The Candle Extinguisher

By

Casey Labuda

Matthew Nee

Aaron VanDeCasteele

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TA: Dan Frei

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Abstract

Candles have been around for centuries and mostly used as a source of light. Today candles are used as decor and to spread different wonderful aromas around the household. It is a very simple and cheap device, yet candles are still seen as a safety hazard. We wanted to create a device that can safely extinguish these candles and prevent house fires from starting. The common safety idea of never leaving candles unattended can now be a worry of the past. The Candle Extinguisher successfully eliminates this worry of burning your house down with a simple candle.

Contents

1. Introduction

1.1 Motivation and Purpose

Candles have been used around the world for thousands of years. They were the main source of light before electricity and the common light bulb were discovered. Today candles are still used, not as much as a source of light, but instead to give off different scents. Candles come in all kinds of different shapes, scents, and colors, and can be found in almost every household. Many users believe that candles are a very simple and safe device, but there are many precautions that must be taken. When candles are left unattended, unexpected fires can occur. These fires can spread quickly and can easily destroy an entire house. Another issue that is often forgotten is the fact that candles need to have a cool down period and should not be burned for a long period of time.

Our goal is to create a device that can monitor the use of a candle. This will be used to ensure that the candle does not burn for too long and that it is safely extinguished. A majority of the fires started by candles occur because the user simply forgets about the candle. The Candle Extinguisher does exactly what its title states, it will safely extinguish a commonly sized candle. Through our device, the user will be able to input a desired time (within a set range) that the candle will be extinguished. In order to accommodate the different candle sizes, the device is based around a one-gallon glass jar. Any candle that will fit into this jar will be extinguished. Once the inputted time has been reached, power will be sent to a motor that will rotate the lid to the top of the jar creating a seal. This seal will cut off oxygen and suffocate the flame of the candle. A temperature sensor will also be implemented to ensure that the flame has been successfully extinguished.

As mentioned above, candles can cause many house fires. For the five year period from 2009 to 2013, candles cause an average of around twenty-five house fires every day. These fires have cost millions in property damage and haven taken the lives of many users [1]. Many of these fires occur when the user is asleep. With our device, the user can have their candle safely extinguished while they are sleeping. Another reason why candle fires are so common is due to drafts that may occur in the room. These drafts can cause nearby items to move into the path of the candle. This could then create an unwanted fire that can easily spread [2]. Since The Candle Extinguisher is based around a glass jar, unexpected items cannot be blown into the path of the flame.

Another key issue with candles, that many users do not realize, is that candles should not be burned for more than four hours at a time [3]. Major candle companies stress the importance of this idea, because candles need a chance to cool down. Constantly burning a candle for more than four hours can cause damage to the candle and can cause too much liquid wax to form on the surface. Most importantly, candles should not be left unattended. Our device stresses this idea. The Candle Extinguisher should not be neglected and should still be in the same room as the user.

In conclusion, The Candle Extinguisher was overall a success. Our device was able to successfully extinguish a wide variety of candles within five minutes. There were a couple of issues that occurred during the semester, but we were all able to persevere and complete our project. The Candle Extinguisher also has a modern look to it, and we are all excited to share our project with the rest of the class.

1.2 Objectives

High Level Requirements

- Device must successfully extinguish the candle within five minutes after the desired time has been reached.
- Device must urge user to not burn the same candle for more than four hours at a time.
- Device must extinguish the candle during a power outage.

Features

- User can input a time up to four hours until the candle is extinguished
- Can plug into any U.S. outlet
- Has a backup battery so that the device may still work during a power outage
- Backup batteries can be switched out without taking apart the device
- Has a fail-safe alarm to warn the user in the case of an unsuccessful extinguish
- Fairly portable
- Has a modern aesthetic look

1.3 Block Diagram and Descriptions

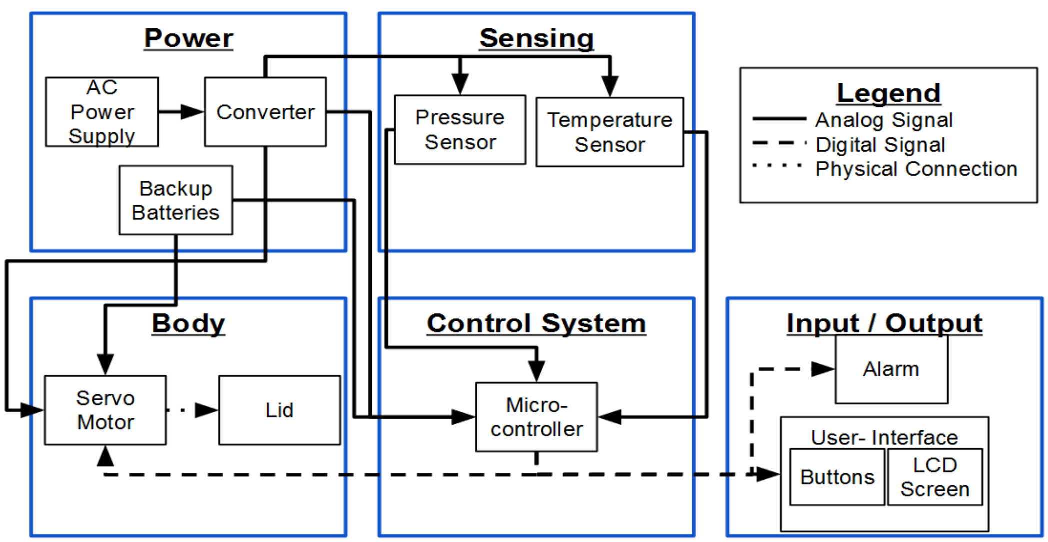

Figure 1. The Candle Extinguisher Block Diagram

1.3.1 Power

AC Power Supply

The power supply takes in power from an AC wall outlet rated for 120V at 60Hz. This power supply is also part of the converter that converts the AC power into DC power. The power from the wall outlet is the main primary source of power for each component. A standard three prong plug is used to connect our device to a typical wall outlet.

Backup Batteries

The backup batteries provide the necessary power to the device to make the necessary electronics work properly when there is a power outage. Six AA batteries power the device long enough so that it can continue the cycle and seal the container. The battery powers all of the components when wall power is not present.

Converter

The converter is needed to convert the wall outlet voltage to voltages that the other electronic components can use. It converts the AC voltage from the wall outlet into a DC voltage. This component will output 9 Volts, which will then be regulated to 5 Volts in order to power all of our components. The output needed to be greater than 5 Volts due to a loss of voltage over a diode.

1.3.2 Body

Servo Motor

The motor is a very important component to The Candle Extinguisher. The motor is a servo motor that is controlled by the microcontroller. The motor rotates the lid 90° in order to be placed on top of the jar. The motor also rotates in the opposite direction so that the user can place a candle in the jar.

Lid

The lid is attached to the top of the jar as seen in Figure 13 Appendix E. The lid creates a seal with the top of the jar, which suffocates the flame. It is constructed out of aluminum in order to lower the value of the starting torque required to move the lid. The lid also has a high heat tolerance and will not warp over time.

1.3.3 Input/Output

User Interface

The user interface is mounted on the bottom of The Candle Extinguisher as seen in Figure 13 Appendix E. There is an LCD screen which displays the time remaining on the alarm system. The user interface has an on/off button, arrows to increase/decrease time, arrows to increase/decrease brightness, and a button to start the timer. The user enters the amount of time they want The Candle Extinguisher lid to stay open. This information is transmitted to the microcontroller to track how long to keep the lid open on the device. The dimming feature of the user face is key part of our alarm system. If the alarm were to be triggered, then the screen flashes rapidly to add to the warning of the user.

Alarm

The alarm is triggered five minutes after the allotted time on the user interface has expired and the temperature sensor detects a flame. There is an audio alarm and also a visual alarm. If the temperature sensor detects a flame still present after time expires, the microcontroller sends power to the audio buzzer and the screen will flash rapidly.

1.3.4 Sensing

Pressure Sensor

The lid position sensor is a force sensitive sensor that will detect if the lid is open or closed. The sensor is on the edge of the lid as seen in Figure 12 Appendix E. When the sensor reads pressure readings, the lid is closed, when the sensor is not reading anything, the lid is open. The lid position sensor communicates with the microcontroller.

Temperature Sensor

The temperature sensor detects if a flame is present in The Candle Extinguisher. Once the initial alarm goes off, the microcontroller communicates with the temperature sensor to determine that the flame has been extinguished. The sensor is placed through a small hole in the lid as shown in Figure 13 Appendix E. It takes an initial room temperature reading before the lid is lowered and then more readings once the lid lowers the sensor into the glass jar.

1.3.5 Control System

Microcontroller

The microcontroller is the brains in the device. The chip chosen is the Atmega328P-PU, the same that can be found on an Arduino UNO development board. The microcontroller is placed on our PCB (Printed Circuit Board) which is connected to the rest of the components. This microcontroller is needed to carry out all of the functions of The Candle Extinguisher. This microcontroller communicates with the user interface to determine how long before the candle needs to be extinguished. Once the time has been reached the microcontroller sends a signal to the servo motor to rotate the lid to the top of the jar. After this has been achieved, the microcontroller communicates with the temperature sensor to ensure that the flame has been successfully extinguished. Lastly, the microcontroller communicates with the lid position sensor.

2. Design

2.1 Hardware Descriptions

2.1.1 Power

AC Power Supply

The AC power is provided by a wall outlet. A NEMA 5-15P To IEC 320-C13 SVT power cord is used [4]. This provides the AC power. The IEC 320-C13 is then connected to a power entry connector receptacle which is IEC 320-C14 [5]. This allows connection to the power cord mentioned earlier. Wires are then soldered to the other side of the connector which can then be connected to the PCB.

Backup Batteries

The backup batteries were chosen to be six AA batteries of any brand. A battery holder was used to house the six batteries in a neat fashion. Wires were then sent to a connector on the PCB. The battery holder allows the user easy access to change out batteries that no longer work.

Converter

The VSK-S15-9U is chosen to meet the specifications needed for the design [6]. The AC to DC converter can have an input voltage 80 to 264 Volts AC and an input frequency from 47Hz to 63Hz. The expected input voltage is 120 Volts AC and an input frequency of 60Hz. The output voltage of the converter is 9 Volts DC and is able to output a max current of 1.6 Amps, which is enough for what the device needs. There are several recommended components to include with the converter as specified by the datasheet and is included in Figure 5 in Appendix C. The capacitors are used to filter any ripple and noise. The fuse, metal oxide varistor, and the transient-voltage-suppression diode are used to help protect the converter and the rest of the circuit.

2.1.2 Body

Servo Motor

The servo motor chosen was the Tower Pro SG-5010 [7]. This servo motor is able to operate off of the 5 Volts from the linear voltage regulator. It is also able to communicate with the microcontroller used in this product. The servo motor can output 0.5366 Nm, which is able to raise and lower the chosen lid. There are connectors on the PCB to allow easy connection from the motor, which is off the the PCB. The servo motor operates using the 5 Volts provided.

Lid

The lid is designed by the ECE Machine shop as shown in Figure 12 in Appendix E. There are several reasons why this lid was chosen. The lightweight properties of the aluminum lid allow for less stress on the motor to raise and lower the lid. The metal lid is also more resistant to changes in heat, which will come from the candle. Finally, the lid allows for alterations, such as drilling a hole so the temp sensor can be inside the jar.

2.1.3 Input/Output

User Interface

The user interface chosen is the Adafruit 772 LCD Shield [8]. The LCD Screen communicates with the microcontroller used. The ability to alter the brightness of the screen is another reason for the choice. The screen is off the board, so there are connectors on the PCB to connect the wires and allow for an easy connection. The user interface is able to operate using the 5 Volts.

Alarm

The alarm chosen is a magnetic buzzer [9]. This alarm produces a loud enough sound to alert the user if there is an issue with the fixture. The buzzer is also able to use the 5 Volts that is provided in the circuit.

2.1.4 Sensing

Pressure Sensor

The pressure sensor is a force sensitive resistor [10]. This sensor detects between 0.04lbs to 4.5lbs. This is within weight range of the lid.

Temperature Sensor

The temperature sensor is an analog temperature sensor [11]. This temperature sensor detects temperatures up to 125 degrees Celsius, which allows for detection of a flame present within the fixture. The component communicates this data with the microcontroller which uses that data to determine the next action. The temperature sensor operates using the 5 Volts provided.

2.1.5 Control System

Microcontroller

The microcontroller chosen is the Atmega328P-PU [12]. The chip operates using 5 Volts. It is also communicates with other components used such as the sensors, inputs, outputs, and motor. The choice of this chip also allows for useful debugging and testing with the help of the Arduino Uno.

2.2 Calculations

2.2.1 Power

The fixture mainly uses 5 Volts. It runs at about 0.3 Amps. The total average power of the system is shown by the following equation.

$$P = I*V = 0.3 \text{ A} * 5 \text{ V} = 1.5 \text{ Watts} \tag{1}$$

It is found that on average there is about 1.5 Watts of power, which means that device is not using a large amount of power.

2.2.2 Body

In order to find the minimum torque required to move the lid into position, the following two equations were used. Equation (2) finds the moment of inertia of a disk that has an axis passing through the edge of the disk. The torque is found using equation (3).

$$I = \frac{3}{2} * M * R^2 \tag{2}$$

$$\tau = I * \alpha \tag{3}$$

$$I = \frac{3}{2} * 2 * .165 = 0.817kgm^2 \tag{4}$$

$$\tau = .0817 * .5 = \mathbf{.0408Nm} \tag{5}$$

2.3 Printed Circuit Board (PCB) Design

The final PCB design is shown in Figure 2. The bottom part of the board focuses on the power area and converting to the voltages needed. The top center part of the board contains the microcontroller, which takes the data from the sensors, and is able to control the servo motor, LCD screen, and alarm. Finally, the top left of the PCB consists of connectors that connect to sensors and other components that are not directly on the PCB. A ground plane was used so no vias were needed to connect components to ground.

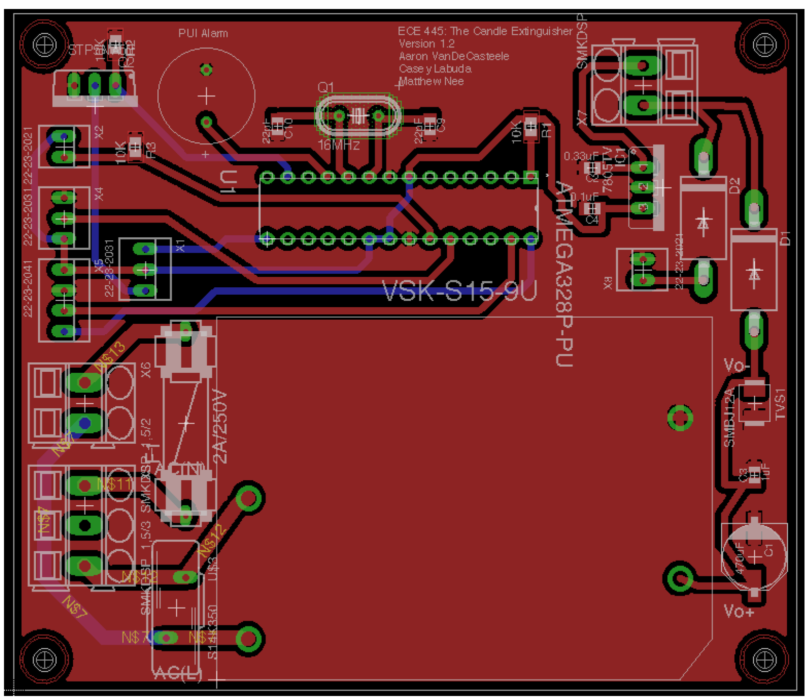

Figure 2. Final PCB design for The Candle Extinguisher.

3. Software Descriptions

The core algorithm behind our candle extinguisher can be seen in Figure 3 Appendix B.

3.1 Power

The Atmega328P-PU chip runs off of the 5 Volts power that comes from the linear regulator.

3.2 Body

3.2.1 Servo

The servo motor is controlled by a digital PWM signal. In Figure 4 Appendix B, the servo motor is used during the “Start”, “Lid Close”, and “Raise Lid” states. The software takes advantage of the arduino built in servo library [13]. To be able to send a signal to the motor, it must first be attached with the software. We made a modification to the source code so that when the motor is attached, it is not sent a pulse. This modification keeps the motor in place and prevents the motor from shaking when it is in place. In the states mentioned, the code sends a digital pwm signal to the servo motor when it is time to move the motor. The motor movement is implemented with a for loop in order to rotate the 90° to open or closed positions. In order to keep the current draw to a minimum (less than one amp), we added a time delay within the for loop to slow the movement down. This also keeps the lid from slamming when it closes.

3.3 Input/Output

3.3.1 User Interface

The software takes advantage of the Adafruit_RGBLCDshield library [8] in order to communicate with the user interface. The user interface has five buttons and a LCD screen. The buttons are used in the “User Input” state of Figure 4 in Appendix B to control the time the user wants to run The Candle Extinguisher. The software does not allow the user to hit the start button if the time is zero. The software also limits the time input to four hours. The buttons are also used in the “Idle” state in order to turn the LCD backlight on or off. The LCD screen displays the time remaining in the “Idle” state as well as communicates to the user to turn off the device in the “End” state.

3.3.2 Alarm

In Figure 4 Appendix B, the “Alarm” state can be seen with two ways of reaching it: “Lid Close” or “Temp Readings”. Once the “Alarm” state is reached, the software sends out a 1Khz signal to our buzzer in order to sound the alarm. The alarm and LCD screen turn on and off at one second intervals. The buttons sense that someone has responded to the alarm, thus turning off the alarm.

3.4 Sensing

3.4.1 Temperature Sensor

The temperature sensor sends a voltage that is linearly proportional to the degrees celsius of the environment. The software converts the voltage to degrees fahrenheit in order to determine whether or not the candle is lit. The temperature readings we take are the room temperature (before lid closed) and lid closed readings. We have a maximum temperature function that keeps track of the maximum reading while the lid is closed. Once the current reading of the temperature is 18° F lower than the maximum reading, we determine that the candle has been extinguished. If the lid closed reading is within three degrees of the room temperature reading, we determine that the candle was never lit. We verified these threshold numbers through multiple tests with candles of varying sizes and wick lengths.

3.4.2 Pressure Sensor

The pressure sensor acts as the lid position sensor and safety device in our software implementation. The software reads the analog signal from the force sensor on startup to decide whether or not the lid is closed. This happens in the “Start” state of Figure 4 in Appendix B. The software also takes in pressure sensor readings during the “Lid Close” state of Figure 4 in Appendix B. This allows the software to determine if the lid was properly closed in order to create the seal that will extinguish the candle. During the “Temp Reading” state of Figure 4 in Appendix B, the pressure sensor sends out readings. The reason behind this is to assure that the lid seal has not been disrupted. If the seal has been disrupted without the candle being extinguished, the alarm goes off.

3.5 Control System

3.5.1 Microcontroller

The Atmega328P-PU is the microcontroller we chose to implement our software because it is compatible with the Arduino Uno. We used the Arduino Uno to program the chip, and also to help with testing components before the PCB was delivered. Because we used the Atmega328P-PU, we used the arduino software to implement the code [13]. The ATmega328P-PU sends digital data to the servo motor and buzzer. It receives analog inputs in the form of voltage from the pressure and temperature sensor. It also receives analog signals from the buttons on the user interface and sends analog signals to the lcd screen on the user interface.

4. Design Verification

4.1 Power

4.1.1 AC Power Supply

The AC power was verified through normal use of the device. Many different common wall outlets were used to power our device. The power supply most consists of the converter and the high voltage connectors. These connectors were chosen due to the fact that they can handle high input AC voltage.

4.1.2 Backup Batteries

The backup batteries consist of six AA batteries. Any AA brand of batteries could be used in the device. These batteries are able to withstand normal heat from the device and are not a fire hazard. The most important requirement for the batteries, was that they need to power our device for at least four hours. This scenario could happen with a power outage early on in a four hour cycle. This is verified through a four hour test with only battery power; the test was successful.

4.1.3 Converter

The most important power component in the design is the converter. It was agreed upon to buy a converter rather than making our own. The converter passed all verification tests. The 120 Volts AC input voltage is successfully converted to 9 Volts DC. This can be seen in Figure 7 in Appendix D. The converter also handles heat from the candle and is verified through constant use with a lighted candle.

4.2 Body

4.2.1 Servo Motor

The servo motor consistently raises and lowers our aluminum lid. The motor needed to output at least 0.048Nm. The motor that was chosen was oversized so that this would not be an issue. According to the datasheet, the motor can output a torque of 0.5366Nm [7]. The motor also runs off both the wall power and the backup batteries. Both of these sources were regulated to a constant 5 Volts. The verification for the linear regulator can be seen in Figure 8 in Appendix D.

4.2.2 Lid

The requirements of the lid were all verified through normal use. The servo is able to raise and lower the lid 90°, and the lid made a seal so that the flame would be smothered out.

4.3 Input/Output

4.3.1 User Interface

The verifications were all met and can be seen in Figure 9 and 10 in Appendix D.

4.3.2 Alarm

The verifications were met and can be seen in the video from Reference [14].

4.4 Sensing

4.4.1 Pressure Sensor

This sensor was verified through its datasheet [10].

4.4.2 Temperature Sensor

The temperature sensor is able to detect the difference between a lit and unlit candle using the method mentioned in 3.4.1 of this report. The maximum temperature reading that was found can be seen in Figure 11 in Appendix D.

4.5 Control System

The microcontroller was verified through normal use.

5. Costs

5.1 Parts

Table 1: Parts Costs

Part Name	Manufacturer	Vendor	Part Number	Quantity	Unit Cost ($)	Actual Cost ($)
5VDC Servo Motor	Tower-Pro	Digi-key	SG-5010	1	12.00	12.00
AC/DC Converter	CUI Inc.	Digi-key	VSK-S15-9U	1	21.25	21.25
Six pack AA Batteries	Duracell	Target	MN1500	1	4.99	4.99
One-Gallon Glass Jar	Anchor Heritage	Target	200-10-0168	1	7.99	7.99
LCD Shield Kit	Adafruit Industries LLC	Mouser	772	1	19.95	19.95
Magnetic Piezo Buzzer	PUI Audio Inc.	Digi-key	AT-1224-TWT-5V-2-R	1	0.55	0.55
Force Sensitive Resistor	Interlink Electronics	Digi-key	FSR 402	1	8.64	8.64
Temperature Sensor	Analog Devices Inc.	Digi-key	TMP36GT9Z	1	1.48	1.48
Microcontroller	Microchip Technology	Digi-key	ATMEGA328P-PU	1	2.14	2.14
5V Linear Regulator	STMicroelectronics	Digi-key	L78S05CV	1	0.68	0.68
Schottky Diode	Fairchild/ON Semiconductor	Digi-key	SB340	3	0.47	1.41
2 Pin Header Connector	Molex LLC	Digi-key	22-23-2021	2	0.16	0.32
2 Pin Housing Connector	Molex LLC	Digi-key	22-01-3027	2	0.13	0.26
3 Pin Header Connector	Molex LLC	Digi-key	22-23-2031	2	0.23	0.46
3 Pin Housing Connector	Molex LLC	Digi-key	22-01-3037	2	0.19	0.38
4 Pin Header Connector	Molex LLC	Digi-key	22-23-2041	1	0.27	0.27
4 Pin Housing Connector	Molex LLC	Digi-key	22-01-3047	1	0.20	0.20
Connector Crimps	Molex LLC	Digi-key	08-50-0113	25	0.049	1.22
DPST Switch Push Button	E-Switch	Digi-key	PR142C1411	1	1.87	1.87
Tactile Switch	TE Connectivity	Digi-key	3-1825910-1	6	0.17	1.02

Power Entry Connector	Qualtek	Digi-key	701W-X2/02	1	0.78	0.78
3-Prong Power Cord	Tensility International Corp	Digi-key	11-00022	1	3.54	3.54
IC DIP 28POS Socket	On Shore Technology Inc.	Digi-key	ED281DT	1	0.33	0.33
3 Position Terminal Block	Phoenix Contact	Digi-key	1733583	1	1.95	1.95
2 Position Terminal Block	Phoenix Contact	Digi-key	1733570	2	1.30	2.60
Fuse	Littelfuse Inc.	Digi-key	0877002.MXEP	1	1.46	1.46
TVS Diode	Littelfuse Inc.	Digi-key	SMBJ12A	1	0.55	0.55
Disc Varistors, MOV	EPCOS (TDK)	Digi-key	B72214S351K10 1	1	0.52	0.52
Resistors	Stackpole Electronics	Digi-key	RMCF0805JT10 K0	2	0.10	0.20
6 AA Battery Holder	Memory Protection Devices	Digi-key	SBH361A	1	2.57	2.57
16Mhz Crystal	ECS Inc.	Digi-key	ECS-160-20-1	1	0.60	0.60
Aluminum Electrolytic Capacitor	Panasonic Electronic Components	Digi-key	EEE-1CA471UP	1	0.59	0.59
Various 0805 Package Capacitors	Taigo Yuden	Digi-key	--	5	0.18	0.90
Total						**103.67**

5.2 Labor

Table 2: Labor Cost

Name	**Rate (Per Hour)**	**Overhead**	**Hours (Per Week)**	**Total (16 Weeks)**
Casey Labuda (Electrical Engineer)	$32.00 [15]	*2.5	20	$25,600
Aaron VanDeCasteele (Computer Engineer)	$40.50 [15]	*2.5	20	$32,400
Matthew Nee (Electrical Engineer)	$32.00 [15]	*2.5	20	$25,600

5.3 Total Cost

Table 3: Total Cost

Type	Total
Labor	$83,600.00
Parts	$103.67
Grand Total	$83,703.67

6. Conclusion

6.1 Accomplishments

In the end, The Candle Extinguisher performs as expected. For each candle that was tested, the device successfully extinguished the flame within five minutes. Each requirement was also tested and verified. The device is also able to operate using either wall power or the backup battery voltage. The user is also able to input a time from one minute to four hours. An alarm was implemented as a failsafe both for the lid not closing completely and if the flame is not extinguished due to a problem. However, this should not happen when the device is used correctly.

6.2 Issues

Several issues were encountered throughout the semester. One issue was the ATmega328P-PU. In the initial PCB design, a timing crystal was not implemented on initial PCB design. This caused a new PCB order to be made. This also allowed for improvements to be made to the board and for the size to be cut to a smaller size. Another issue was burning numerous chips. This was due to a flyback voltage from the servo motor. This issue was resolved by using a flyback diode connected to the voltage connections for the servo motor. Random resets of the microcontroller also occurred. To fix this, extra capacitors were placed between the microcontroller's power and ground. Lastly, there was an issue with the backup batteries. The initial plan of four AA batteries did not provide enough voltage due to the dropout voltage of the chosen linear regulator. To fix this, six AA batteries were chosen to output 9 Volts instead of 6 Volts.

6.3 Ethical considerations

Candles should always be attended and have someone present in case of a problem. The Candle Extinguisher will come with warnings to inform the user that they should not leave the candle unattended. However, the user can ignore these warnings and still leave the candle unattended, causing the risk of fire to increase. There is not a solution to prevent the user from leaving the room and leaving the candle unattended. The features built into The Candle Extinguisher will help keep the user safe. The time limit on The Candle Extinguisher ensures that the candle does not burn for time periods greater than four hours. The container surrounding the candle helps mitigate the risk of the flame spreading to a nearby flammable object. There will always be risks and unfortunately cannot account for everything. We believe that the features offered with The Candle Extinguisher provide safety for the user.

Due to the nature of the product, there is the issue of fire and the fire causing damage. The important first step in dealing with this problem is addressed in the IEEE Code of Ethics #1: "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment"[16]. To follow this code, The Candle Extinguisher will need to be made to comply with the rules for health and safety with both the fire and the electronic components. The Candle Extinguisher will also need to provide warnings of the danger of fire provided with the product.

Another issue that arises is the result of an injury occurring. Fire can be dangerous in certain situations if the correct conditions occur, resulting in injury to a person or property. This product could then be used maliciously by someone to cause this event to occur, going against the IEEE Code of Ethics #9 “to avoid injuring others, their property, reputation, or employment by false or malicious action”[16]. While this event could occur, we believe that the probability of The Candle Extinguisher being used maliciously is very low, and that the standard use of this product makes the pros outweigh the cons. The warning of fire and not to misuse the product in combination with fire will be included with the product.

As mentioned before, there are both positive and negative aspects to The Candle Extinguisher. Positive points include the ability to have candles lit for the desired amount of time and for an extra safety of extinguishing a forgotten candle. Negative points include the risk of the fire spreading outside of the candle. This follows #5 in the IEEE Code of Ethics: “to improve the understanding of technology; its appropriate application, and potential consequences”[16]. The goal is to improve the understanding of technology working in combination with candles to provide a safe and enjoyable experience for the user. Potential consequences have been addressed and will be handled accordingly.

The project and design process will address these issues in several ways. The first issue is in the design process. While designing and testing the product, the proper safety was taken in both dealing with the electronics and with fire. The next issue is the product. We address this issue in two ways. The first way is providing warnings to the user through a provided means, such as a pamphlet or on the product itself. The second way is by having different ways of the product addressing the issue of fire. The lid on The Candle Extinguisher rotates and suffocates the flame. The device also has an alarm to warn the user if the fire is still not extinguished. If the power fails, then the backup battery powers the motor to rotate the lid in order to put out the fire. The Candle Extinguisher also prevents the user from burning candles for too long within a time period. The electronic equipment is protected from the fire and heat due to the metal enclosure which prevents them from becoming too hot and failing.

Finally, since the product is using not only electronics, but the candle itself, the product will have to meet all candle safety and regulatory standards. The candle will have to follow ASTM standards for candles, specifically the following few mentioned. Cautionary Labeling Standard (ASTM F-2058) addresses that the product will have to provide a label with the appropriate warnings. Heat Strength of Glass Containers Standard (ASTM F-2179) will address the all specifications pertaining to the container. Finally, Candle Accessories Standard (ASTM F-2601) will address the procedures and practices that must be followed since The Candle Extinguisher is an accessory to the candle [17].

6.4 Future work

The Candle Extinguisher was a success, however we have thoughts of ideas that we can implement to improve The Candle Extinguisher in order to better market the product. The first idea is rechargable batteries. The Candle Extinguisher is designed to be run on wall power for the majority of its life, except during power outages. Rechargeable batteries lower the consumer maintenance on The Candle Extinguisher.

The current design of The Candle Extinguisher is a prototype and can be seen in Appendix E Figure 13. We want to lower the cost and make the product more aesthetically pleasing. We plan to do this by making the design smaller and doing away with the gray metal enclosure. The Candle Extinguisher will look better in the home of the consumer by adding softer colors to our design. We also want to add an adjustable motor height to our design. The adjustable motor height allows the user to use the device on different size jars which helps with the aesthetics of the design.

Another feature that we can add to The Candle Extinguisher is an Android and Iphone app to control the user interface. Many candle consumers have multiple candles throughout their homes, meaning they will need more than one Candle Extinguisher in order to safely monitor their candles. A phone application allows the user to monitor multiple candles. If the user leaves the house and does not remember if they started The Candle Extinguisher, they can monitor the candles and control the device accordingly.

Lastly, a MOSFET was incorporated into our PCB design, but we did not end up using this for our final prototype. This was an idea that was brought up later in the semester, so we did not have enough time to successfully implement this into our design. The purpose of this MOSFET would act as a switch for our servo motor. This was so that 5Volts would not always be fed into the motor and instead just be supplied when the motor is needed.

References

[1] "NFPA - Candle Fire Safety". Nfpa.org. N.p., 2017. Web. 6 Feb. 2017.

[2] "Candle Safety Rules | NCA". National Candle Association. N.p., 2017. Web. 6 Feb. 2017.

[3] Karol, Aaron. "Basic Candle Care". Learning-scenter.yankeecandle.com. N.p., 2017. Web. 6 Feb. 2017.

[4] *11-00022, 1st ed. Bend: Tensility, 2012 [Online]. Available: http://www.tensility.com/pdffiles/11-00022.pdf. [Accessed: 03- May- 2017]*

[5] Zhang, 2nd ed. Qualtek Electronics Corp. PPC DIVISION, 2004 [Online]. Available: http://www.qualtekusa.com/Catalog/AC_Receptacles/pdfs/701wx202.pdf. [Accessed: 03- May- 2017]

[6] CUI Inc., 10-Jun-2015. [Online]. Available: http://www.cui.com/product/resource/vsk-s15-series.pdf. [Accessed: 01-May-2017].

[7] Tower Pro, 10-Dec-2015. [Online]. Available: http://www.datasheetcafe.com/sg-5010-datasheet-servo-motor/. [Accessed: 01-May-2017].

[8] L. Ada, *RGB LCD Shield*, 1st ed. Adafruit Industries, 2015 [Online]. Available: http://www.mouser.com/ds/2/737/rgb-lcd-shield-773073.pdf. [Accessed: 03- May- 2017]

[9] *AT-1224-TWT-5V-2-R*, 1st ed. PUI Audio, Inc., 2014 [Online]. Available: http://www.puiaudio.com/pdf/AT-1224-TWT-5V-2-R.pdf. [Accessed: 03- May- 2017]

[10] Interlink Electronics, [Online]. Available: http://www.interlinkelectronics.com/datasheets/Datasheet_FSR.pdf. [Accessed: 01-May-2017]

[11] Analog Devices, 2015. [Online]. Available: http://www.analog.com/media/en/technical-documentation/data-sheets/TMP35_36_37.pdf. [Accessed: 01-May-2017].

[12] *ATMEL 8-BIT MICROCONTROLLE R WITH 4/8/16/32KBYTES IN-SYSTEM PROGRAMMABLE FLASH DATASHEET*, 1st ed. Atmel, 2015 [Online]. Available: http://www.atmel.com/images/Atmel-8271-8-bit-AVR-Microcontroller-ATmega48A-48PA-88A-88PA-168A-168PA-328-328P_datasheet_Complete.pdf. [Accessed: 03- May- 2017]

[13]"Arduino - Reference", *Arduino.cc*, 2017. [Online]. Available: https://www.arduino.cc/en/reference/HomePage. [Accessed: 03- May- 2017]

[14] VanDeCasteele, Aaron. "Alarm - Youtube". Youtube.com. N.p., 2017. Web. 3 May 2017.

[15] Services, Engineering. "Salary Averages :: ECE ILLINOIS". Ece.illinois.edu. N.p., 2017. Web. 21 Feb. 2017.

[16] "IEEE IEEE Code Of Ethics". Ieee.org. N.p., 2017. Web. 6 Feb. 2017.

[17] "Candle Safety Regulations & Standards | NCA". National Candle Association. N.p., 2017. Web. 6 Feb. 2017.

Appendix A Requirement and Verification Table

All verifications were successfully verified and approved by our TA.

Table 4: Requirements and Verification Table

<u>Points</u>	<u>Requirements</u>	<u>Verifications</u>
	<u>Power</u>	
	I. <u>AC Power Supply</u>	
1	1. Must be able to take in a range of 108V - 122V AC at 58 - 62Hz.	A. Connect positive terminal of the multimeter to positive wire of the AC power cord. B. Connect negative terminal of the multimeter to negative wire of the AC power cord. C. Connect ground terminal to ground wire of the AC power cord if available. D. Measure voltage at load end using voltage multimeter. E. The requirement is verified if the voltage and frequency measurements are found within range.
	II. <u>Backup Battery</u>	
3	1. The battery must be able to power the device for a full four hour cycle.	A. Unplug device from wall power. B. Run device on only battery power for a four hour cycle. C. If the batteries were able to power all the components for four hours and successfully lower the lid, it is verified.
1	2. Battery must be able to withstand heat other components, the candle, and itself.	A. Measure temperature of unit that has been running for at least 15 minutes with candle lit in the area where the candle is to be placed. B. Check datasheet to see if battery can tolerate up to 1.5 times that temperature. C. Test battery's operation using oscilloscope to measure voltage and

		current when part of device. D. The voltage should remain within the voltage range of the battery within ±5% if the battery is new. E. Requirement is verified if battery is able to withstand the heat and power the components within the specifications of the battery.
2	3. The battery must not be a fire hazard.	A. Read datasheet to determine if battery is fine to operate near a source of fire. B. Requirement is verified if the data sheet does not indicate it is a fire hazard.
	III. <u>Converter</u>	
1	1. The converter must be able to withstand heat of other components, the candle, and itself.	A. Measure temperature of unit that has been running for at least 15 minutes with candle lit in the area where the candle is to be placed. B. Check datasheet to see if converter can tolerate up to 1.5 times that temperature. C. Test converter's operation using oscilloscope to measure voltage and current when part of device. D. Voltage and current should be within specifications given on datasheet. E. Also take temperature measurement every minute for 15 minutes to graph to see how converter changes with heat. Measure at different times of operation, both start-up and after running for time greater than 30 minutes. F. Requirement is verified if the converter is able to operate in heat conditions and still meet specifications on datasheet.
1	1. The converter must be able to convert the AC power from the	A. Connect converter to AC power source B. Connect output to multimeter and

	wall outlet to 9V±5% DC power to be used by the motor, sensors, and microcontroller. The current should be less than 2.0±5%Amps.	measure for voltage. C. Check to see if voltage outputs are within range of given voltages in requirements. D. Measure output current using a controlled DC load and confirm it is limited to less than 2.0 Amps. The voltage will also be monitored to ensure that a voltage drop does not occur under full load.
	Body	
	I. Servo	
5	1. Must be able to output at least 0.048 Nm to move the lid into either positions.	A. Research using datasheet to see if motor can supply the output force. B. Connect the motor to the apparatus that moves the lid. C. Have the motor attempt to turn the lid 90 degrees. A marking will be made on the lid to be used as a reference when measuring the degrees of rotation. D. Requirement is verified if the motor is able to turn the lid 90 degrees ±5%.
2	2. Must be able to operate using six 1.5V AA batteries.	A. Connect backup batteries to motor power terminals. B. Make sure AC power is disconnected. C. Requirement is verified if servo is able to raise and lower the lid into position.
1	3. Must be able to operate using 5V±5% from linear regulator.	A. Connect converter output to motor power terminals. B. Make sure batteries are disconnected. C. Requirement is verified if servo is able to raise and lower the lid into position.
	II. Lid	
2	1. Must be able to rotate 90°±5%.	A. Check to see if lid can rotate 90° without hitting the jar when it is rotated.

		B. Have it start in an upright position. C. Have it end with the lid on top of the jar completely covering the opening. D. Requirement is verified if the lid is rotated 90 degrees ±5%
5	2. Must create a good enough seal with the jar to extinguish the candle within five minutes.	A. Light candle in jar. B. Put lid on top of the jar. C. Set timer to see if candle extinguishes within five minutes. D. Requirement is verified if candle extinguishes within five minutes.
	<u>Input / Output</u>	
	I. **<u>User Interface</u>**	
1	1. Ability to turn on and off backlight.	A. Turn off all lights so the test is completed in the dark. B. First have screen backlight on using test program from microcontroller. C. Determine if the screen can be seen in the dark when it is lit. D. Then use the assigned button to turn backlight off using a test program from microcontroller. E. Determine if the screen cannot be seen in the dark when backlight is off. F. Requirement is verified if the screen can be seen in the dark when the backlight is on, and cannot be seen in the dark when backlight is off.
4	2. Ability to increase time on alarm for up to four hours.	A. Program microcontroller to keep track of time. B. Use assigned up and down buttons to input up to four hours. C. See if time entered displays up to four hours on the screen by it showing 4:00. D. Then, set the time for 10 minutes. E. Set a different timer using a stopwatch for 10 minutes. F. Observe if timer completes around same time as the stopwatch within ±5%. G. Requirement is verified if the steps

		listed above are met.
1	3. Constantly display the time remaining on the display.	A. Program microcontroller to keep track of time. B. Verify that time display on LCD screen agrees with time that is being tracked by the microcontroller.
	II. <u>Alarm</u>	
1	1. Audio buzzer must emit a sound that can be heard twenty meters away.	A. Measure twenty meters away from audio buzzer with the audio buzzer facing the other direction. B. Have someone activate the audio buzzer. C. See if the audio buzzer can still be heard.
1	2. Screen flashes on and off with a period no greater than 2 seconds when the alarm goes off.	A. Perform test in a room that has natural lighting. B. Perform test about 2 feet away. C. Program microcontroller so that when alarm goes off, the screen flashes. D. Have the alarm go off when time expires. E. Have screen flash in response. F. See if the screen brightness adjustment can be seen from at least 20 feet away. G. Measure the time it takes for the screen to be on, then off, then on again. H. Requirement is verified if the screen is able to complete the period time given in the requirement.
2	3. Alarm will always sound if it is triggered by the microcontroller.	A. Have microcontroller send signal to alarm to have it emit a noise. B. See if alarm actually makes noise C. Test 25 times total. D. Check that alarm passes all 25 times. E. Requirement is verified if alarm passes all 25 times.
	<u>Sensors</u>	

	I. Lid Position Sensor	
2	1. Must detect a force of at least 0.2N.	A. Have the lid in complete open position, make sure sensor is not triggered. B. Have the lid rotate to the closed position. While it is in the process of closing, make sure the sensor is not triggered. C. When the lid reaches the closed position, make sure it activates the sensor to send the signal that it is now closed. D. Make sure the lid does not continue past the closed position after the sensor is activated.
	II. Temperature Sensor	
2	1. Detect the difference between when a candle is lit and when there is no lit candle.	A. Place a lit candle in front of the sensor at the distance the sensor will be from the candle in the product. Record data sent from sensor. B. Place a candle that has not been lit for at least a day in front of the sensor at the distance the sensor will be from the candle in the product. Record data sent from sensor. C. Place a recently lit candle that is then extinguished in front of the sensor at the distance the sensor will be from the candle in the product. Record data sent from sensor. D. Compare results to confirm is sensor is able to measure a difference of at least 30 degrees between the different states of the candle.
1	2. Sensor must be able to read temperatures from 0° to at least 250°F	A. Confirm using datasheet if sensor is able to read within range. B. Requirement is verified if sensor is able to operate in the temperature range according to the datasheet.
1	3. Sensor needs to be able to read	A. Look at temperature results from different distances within the required

	temperatures from 1 inch to 6 inches away from the flame.	range. B. Requirement is verified if the temperature is read by the sensor and the information from the sensor is sent to the microcontroller and the data agrees.
	<u>Microcontroller</u>	
1	1. Needs to operate on 5V±5%.	A. Supply the microcontroller 5V±5% and try to run a program. Then use a multimeter to determine the input voltage to the microcontroller B. Check datasheet C. Requirement is verified if the microcontroller is able to complete a program using the power given.
4	2. Needs to turn on and communicate with the temperature sensor 5 minutes ±5% after the candle has been extinguished.	A. Have microcontroller receive readings five minutes after candle is supposed extinguished from temperature sensor. B. Use that data to determine if the candle has been extinguished by sensing a change in the temperature data.
5	3. Needs to turn alarm on within five minutes ±5% if temperature sensor detects a flame.	A. Remove the lid from the top of the jar and the servo motor. B. Produce a test that has candle still burning even though the position of the lid is read as closed by the microcontroller. Lid will be removed from the servo to ensure this. C. Have temperature sensor send data that shows candle is still burning after five minutes. D. Have microcontroller send signal to alarm as a result to warn user that candle is still burning. E. Make sure alarm is audible and continues until the sensor sends data to suggest flame has been extinguished. F. Requirement is verified if the alarm goes off in the given time range for a candle that is still burning.

Appendix B Software Design

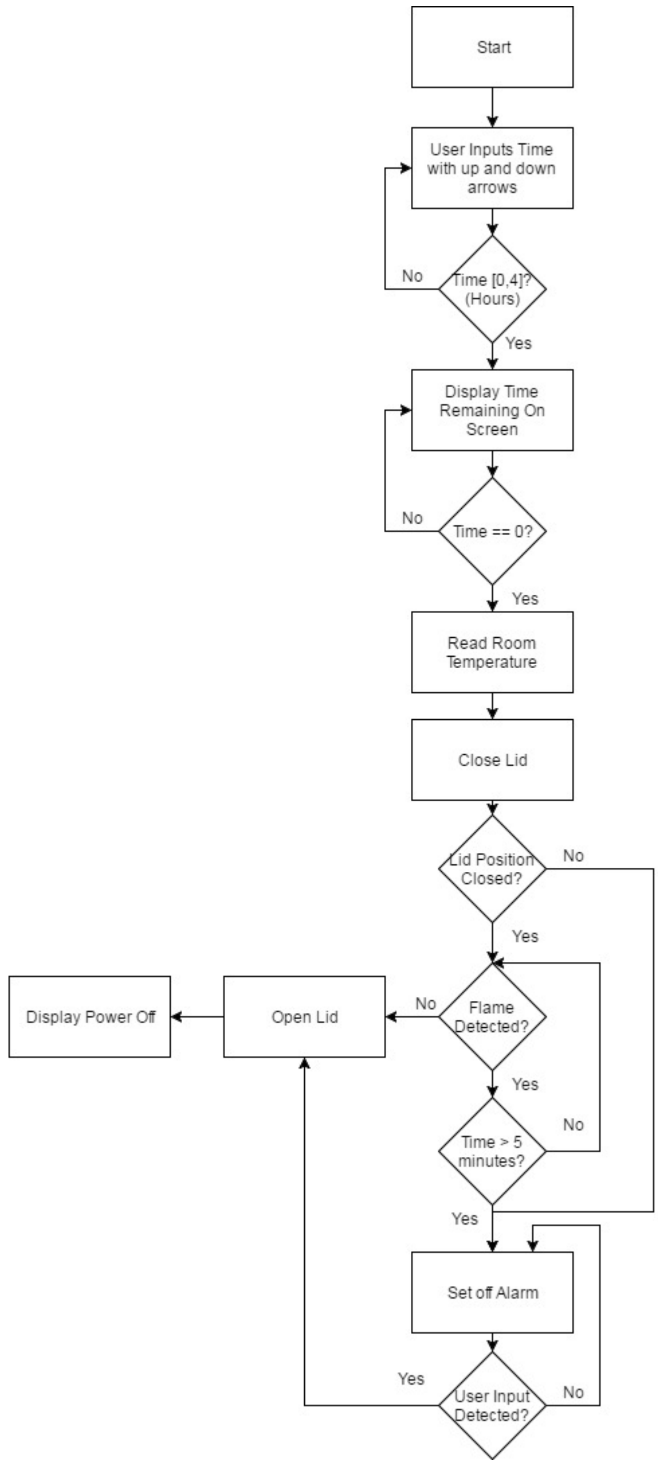

Figure 3. Software Flow Chart

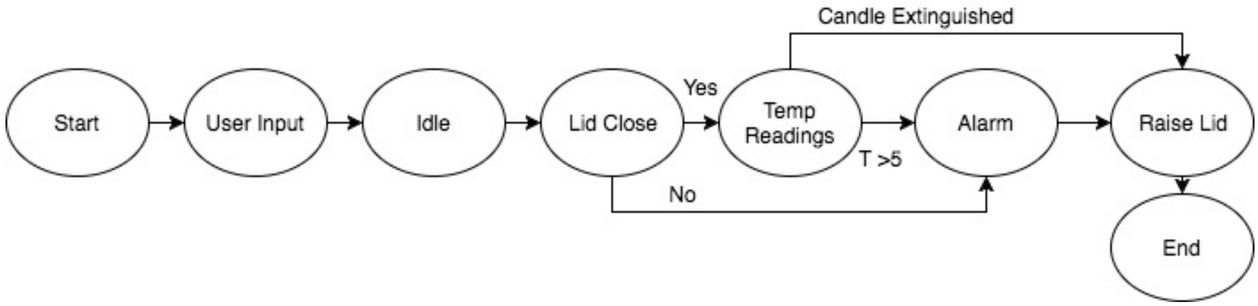

Figure 4. Software State Diagram

Appendix C Circuit Schematics

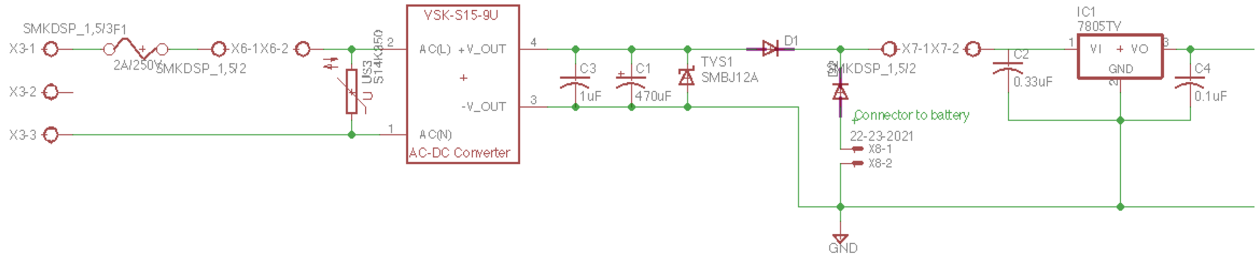

Figure 5. Circuit schematic of our power circuit.

Starting from the left in Figure 5, the input 120V AC voltage enters our three pin high voltage connector. Power is then fed through a 2A fuse which then continues to another high voltage connector. At this connector, wires lead to the connectors of our master switch. This is to ensure that no voltage is running through the power circuit when the device is off. After the switch, the circuit continues through our MOV (Metal Oxide Varistor) and then the AC/DC converter. After the converter, the 9V gets filtered through two capacitors. The last component in parallel with these two capacitors is a TVS diode. This diode shunts voltage spikes from occurring. After this diode, there is a pair of diodes. These are used so that only wall power or only battery power is used. When wall power is available the diode blocks the voltage from the batteries so that they are not constantly drawing power. After the diodes is the last connector. This connector has the same use as the previous, it connects to our main switch button. Lastly, the circuit concludes with the 5V linear regulator and its filtering capacitors. This circuit connects to Figure 6.

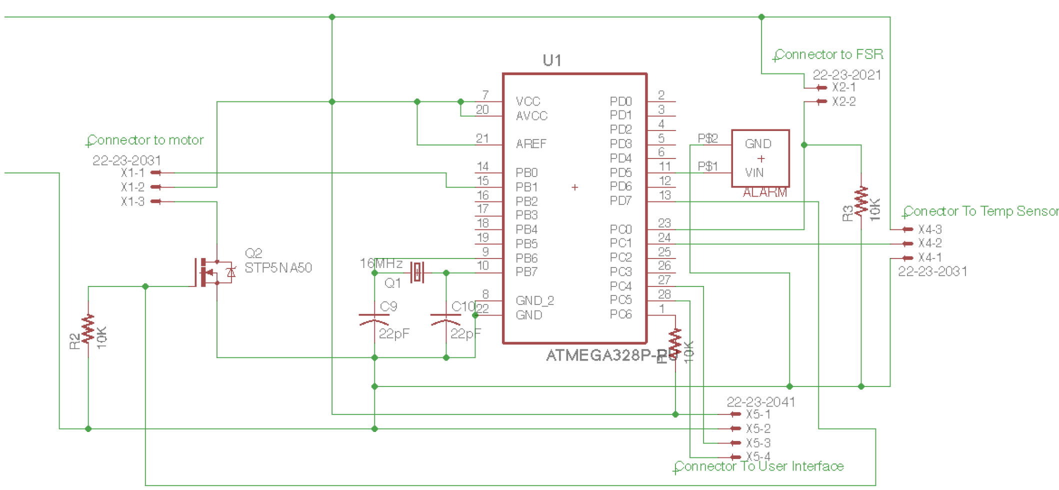

Figure 6. Circuit schematic of our control system.

The microcontroller is seen as U1. This connects to each of our components through wire to board connectors. It should be noted that the MOSFET was not implemented in our final prototype.

Appendix D Verification Figures

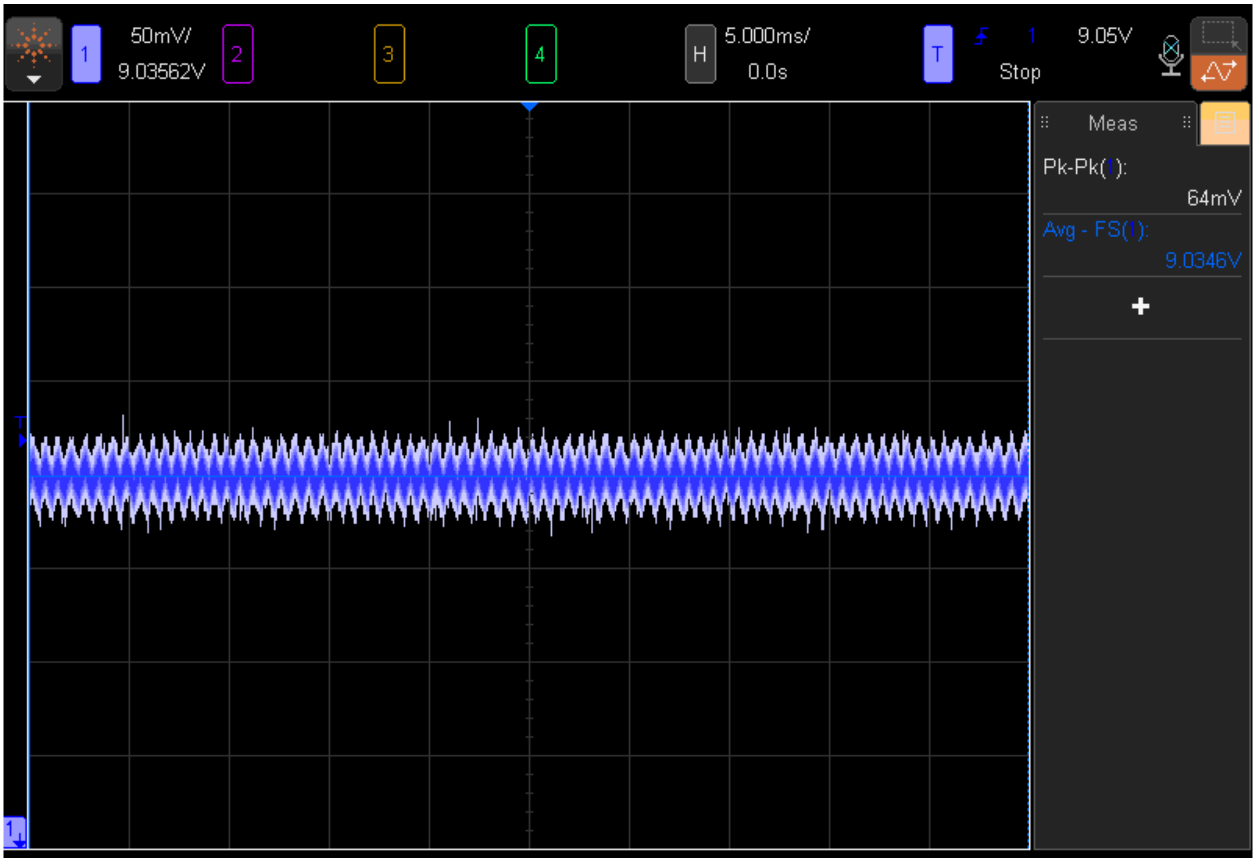

Figure 7. Converter Output Voltage

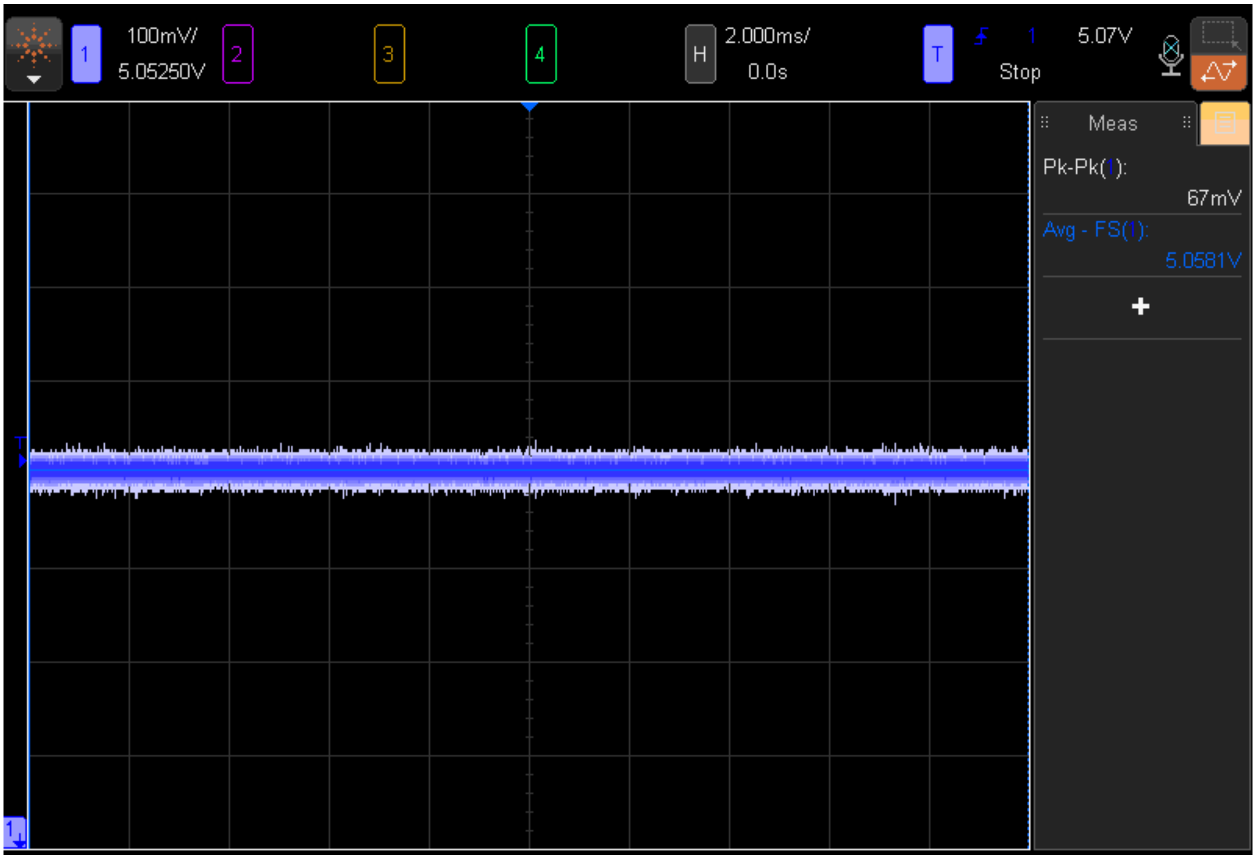

Figure 8. Linear Regulator Voltage Output

Figure 9. User Interface Backlight Off

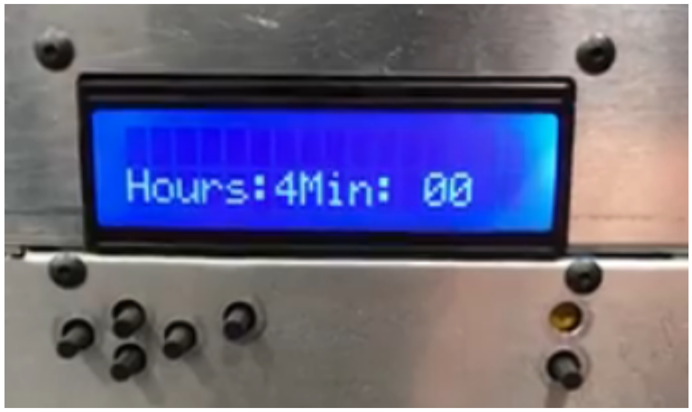

Figure 10. User Interface Backlight On and Time Remaining

Figure 11. Maximum Temperature Reading

The temperature reading of 242°F can be seen twice in this picture. The first reading is the most recent temperature reading whereas the following reading is the maximum temperature that has been read. The number below states the time that has elapsed after the lid has been lowered. In this case zero minutes has passed.

Appendix E Physical Layout

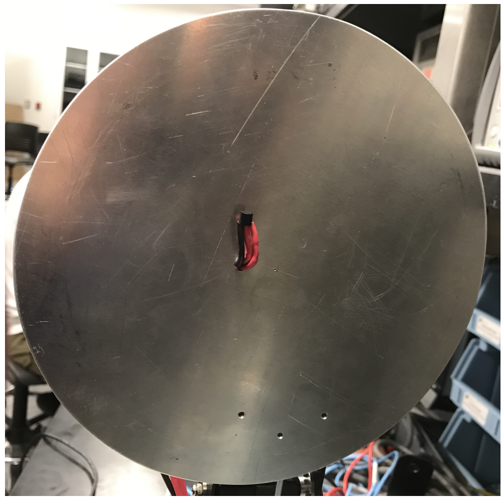

Figure 12. Physical layout of the lid.

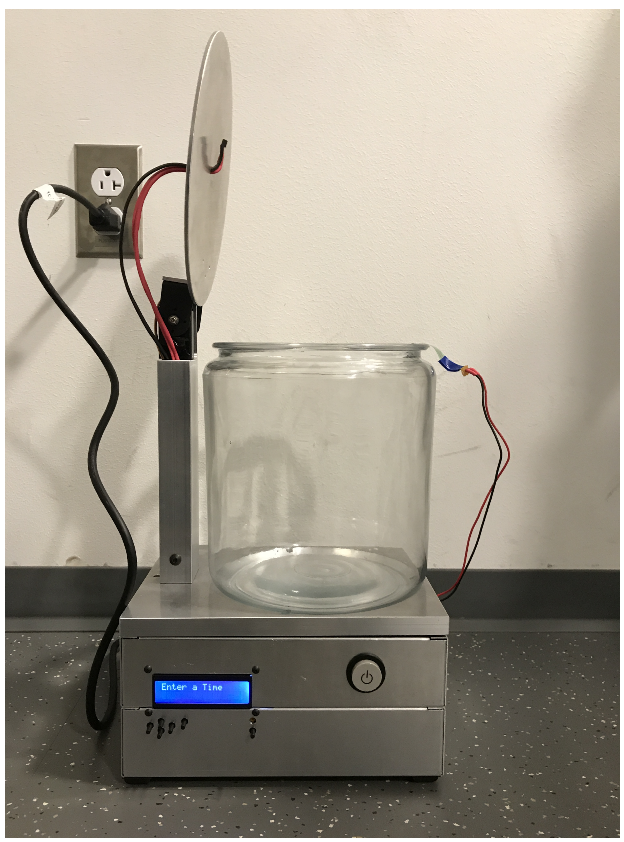

Figure 13. Front View of Candle Extinguisher

Appendix F Acknowledgements

We would like to thank all of the TA's that gave us recommendations and advice.

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