Autonomous Dog Entertainment

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Final Report for ECE 445, Senior Design, Spring 2017

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3 May 2017

Project No. 16

Abstract

Our project attempts to solve the problem of dogs being left at home for a period of time. Our device provides a source of entertainment for dogs by dragging its favorite toy around the house. The device is designed to avoid obstacles and to continue to operate if dropped on any side. Our device requires minimal interface in the form of a timer being set by the owner before they leave the house. Once activated, the device will operate in its active mode for 20 minutes. During active mode, the device will collect input from the IR sensors and accelerometer to control the direction and speed of the motors.

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].

We developed a device that would provide a stimulating source of entertainment for the dog while its owner is out of the house. Furthermore, it will theoretically be able to keep the dog's attention for the full length of its attention span[2]. The device drags one of the dog's toys around the house while emitting 40 kHz sound in order to stimulate the dog's interest and provide entertainment. The device is able to navigate throughout the house by using IR sensors on the vehicle in order to avoid obstacles. The navigation is autonomous and requires no user control. Finally, the device is durable such that it is safe for a dog to play with unsupervised.

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 does not require human interaction and minimizes 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.

1.4 Block Diagram

The block diagram (Figure 1) 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 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 38 kHz signal to power the IR sensor network. The motor drive takes power and pulse width modulation (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 microcontroller that is used to determine if the motors need to be shut off.

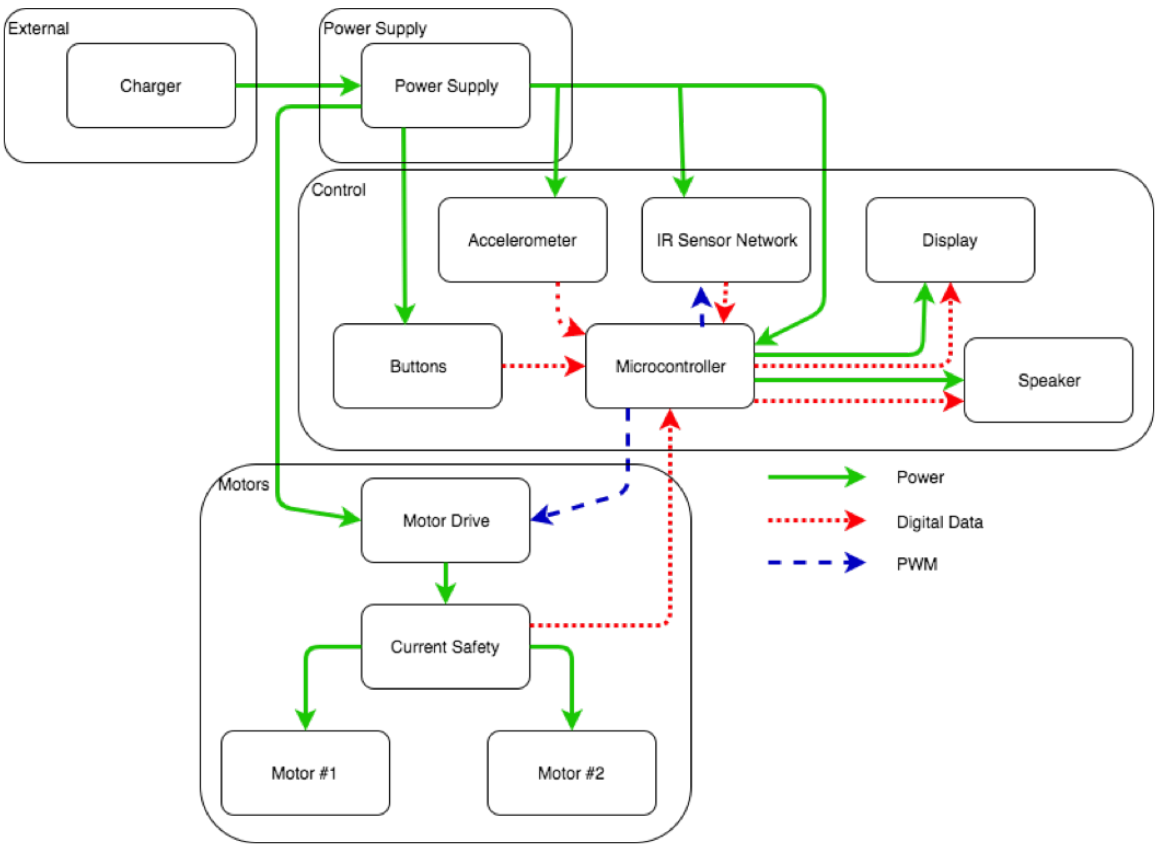


Figure 1: Block Diagram

2 Design

2.1 Design Procedure

2.1.1 Charger

This block converts a standard 120 VAC wall outlet input into a DC source to charge the 12 V sealed lead-acid battery.

2.1.2 Power Supply

The design utilizes a rechargeable 12 V sealed lead acid battery. A lead acid battery was chosen rather than a lithium-ion battery for safety reasons. Lead acid batteries are safer since if punctured they cause less damage. This module outputs 3.3 V, 5 V and 12 V supply to the rest of the device. The battery has 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.

2.1.3 Buttons

The design utilizes three buttons in totals the power button and two buttons to set the timer. One button adds additional hours and the other increments the minutes. The maximum time allowed on the timer is 11:59, and after another button press time will reset to zero hours.

2.1.4 Accelerometer

The original accelerometer we planned to use broke two days before our final demonstration. The only accelerometer we could find at such short notice is more complicated to use but has much higher precision. No modifications needed to be made to the Requirements and Verifications table. The only change made was powering the accelerometer with 5 V instead of the 3.3 V that the original required. The current accelerometer provides data to the first microcontroller via Inter-integrated Circuit (I2C) protocol. The data is used to determine if the device is flipped or tilted more than 30°. To interpret the data provided by the accelerometer, we use a prewritten Arduino program that we modified to include the rest of our code for the first microcontroller[3].

2.1.5 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 are driven by a 38 kHz frequency signal from the microcontroller. If there is an object that becomes present in front of the vehicle, the sensor will send a digital low signal to the microcontroller. Two emitters are used in the front of the device to widen the horizontal range of the sensor network. More emitters and receivers on the device would be useful, but the physical design of the device limited us to only four.

2.1.6 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. One LED turns on when the battery voltage is equal or greater than 12.1 V, indicating a full charge. The second LED turns on when the battery voltage is equal or less than 11.5 V, indicating a low charge.

2.1.7 Speaker

The speaker emits a 40 kHz sound wave when it receives a trigger signal from microcontroller. This is within the acceptable range for gaining a dogs attention[4]. We chose to use an ultrasonic range finder which operates at 40 kHz since the cost of the range finder was less than other transmitters within the desired frequency range.

2.1.8 Microcontroller

The microcontroller sub-module consists of two ATmega328 microcontrollers. Both are powered by 5V 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 microcontroller takes digital inputs from the buttons and serial input from the accelerometer. It outputs digital signals to the seven-segment display and two orientation signals and a device active to the second microcontroller. The second microcontroller takes the three digital signals from the first microcontroller as well as digital signals from the IR sensors placed throughout the body of the device. It outputs four digital signals to the H-bridge to set the bias of the motors. It also outputs to the H-bridge one PWM signal for each motor. The microcontroller is programmed utilizing Arduino coding language.

2.1.9 Current Safety

The current safety module has a current limiter in series with each motor that limits the current to a value that is below the maximum current threshold of the motor drive. A resistor and a zener diode are used to set a reference voltage. Operational amplifiers are used to compare the reference voltage to the motor voltages. The comparator outputs are then connected to the inputs of a NAND gate that sends a signal to the microcontroller. If the motor voltage is lower than the reference voltage, the motor is stalled and the NAND gate sends a signal to the microcontroller to turn off the motors. We chose to use two methods to limit current for added safety. The comparator circuit should detect a motor stall before the current limiter is needed, but the current limiter is included as a backup method in case any part of the comparator circuit fails.

2.1.10 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 through the current safety module to the motors. The particular H-bridge was chosen based on maximum current ratings needed to operate the motors. It also needed to be able to tolerate the current spike when the motors are stalled. We found that the average current draw when the motor is stalled is about 1.5 A, so we chose an h-bridge that can tolerate up to 2 A.

2.1.11 Motors

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

2.2 Software

2.2.1 Microcontroller 1

The first microcontroller controls the display, buttons, and accelerometer. The button inputs are configured as interrupts. When one is pressed, the time until activation increases by an hour or a minute, depending on the button. After 10 seconds without a button press, the program begins counting down. Once the activation time is reached, a 20 minute timer is set, and the program begins interpreting accelerometer data. If the accelerometer detects a tilt of more than 30°, the device active signal that is sent to the second microcontroller is set to low. If the device is not tilted, the program determines if the device is flipped by checking if the accelerometer measures greater than or less than 0 g. The orientation signal is set based on this data and then the device active signal is set to high. After 20 minutes, the device active signal is permanently set to low (Appendix D: Figure 16).

2.2.2 Microcontroller 2

The program on the second microcontroller controls the motors, IR sensors, and speaker. It does nothing until the device active signal from the first microcontroller goes high. When active, at the beginning of each iteration in the main loop, a random number from 0 to 100 is generated. If it is less than ten, the speaker outputs a short burst. This causes the speaker to output at the beginning of about 10% of the iterations. The main part of the program is a basic object-avoidance algorithm. It checks for obstacles by outputting a short 38 kHz burst to the IR emitters and then reading the IR receivers. If nothing is detected by the front sensor, the device moves forward. If something is blocking the front, it will turn towards whichever side is not blocked by an object until the front sensor is clear again. If all three sensors are blocked, it will alternate turning towards one side and then the other for 7 seconds each until the front sensor is not blocked. To make the motors move, the program sends digital signals to the H-bridge to bias the motors either forward or backward. It also sends PWM signals to the h-bridge to determine the speed of the device. Currently a 100% duty cycle is used in order to achieve the level of speed we desire.The orientation signal from the first microcontroller that determines if the device is flipped is configured as an interrupt. If the signal changes, the bias to make the motors turn forward is flipped (Appendix D: Figure 17).

3 Verification

To test the obstacle avoidance feature of the device, we set it on a block so that the wheels could spin freely and then used our hands to block various sensors. We verified that the device moves forward when the front sensor is unblocked, turns to the right when the front and left sensors are blocked, and turns left when the front and right sensors are blocked. When we blocked all three sensors, the device alternated turning right for 7 seconds and turning left for 7 seconds. We then recreated the same situations while it was on the ground, and the results were the same.

The motor stall logic was also tested first with the device on a block. To test it, we held one wheel until a stall was detected while also monitoring the current draw of the motor. We verified that the current draw up to the time the stall was detected never exceeded the maximum current draw of 2 A. We also verified that the motors turned off for 3 seconds after a stall and then resumed normal functionality as intended. When the device was placed on the ground with the motor stall logic, a stall was detected every time the motors turned on. We believe this is because the difference between stalled and not stalled is sensitive. The increased resistance of the wheels on the floor, combined with current spikes when the motors started or changed direction, caused a stall to be detected whenever the device tried to move. This caused us to be unable to integrate the motor stall logic in the final design.

3.0.1 Charger

We were unable to verify that the battery charged with a maximum charge current of 1.5 A. This requirement was unable to be met due to the fact that the store bought charger did not register that a battery was connected. Therefore the charger only supplied a current of about 50 mA which is not sufficient to charge the battery.

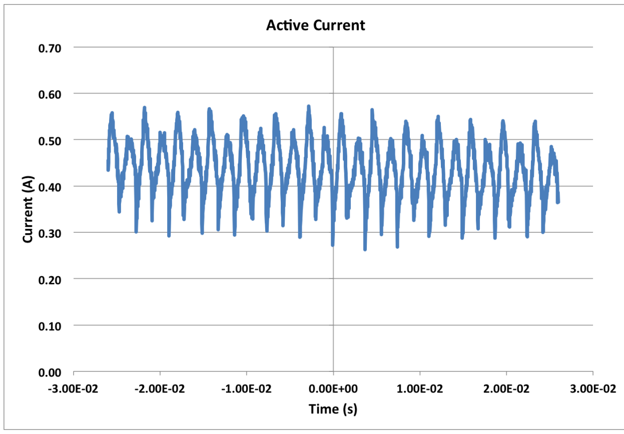
3.0.2 Power Supply

The power supply was able to output 12 V, 5 V, and 3.3 V. Furthermore, the battery life exceeded our need of at least 12 hours of idle time as seen in Equation 1. Furthermore, Equation 2 shows that the idle time is also long enough when the device is drawing its stall current for the duration of operation. Figure 2a shows the active current when the device is traveling forward on the ground. Figures 2b and 2c show the current when the device is in idle mode or stalling, respectively.

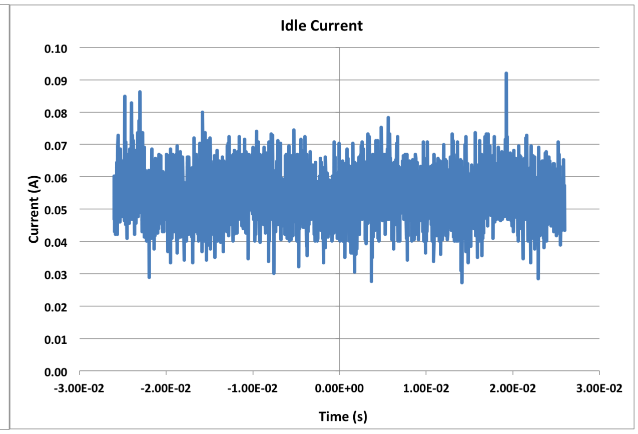
$$\begin{aligned} \mathrm{I_{active}} * \mathrm{h_{active}} &= 0.47\mathrm{A} * 0.33\mathrm{h} = 0.1551\mathrm{Ah} \\ 5\mathrm{Ah} - 0.1551\mathrm{Ah} &= 4.845\mathrm{Ah} \\ 4.845\mathrm{Ah} = 0.055\mathrm{A} * \mathrm{h_{idle}} &\Rightarrow \mathrm{h_{idle}} = 88.1\mathrm{hours} \end{aligned} \tag{1}$$

$$\begin{aligned} \mathrm{I_{stall}} * \mathrm{h_{active}} &= 1.4\mathrm{A} * 0.33\mathrm{h} = 0.47\mathrm{Ah} \\ 5\mathrm{Ah} - 0.47\mathrm{Ah} &= 4.53\mathrm{Ah} \\ 4.53\mathrm{Ah} = 0.055\mathrm{A} * \mathrm{h_{idle}} &\Rightarrow \mathrm{h_{idle}} = 82.36\mathrm{hours} \end{aligned} \tag{2}$$

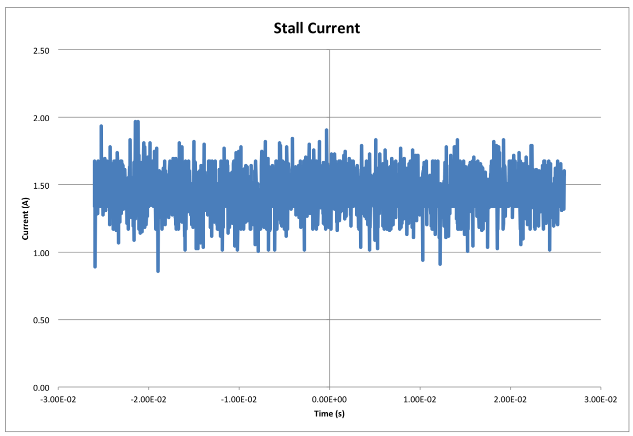
The results show that, even if the motors are stalling the entire active period, our available idle time far exceeded our requirements. Therefore, there is room to alter the design for more power consumption.



(a) Active Current



(b) Idle Current



(a) Stall Current

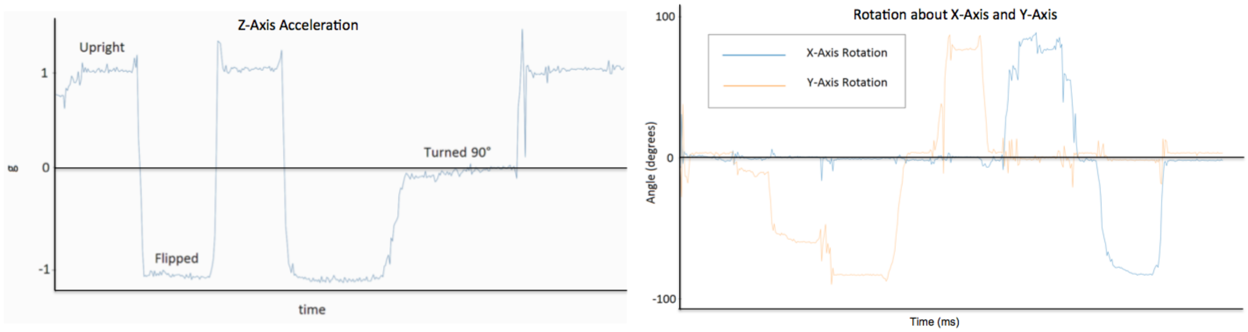
Figure 2: Current Measurements

3.0.3 Buttons

The timing buttons were indented within there respective holes in order to minimize potential damage from the dog. They were successfuly able to change the time on the display. Furthermore, the power button was able to control the power to the other boards.

3.0.4 Accelerometer

The accelerometer was able to output X, Y, and Z values. Figure 3a shows the output values of the Z-axis at different angles. In the first time segment, the device is upright and then flipped 180°. This process is repeated before the device is then balanced on its side. When on its side, the device has a 0 g output. Figure 3b displays the rotation about the X and Y axes as they are each flipped over a 180° range. In both cases, we see that the resolution is high enough for the microcontroller to determine relative orientation.



(a) Z-Axis Detection

(b) X and Y Axes Detection

Figure 3: Accelerometer Output

3.0.5 IR Sensor Network

The initial requirement for the IR sensor was to observe an object within a 40° angle from the center of the receiver, which was located at the center of the device. The actual angle achieved was 28.08° (Equation 3). This was found by placing an object 12 inches in front of the device and moving it perpendicular to the center line of the device. The threshold of our sensing abilities occured 3 inches from the center of the device.

$$\tan^{-1}(\frac{12\text{in}}{3\text{in}}) = 75.96^\circ \Rightarrow 90^\circ - 75.96^\circ = 14.04^\circ \Rightarrow 2 * 14.04^\circ = 28.08^\circ \tag{3}$$

On the other hand, we found that when an object was placed directly in front of the sensors, we achieved a sensing range of 0.66 m. This was found to be an acceptable range for our device to be able to detect an obstacle and turn. The range did not have to be greater because the use of omni-wheels (Appendix C: Figure 12) allowed for a decreased turn radius. Figure 4 shows that the voltage output of the receiver is low when an object is detected in range. The range was regulated by changing the resistance to both components. The optimized values are shown in Appendix B: Figure 11.

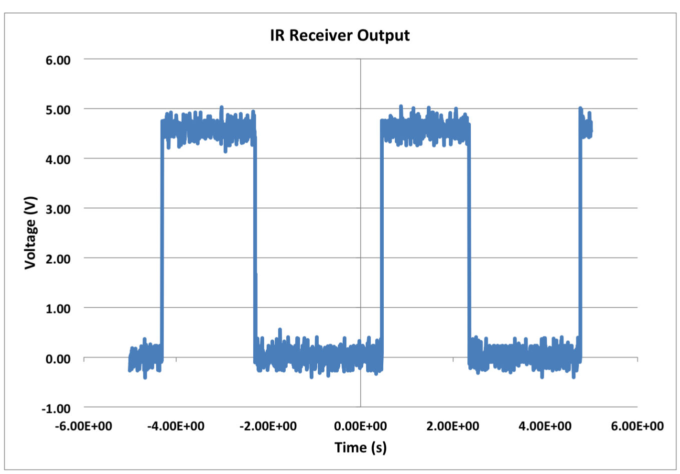


Figure 4: IR Receiver Output

3.0.6 Display

The battery level detection circuitry (Appendix B: Figure 9) was based off of the battery life graph that was provided on the data sheet[5]. The low battery indicator was active when the battery had a voltage of 11.5 V or less, while the full battery indicator was active for 12.1 V or greater. Furthermore, the display was successfully able to show the value of the time set by the user.

3.0.7 Speaker

The speaker was an ultrasonic range finder that emitted a 40 kHz sound wave. For verification purposes, we used the echo pin of the device to measure whether or not a signal was received. We found that as we moved an object closer to the range finder, the time that the device has a high voltage was shorter (Figure 5). The length of time at a high value increased with the distance from the device. Overall, the ability to detect variation in distance proves that the device was emitting a 40 kHz sound wave.

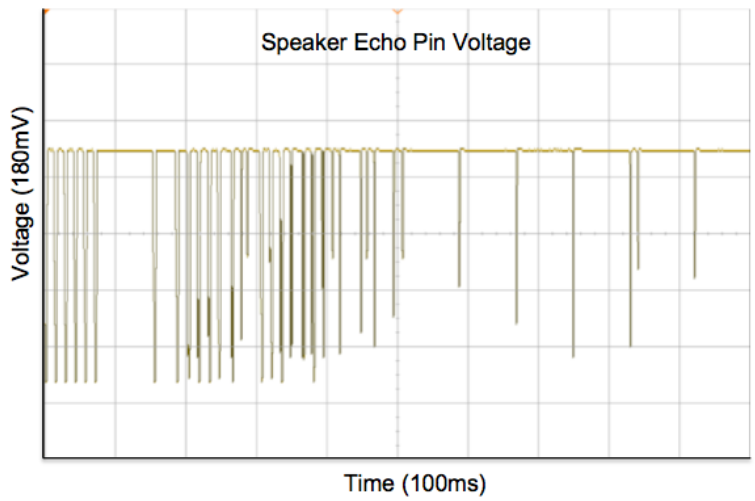
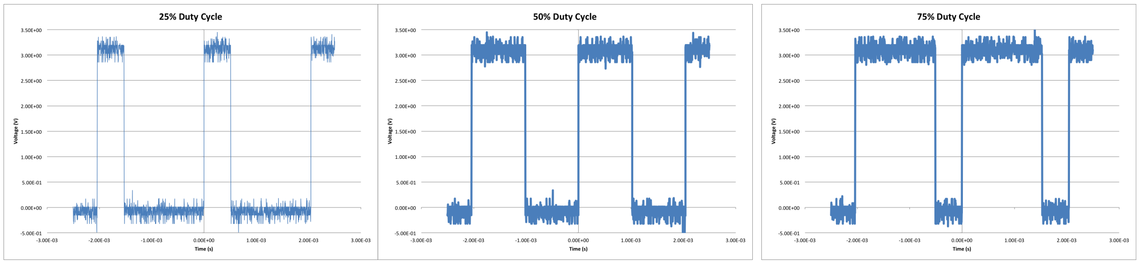


Figure 5: Speaker Verification

3.0.8 Microcontroller

The microcontrollers could successfully download and run programs that were installed using serial communication with a computer. Furthermore, the analog pins were able to create PWM signals of various duty cycles, as can be seen in Figures 6a, 6b, and 6c. The microcontroller was also able to distinguish milli-Volt level differences for inputs when using analog pins.



(a) 25% Duty Cycle (b) 50% Duty Cycle (c) 75% Duty Cycle

Figure 6: PWM Signals

3.0.9 Current Safety

The current safety module was able to use the initial voltage drop across the motors during a stall (Figure 7) and compare it to a reference voltage that was set by a zener diode. A zener diode was used because it was determined to be lesss susceptible to voltage changes. Therefore, the reference voltage was more consistent. A 330 Ω resistor was used in series with the diode in order to limit the amount of current that traveled through the reference circuit. We found that the voltage of the comparator's low output was greater than the NAND gate's low voltage threshold. However, there was still a 50 mV difference that could be seen at the output of the NAND gate. Therefore, we used an analog pin on the microcontroller to read the small voltage difference and interpret a stall signal.

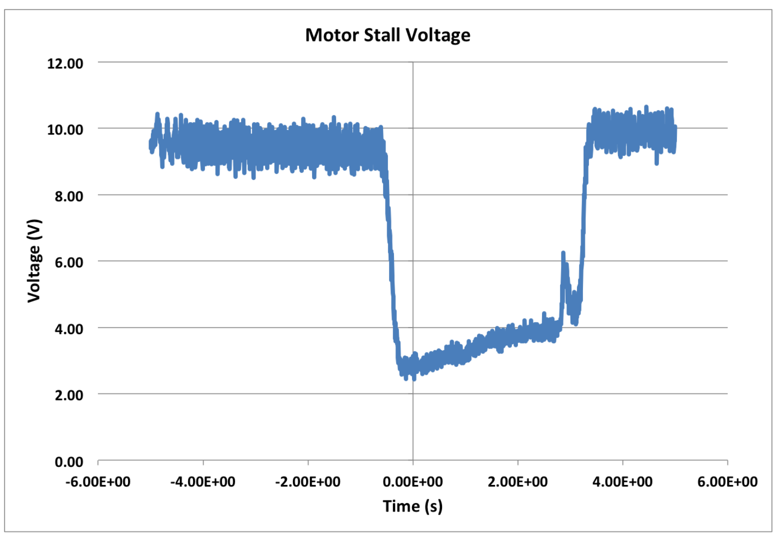


Figure 7: Voltage Across Motor During Stall

3.0.10 Motor Drive

The motor drive was successfully able to operate the motors in both directions by using signals from the microcontroller to switch the direction of the voltage across the motor. In Figure 8, we see that the motor has a positive voltage when moving forward, and a negative voltage when moving backward. We ended up using a 100% duty cycle signal from the mircontroller to achieve the speed that we desired.

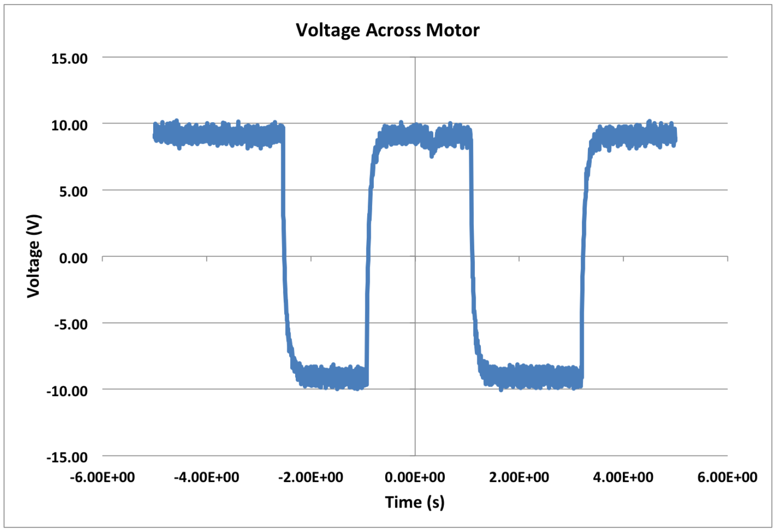


Figure 8: Voltage Across Motor during Bidirectional Operation

3.0.11 Motors

The motors were successfully able to change direction and move the device. Equation 4 shows that we were able to achieve a forward speed of approximately 24.096 feet per minute. This converts to approximately 15.34 rpm (Equation 5), which is greater than the required 10 rpm.

$$7\text{ft} \equiv 17.43\text{s} \Rightarrow \frac{60\text{s}}{1\text{min}} * \frac{1}{17.43\text{s}} * 7\text{ft} = 24.096\frac{\text{ft}}{\text{min}} \tag{4}$$

$$\begin{gathered} \text{Circumference}_{\text{wheel}} = 2 * \pi * \text{r} = 2 * \pi * 0.25\text{ft} = 1.571\frac{\text{ft}}{\text{rev}} \\ \frac{24.096\text{ft}}{1\text{min}} * \frac{1\text{rev}}{1.571\text{ft}} = 15.34\text{rpm} > 10\text{rpm} \end{gathered} \tag{5}$$

The wheel caps were made out of solid plastic, which made them approximately 4 lbs each. We believe that the speed could be further increased by hollowing out the wheel caps in order to reduce the device weight. The necessary torque would decrease; therefore, the speed would increase and the motor current would decrease.

4 Costs

4.1 Parts List

Table 1: Parts List

Manufacturer	Part No.	Cost ($)	Number of Parts	Total Cost ($)
Adafruit	GY-521	3.46	1	3.46
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
Bourns Inc.	Inductors	0.24	2	0.48
ECEShop	Resistors	0	37	0
ECEShop	Capacitors	0	10	0
ECEShop	LEDs	0	2	0
ECEShop	Diodes	0	3	0
			Total Part Cost ($):	204.78

4.2 Labor Costs

Table 2: Labor Costs

People	**Hourly Rate**	**Hours Worked**	**Total Labor Costs (Multiplier = 2.5)**
Robert	$30.00	60	$4,500
Mary	$30.00	60	$4,500
Aimee	$30.00	60	$4,500
Machine Shop	$50.00	23	$2,875
		Overall Labor Cost:	$16,375

4.3 Grand Total

Grand Total = Parts Costs + Labor Costs = $204.78 + $16,375 = $16,579.78

5 Conclusions

5.1 Accomplishments

We were able to meet most of our high-level requirements for our project. The device does detect and avoid objects when they are within the range of the sensors. The second requirement, operating when dropped on any side, was fully achieved. The hemispherical wheel caps (Appendix C: Figure 13) ensure that the device will roll onto its top or bottom rather than remain stuck on one of its sides. Furthermore, the accelerometer successfully alerts the microcontroller when the device is flipped over. We did verify that the device can run in active mode for 20 minutes and that the speaker on the device attracts a dogs attention. Other achievements made during the design process were exceeding our drag weight and sensor range requirements. Initially we set out to have the device drag a minimum weight of 0.5 lbs but in in the end were able to exceed this goal and drag up to 15 lbs. We had originally set out to achieve a minimum sensor range of 0.5 m and were able to surpass this goal with a sensor range of 0.66 m. This allowed us to detect obstacles faster and allows the device to have more time to react.

5.2 Uncertainties

Though we were able to detect obstacles, there are significant blind spots in front of the wheels due to the limited horizontal range of the sensors and the size of the wheel caps. Though we did verify that the device can operate in active mode for 20 minutes, we were not able to fully verify our third requirement, attracting a dogs attention for 20 minutes, because we were not able to test the device with a dog.

5.3 Ethical Considerations

Our project adheres to the IEEE code of ethics[6]. 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 polycarbonate 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[7].
- The device is water resistant so that it will not be damaged by slobber or spills.
- 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[7].

- The wheels are hemispherical 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 parts of the toy that are accesible to the dog are large enough to avoid a potential choking hazard[7][8].

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.
- Only use the device with dogs that weigh more than 30 lbs.

5.4 Future Work

One point of improvement for our project is the motor stall logic. Our current safety circuit correctly detects when a motor is stalled, but current spikes when the motors turn on or change direction cause too many false alarms. Because of this, we had to remove the stall logic function for the final project. We believe a low-pass filter on the output of the stall circuit would eliminate most false alarms and enable full integration of the motor stall logic.

Another needed improvement is decreasing the size of the blind spots. As stated previously, the IR sensor angle was smaller than expected, so blind spots are present. This can be corrected by widening the holes for the IR emitters to allow more light to escape, or adding more IR emitters and receivers throughout the device.

Finally, we could add more features that entice the dog to play with the device. For example, a recording of the owners voice instead of a single 40 kHz tone would probably make the device seem more familiar to the dog. Also, some randomness could be added to the movement control so that the devices path is more unpredictable.

Appendix A Requirements and Verifications

Table 3: Requirements and Verifications

Requirement	Verification	Verification Status (Y/N)
Power Supply 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	Y
2) Provide step down voltage of 5 V within a tolerance of +/- 2%	2) Use multimeter to measure that module outputs voltage within range 4.9 V - 5.1 V.	Y
3) Provide output voltage of 12 V with a tolerance of 5%	3) Use multimeter to measure that module outputs voltage within range 12.6 V - 11.4 V.	Y
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 3.46 V - 3.13 V.	Y
Accelerometer 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.	Y
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.	Y
Buttons 1) Power Button should turn on the device	1) Press power button and measure each module is powered with correct supply voltage	Y
2) Minute and hour buttons should provide digital high signal of a minimum of 3 V to microcontroller while pressed	2) Press button and measure output voltage with multimeter verifying voltage is at least 3 V.	Y
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 1 V.	Y

Requirement	**Verification**	**Verification Status (Y/N)**
IR Sensor Network 1) The IR emitter operates at a frequency of 38 kHz.	1) Measure the output pin of the IR receiver and check that it is high when the IR emitter is in front of it.	Y
2) The IR reciever is able to detect objects up to at least 0.5 m away.	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 m from the direct center of the reciever.	Y
3) The sensor is able to observe objects within 40° of the center of the receiver.	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° from the direct center of the reciever.	N
4) The IR reciever outputs a digital high value when an object is detected.	4) Use a multimeter to measure the output voltage of the reciever when an object is 6 inches in front of the sensor.	Y
Charger 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 1.5 A.	N
Buttons 1) Power Button should turn on the device	1) Press power button and measure each module is powered with correct supply voltage	Y
2) Minute and hour buttons should provide digital high signal of a minimum of 3 V to microcontroller while pressed	2) Press button and measure output voltage with multimeter verifying voltage is at least 3 V.	Y
3) Minute and hour buttons should provide digital low signal of 1 V or lower to microcontroller while not pressed	3) Leave button unpressed and measure output voltage with multimeter verifying voltage is at at maximum 1 V.	Y
Speaker 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.	Y

Requirement	Verification	Verification Status (Y/N)
Microcontroller 1) For at least 16 pins configured as digital output pins, voltage for digital output HIGH is at least 3 V 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 3 V. Load program that outputs LOW to 15 digital I/O pins. Measure output voltage of each pin to ensure each outputs at most 1V	Y
2) Excluding the pins from requirement 1, for at least seven 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 seven digital I/O pins to input and displays their value on a console. Input 3 V 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.	Y
3) Analog voltage input between 0 V and 5 V 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 0 V to 5 V and check console to ensure correct mapping.	Y
4) At least four pins, excluding pins from previous requirements, configured for pulse width modulation, output square wave with arbitrary duty cycle	4) Connect pin five 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	Y
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.	Y
Display 1) The correct value of the timer is displayed on the screen 95% of the time.	1) Set a one hour timer and check that the device counts down properly for at least 57 minutes.	Y
2) The full charge LED turns on whenever the battery charge is above 95%.	2) Use a multimeter and DC voltage supply to determine the level of battery life at which the LED turns on.	Y
3) If the battery voltage level drops below 25%, 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.	Y

Requirement	Verification	Verification Status (Y/N)
Motor Drive 1) H-bridge motor driver can be configured to drive 2 motors in both forward and reverse	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.	Y
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.	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.	Y
Motor 1 1) Motor can provide at least 10 rpm for a torque of 1.9 Nm or greater.	1) Connect a 3 in (7.62cm) radius wheel to the motor. Attach a string to the wheel and connect a 25 kg 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 ten times in one minute.	Y
Motor 2 1) Motor can provide at least 10 rpm for a torque of 1.9 Nm or greater.	1) Connect a 3 in (7.62 cm) radius wheel to the motor. Attach a string to the wheel and connect a 25 kg 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 ten times in one minute.	Y

Appendix B Circuit Schematics

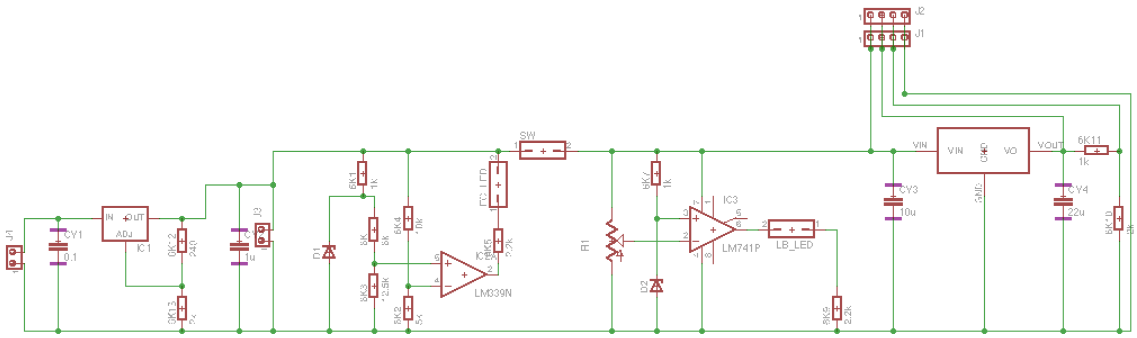


Figure 9: Battery Board Circuit[9][10][5][11][12][13]

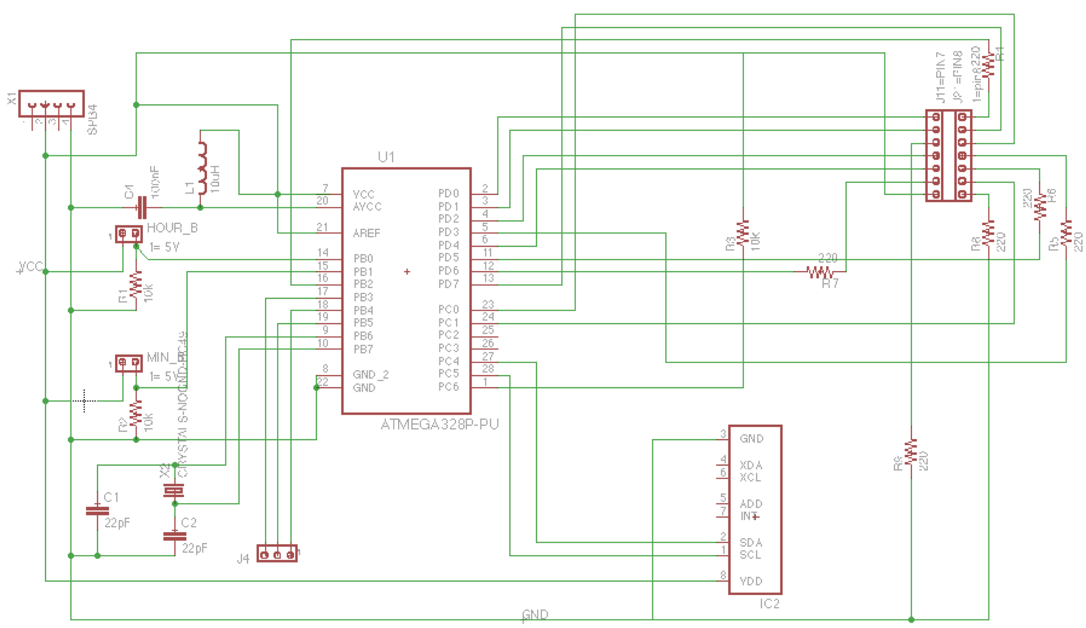


Figure 10: First Microcontroller Board Circuit[14][15][16][17]

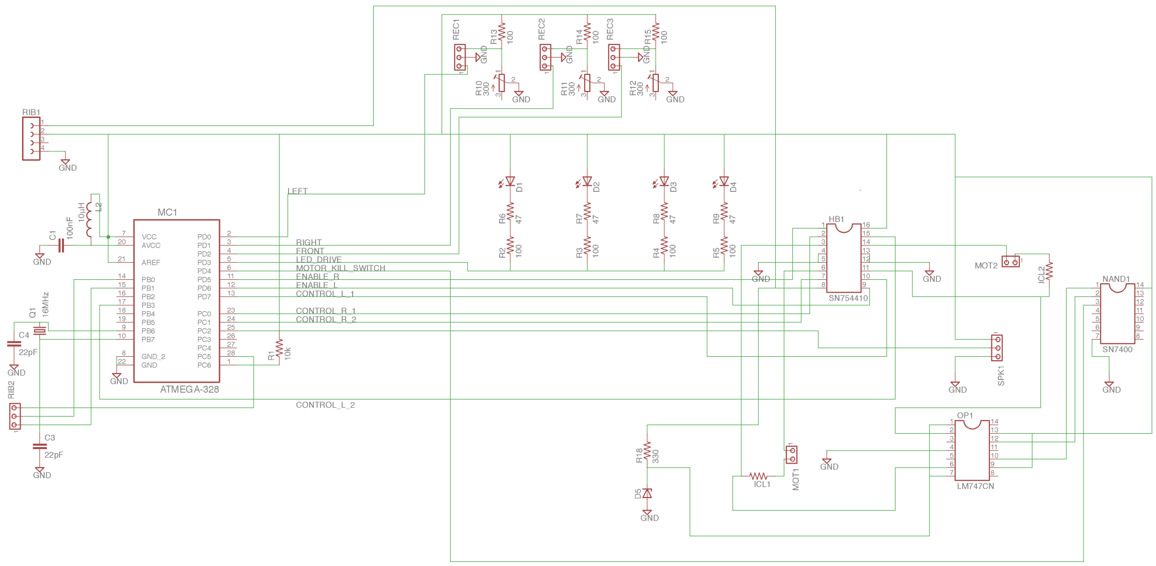


Figure 11: Second Microcontroller Board Circuit[14][15][16][18][19][20]

Appendix C Final Device

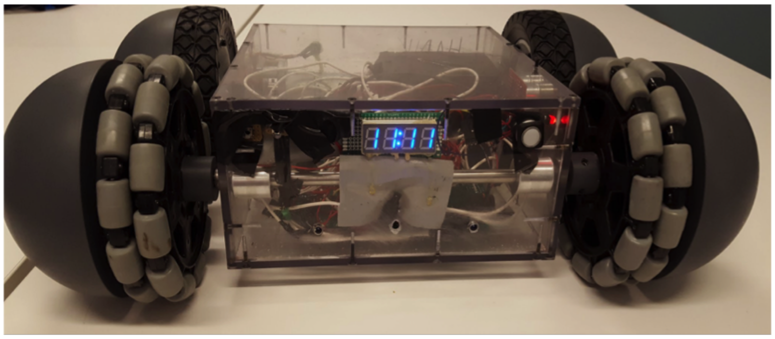


Figure 12: Front View of Final Design

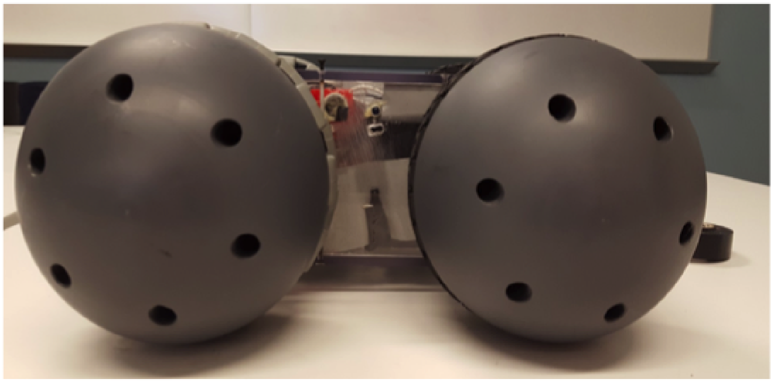


Figure 13: Side View of Final Design

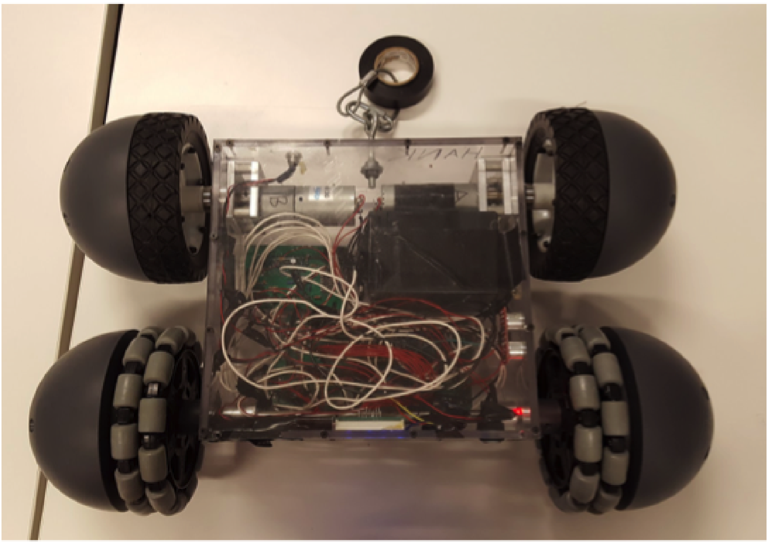


Figure 14: Top View of Final Design

Appendix D Software Flowcharts

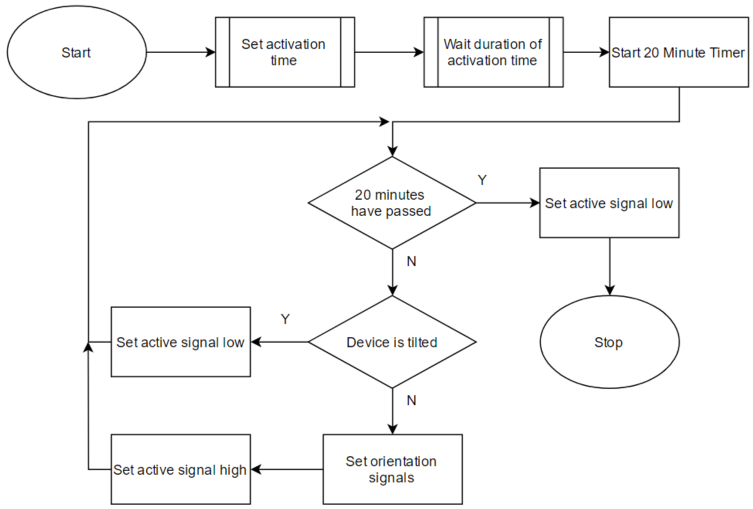


Figure 15: Microcontroller 1 Software Flowchart

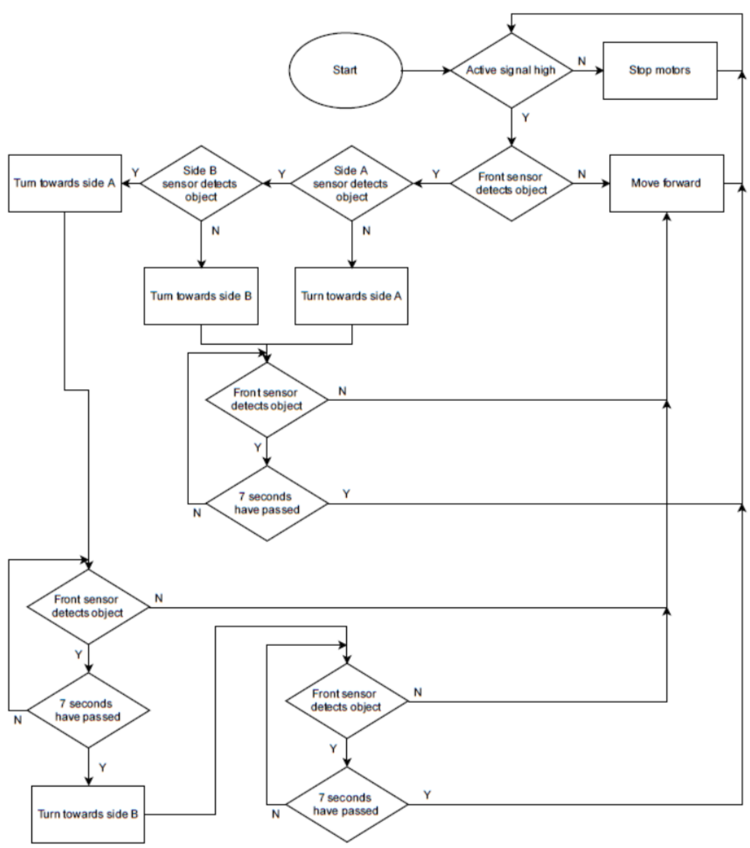


Figure 16: Microcontroller 2 Software Flowchart

Appendix E Common Abbreviations

Unit or Term	Symbol or Abbreviation
alternating current	ac
American wire gauge	AWG
ampere	A
ampere-hour	Ah
amplitude modulation	AM
angstrom	Å
antilogarithm	antilog
atomic mass unit (unified)	u
audio frequency	AF
automatic frequency control	AFC
automatic gain control	AGC
automatic volume control	AVC
average	avg
backward-wave oscillator	BWO
bar	bar
barn	b
beat-frequency oscillator	BFO
bel	B
billion electronvolts*	BeV
binary coded decimal	BCD
bit	b
British thermal unit	Btu
byte	B
calorie	cal
candela	cd
candela per square foot	cd/ft^2
candela per square meter	cd/m^2
cathode-ray oscilloscope	CRO
cathode-ray tube	CRT
centimeter	cm
centimeter-gram-second	CGS
circular mil	cmil
continuous wave	CW
coulomb	C
cubic centimeter	cm^3
cubic foot per minute	ft^3/min
cubic meter	m^3
cubic meter per second	m^3/s
curie	Ci
cycle per second	Hz
decibel	dB
decibel referred to one milliwatt	dBm
degree Celsius	°C
degree Fahrenheit	°F
degree Kelvin**	K
degree (plane angle)	...$^{+}$
degree Rankine	°R
degree (temperature interval or difference)	deg
diameter	diam
direct current	dc
double sideband	DSB
dyne	dyn
electrocardiograph	EKG
electroencephalograph	EEG
electromagnetic compatibility	EMC
electromagnetic unit	EMU

*Deprecated: use gigaelectronvolt (GeV).

**Preferably called simply *kelvin*.

Unit or Term	Symbol or Abbreviation
electromotive force	EMF
electronvolt	eV
electrostatic unit	ESU
erg	erg
extra-high voltage	EHV
extremely high frequency	EHF
extremely low frequency	ELF
farad	F
field-effect transistor	FET
foot	ft
footlambert	FL
foot per minute	ft/min
foot per second	ft/s
foot-poundal	ft-pdl
foot pound-force	ft•lbf
frequency modulation	FM
frequency-shift keying	FSK
gallon	gal
gallon per minute	gal/min
gauss	G
gigacycle per second	Gc/s
gigaelectronvolt	GeV
gigahertz	GHz
gilbert	Gb
gram	g
henry	H
hertz	Hz
high frequency	HF
high voltage	HV
horsepower	hp
hour	h
inch	in
inch per second	in/s
inductance-capacitance	LC
infrared	IR
inside diameter	ID
intermediate frequency	IF
joule	J
joule per degree	J/deg
joule per kelvin	J/K
kilobit per second	kb/s
kilobyte	kB
kilocycle per second	kHz/s
kiloelectronvolt	keV
kilogauss	kG
kilogram	kg
kilogram-force	kgf
kilohertz	kHz
kilohm	kΩ
kilojoule	kJ
kilometer	km
kilometer per hour	km/h
kilovar	kvar
kilovolt	kV
kilovoltampere	kVA
kilowatt	kW

Unit or Term	Symbol or Abbreviation
kilowatthour	kWh
lambert	L
liter	l
liter per second	l/s
logarithm	log
logarithm, natural	ln
low frequency	LF
lumen	lm
lumen per square foot	lm/ft^2
lumen per square meter	lm/m^2
lumen per watt	lm/W
lumen-second	lm•s
lux	lx
magnetohydrodynamics	MHD
magnetomotive force	MMF
maxwell	Mx
medium frequency	MF
megacycle per second	MHz/s
megaelectronvolt	MeV
megahertz	MHz
megavolt	MV
megohm	MΩ
metal-oxide semiconductor	MOS
meter	m
microampere	μA
microfarad	μF
microgram	μg
microhenry	μH
micrometer	μm
micron†	μ
microsecond	μs
microsiemens	μS
microwatt	μW
mil	mil
mile per hour	mi/h
mile (statute)	mi
milliampere	mA
milligram	mg
millihenry	mH
milliliter	ml
millimeter	mm
millimeter of mercury, conventional	mmHg
millimicron‡	nm
millisecond	ms
millisiemens	mS
millivolt	mV
milliwatt	mW
minute (plane angle)	...'
minute (time)	min
nanoampere	nA
nanofarad	nF
nanometer	nm
nanosecond	ns
nanowatt	nW
nautical mile	nmi

†The name *micrometer* (μm) is preferred.
‡The name *nanometer* is preferred.

Unit or Term	Symbol or Abbreviation
neper	Np
newton	N
newton meter	N•m
newton per square meter	N/m^2
oersted	Oe
ohm	Ω
ounce (avoirdupois)	oz
outside diameter	OD
phase modulation	PM
picoampere	pA
picofarad	pF
picosecond	ps
picowatt	pW
pound	lb
poundal	pdl
pound-force	lbf
pound-force foot	lbf•ft
pound-force per square inch	lbf/in^2
pound per square inch§	psi
power factor	PF
private branch exchange	PBX
pulse-amplitude modulation	PAM
pulse code modulation	PCM
pulse count modulation	PCM
pulse duration modulation	PDM
pulse position modulation	PPM
pulse repetition frequency	PRF
pulse-repetition rate	PRR
pulse-time modulation	PTM
pulse-width modulation	PWM
radian	rad
radio frequency	RF
radio-frequency interference	RFI
resistance-capacitance	RC
resistance-inductance-capacitance	RLC
revolution per minute	r/min
revolution per second	r/s
roentgen	R
root-mean-square	rms
second (plane angle)	..."
second (time)	s
short wave	SW
siemens	S
signal-to-noise ratio	SNR
silicon controlled rectifier	SCR
single sideband	SSB
square foot	ft^2
square inch	in^2
square meter	m^2
square yard	yd^2
standing-wave ratio	SWR
steradian	sr
superhigh frequency	SHF
television	TV
television interference	TVI

§Although the use of the abbreviation psi is common, it is not recommended. See pound-force per square inch.

Unit or Term	Symbol or Abbreviation
tesla	T
thin-film transistor	TFT
transverse electric	TE
transverse electromagnetic	TEM
transverse magnetic	TM
traveling-wave tube	TWT
ultrahigh frequency	UHF
ultraviolet	UV
vacuum-tube voltmeter	VTVM
var	var
variable-frequency oscillator	VFO
very-high frequency	VHF
very-low frequency	VLF

Unit or Term	Symbol or Abbreviation
vestigial sideband	VSB
volt	V
voltage controlled oscillator	VCO
voltage standing-wave ratio	VSWR
voltampere	VA
volume unit	vu
watt	W
watthour	Wh
watt per steradian	W/sr
watt per steradian square meter	$W/(sr \cdot m^2)$
weber	Wb
yard	yd

Figure 17: Common Abbreviations[21]

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