return true;}
  return false;
}


int getIRvalue(int x)
{if (x < 7)
    x = analogRead(x);
```

```
 else
   x = digitalRead(x);
 return x;}
```

Appendix C Teensy Microcontroller Code

```
#include <Audio.h>
#include <Wire.h>
#include <SPI.h>
#include <SD.h>
#include <SerialFlash.h>

AudioPlaySdWav           playWav1;
AudioOutputAnalog        audioOutput;
AudioConnection          patchCord1(playWav1, 0, audioOutput, 0);
AudioConnection          patchCord2(playWav1, 1, audioOutput, 1);
AudioControlSGTL5000     sgtl5000_1;

// Use these with the Teensy 3.5 & 3.6 SD card
#define SDCARD_CS_PIN    BUILTIN_SDCARD
#define SDCARD_MOSI_PIN  11  // not actually used
#define SDCARD_SCK_PIN   13  // not actually used

void setup() {
 Serial.begin(9600);
 pinMode(PIN_A3, INPUT);
 AudioMemory(8);
 //sgtl5000_1.enable();
 //sgtl5000_1.volume(0.5);
 SPI.setMOSI(SDCARD_MOSI_PIN);
 SPI.setSCK(SDCARD_SCK_PIN);
 if (!(SD.begin(SDCARD_CS_PIN))) {
   // stop here, but print a message repetitively
   while (1) {
     Serial.println("Unable to access the SD card");
     delay(500);
   }}}

void playFile(const char *filename){
 Serial.print("Playing file: ");
 Serial.println(filename);
 playWav1.play(filename);
 }}

void loop() {
 if(digitalRead(17) == HIGH)
   playFile("DOORBELL.WAV");  // filenames are always uppercase 8.3 format
   delay(10000);
}
```