SMART MEAT DEFROSTER

Design Document

Team 49: Ben Civjan (bcivjan2), Brad Palagi (bpalagi2), Payton Thompson (pthomp22)

TA: Prannoy Kathiresan

Spring 2023

Table of Contents

1 Introduction

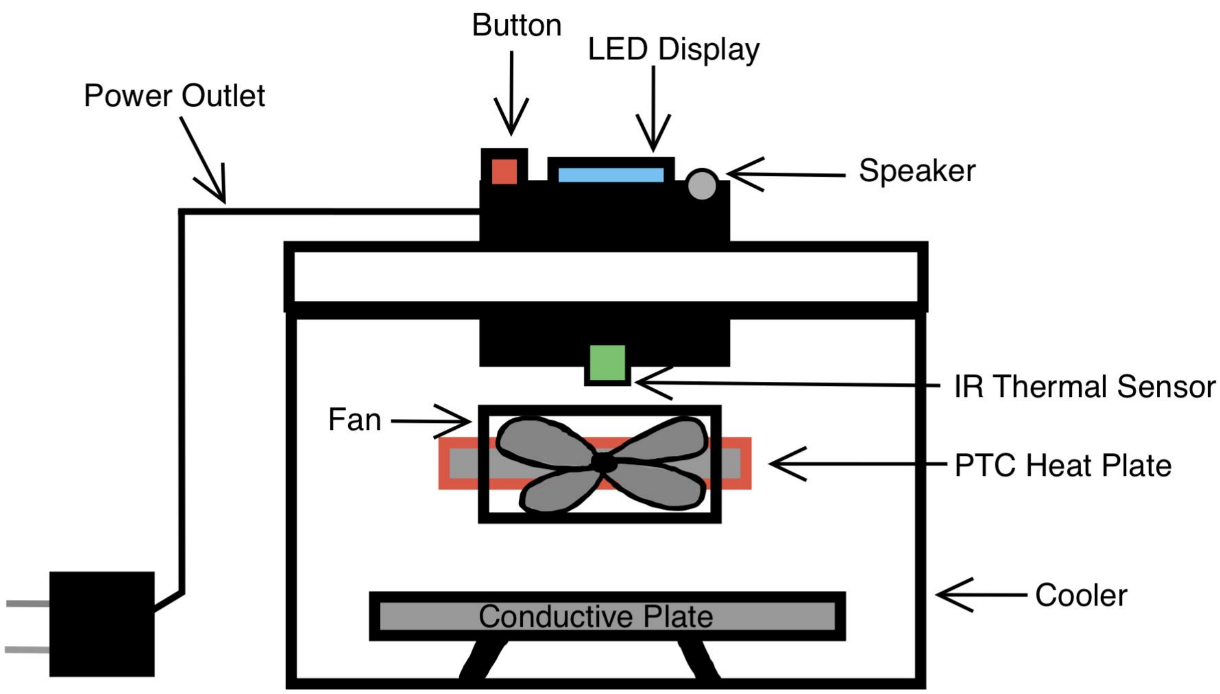
1.1 Problem

Defrosting frozen meat is a very tedious process. There are a few thawing techniques commonly used, each with its own issues. First, one can leave their frozen meat in the fridge to thaw. Although this takes around two days so if one is not prepared in advance their food will remain frozen. Next, you could try heating frozen meat in the microwave. This results in extremely uneven heating where some parts of the meat begin cooking while other parts remain frozen. Simply leaving meat out on the counter is quite slow but also unsafe and can allow for potentially rapid bacterial growth. Additionally, one can run water over the meat to help defrost, but it is a hands-on, tedious process that still takes extensive time to fully defrost. Lastly, one can leave the meat on a defroster plate [1,2], but the length of time varies with the quality of the plate and still takes a significant amount of time and interaction. Ultimately, there are no solutions to evenly thaw frozen meat when trying to make a meal without planning to defrost well in advance.

1.2 Solution

We propose a meat defrosting container that will defrost a frozen chicken breast both quickly and evenly. Using an insulated container with a heating element to warm the air we will use heat conduction to thaw the meat efficiently without cooking it. This device will be extremely easy to use and provide a hands-off experience between placing the meat inside the container and removing it once it has thawed. Our insulated container will be food safe and use a heating element above the meat, and a conductive defrosting plate beneath the meat. This will allow the water frozen in the meat to melt and run off the sides of the plate. The top of the container will feature our electronics, where a PCB with a microcontroller will use temperature data from a thermal sensor to control the heating element. The meat's current temperature will be shown on an LED display on the container, and a sound will alarm when the meat has completed defrosting to alert the user. This will allow for an efficient and versatile hands-off method for people to defrost their meat.

1.3 Visual Aid



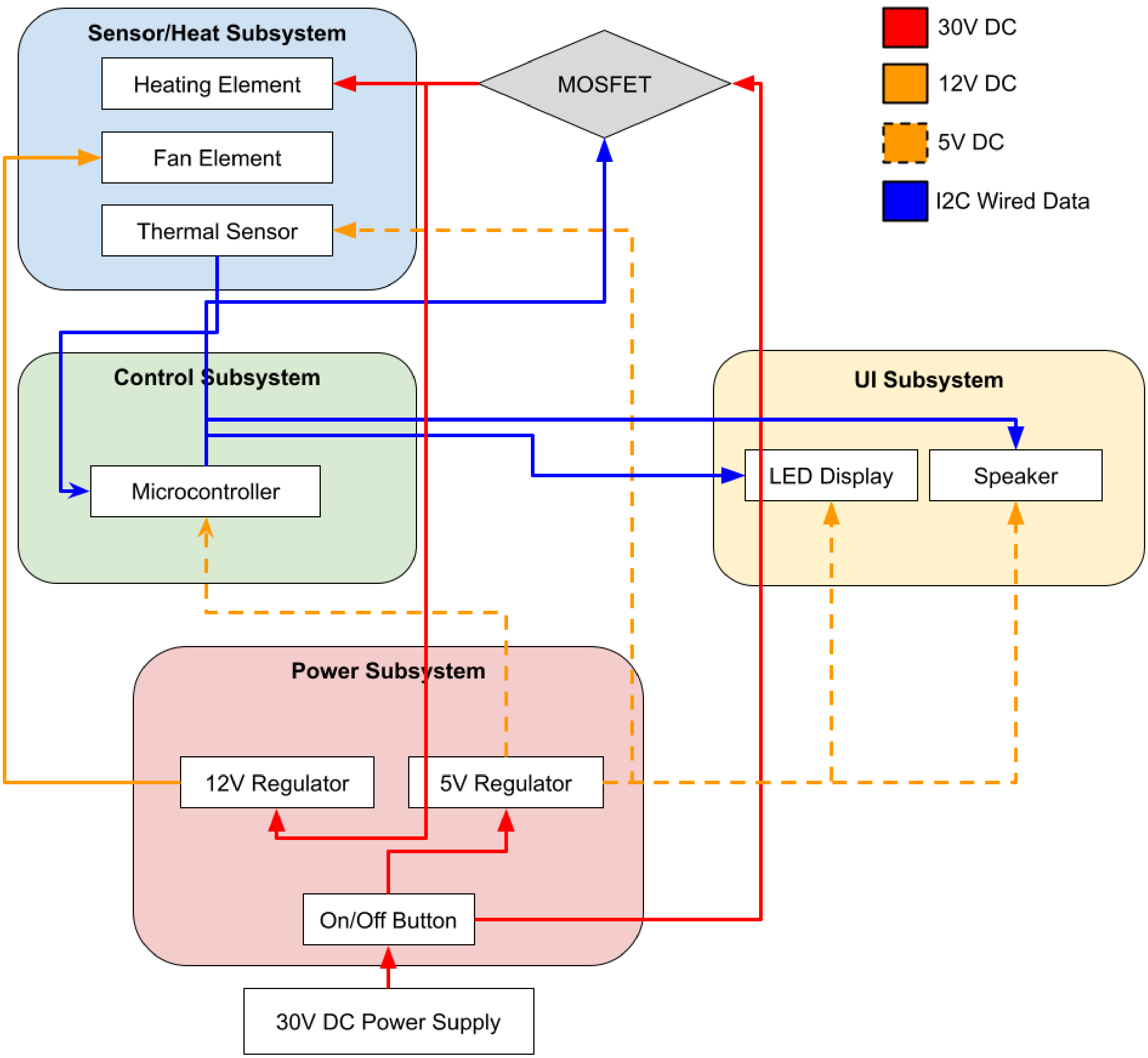
Side View

1.4 High-level Requirements

- The device will power a heating element and display the current temperature until the frozen meat has reached an internal temperature of 2°C with an accuracy of +/- 2°C, then it will cut power from the heater and sound an alarm for the user.
- A frozen chicken breast will thaw faster in our defrosting container than standard techniques, such as placing the meat in water or on a defrosting plate. We expect this time to be at least 20% shorter.
- Defrosted meat will be evenly defrosted, with less than 10% of the meat being frozen or cooked.
- The device is easily washable and reusable without damaging the electronics or heating system.

2 Design

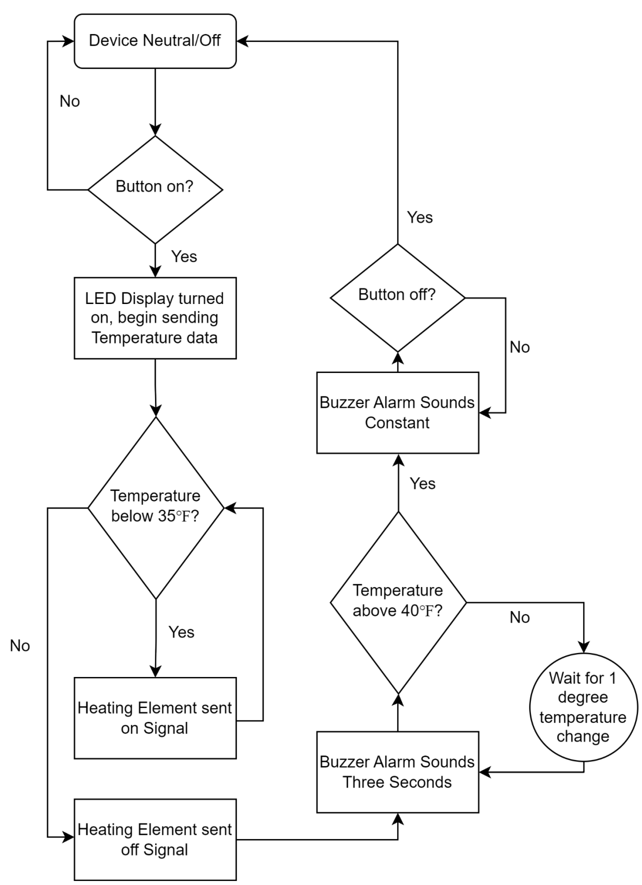
2.1 Block Diagram



2.2 Control Subsystem

The Control Subsystem is responsible for receiving temperature data from the thermal sensor, and controlling the heat and UI subsystems. The microcontroller will send the current temperature from the thermal sensor to be shown on the LED display, and will also control the heating element and speaker according to the thermal data.

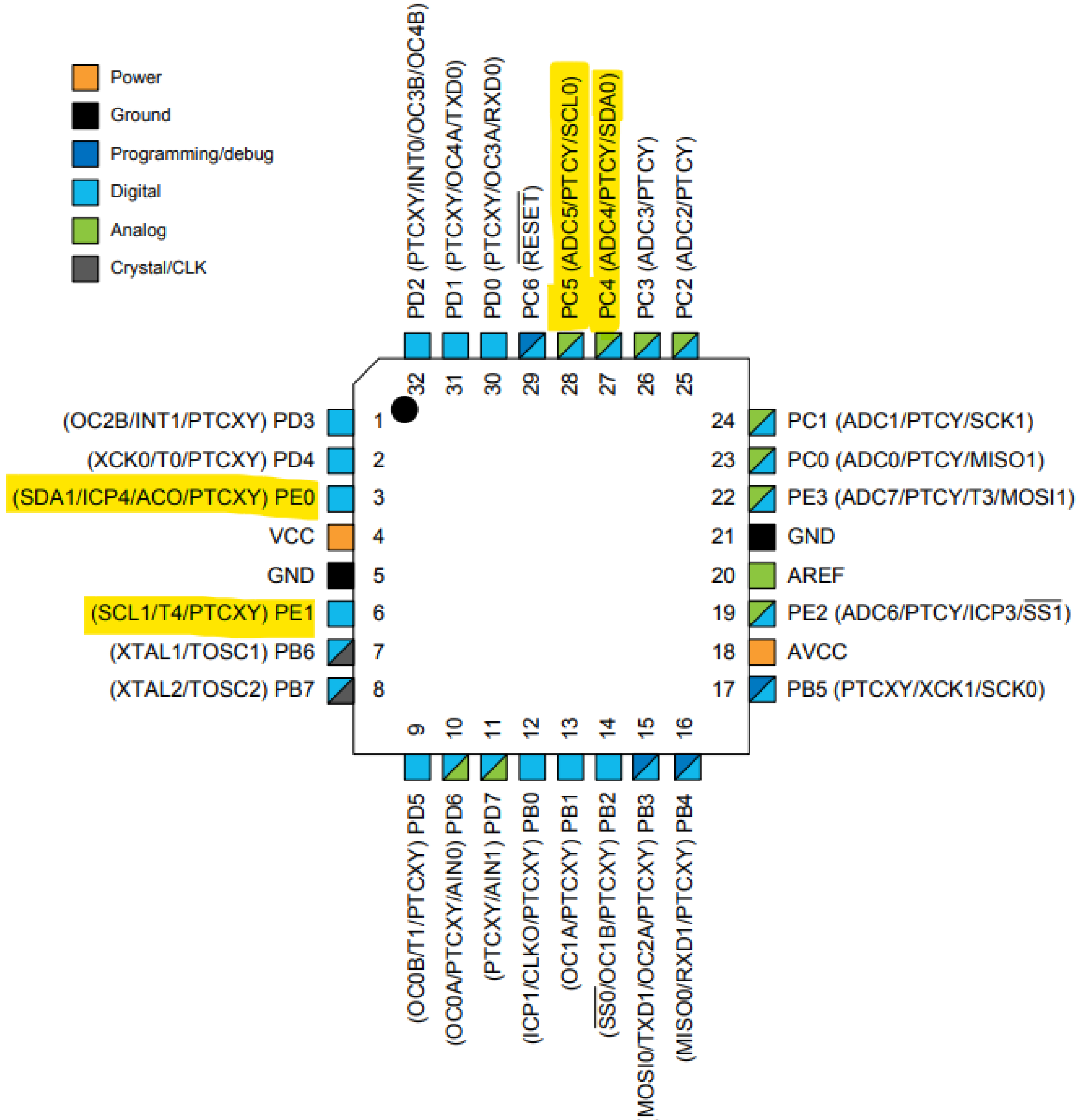
This module will use the ATMEGA328PB microcontroller. This microcontroller can be operated between 1.5V and 5.5V at varying processing speeds. We will operate the microcontroller at 5V, this will allow it to perform at its highest rated speed 20 MHz as well as be powered with the same voltage level as the thermal sensor. The data input will be I2C data, corresponding to the data type from the thermal sensor as well as the data output to the LED display. We will also have the microcontroller output on/off signals for the heating element and speaker.



This flowchart shows what we will program the microcontroller to perform. The input is the temperature data and the output is the control signals for the heating element and speaker as well as the temperature to be shown on the display.

Pin Configurations

Figure 5-1. 32 TQFP Pinout ATmega328PB



This is the Pin Configuration for the ATmega328PB, highlighted are the ports for I2C communication. One will be used to receive the thermal sensor data, and one to send the temperature to the display.

Requirements	Verification
Pass temperature data from the microcontroller to the LED Display	- Press the on button for the device and ensure the LED display receives power - Ensure the user can view the meats current temperature on the seven segment display
Microcontroller disables the heating element once the meat temperature reaches 1.66°C	- Enable the heating element and wait for the thermal sensor to detect a temperature of 1.66°C Ensure the heating element is no longer receiving a voltage
Microcontroller sounds a defrost completion alarm	- Run the device until temperature reaches 1.66°C - Ensure a sound tone is heard for three seconds - As the meat continues to raise in temperature the sound should play again for every degree increase - If the meat reaches 4.44°C then ensure the sound remains constant until the button is pressed off

Once the meat has reached a temperature of 4.44°C the sound will remain constant until the user presses the button turning the device off because at 4.44°C bacteria that was on the food before it was frozen will begin multiplying.

2.3 Sensor Subsystem

Our sensor/heat subsystem will consist of an infrared thermal sensor that will track the external temperature of the meat as it's defrosting and a heating element to speed up the defrosting process of the meat. The thermal sensor will need to take input and relay it to the microcontroller. The heating element will receive voltage from the power subsystem. The voltage will be selected by an AND circuit based on a *HEAT_ON* output signal from the microcontroller. The *HEAT_ON* signal will start at 1 and turn to 0 once the thermal sensor reads a temperature that suggests the meat has reached an internal temperature of 1°C. The thermal sensor will be placed on the roof of the container, away from the heating elements, in order to record as accurate of a measurement as possible. The sensor will communicate with the microcontroller through an I2C bus.

2.3.1 Infrared Thermal Sensor (Omron D6T-1A-02)

Input: 5 VDC$\pm$0.5V from 5V Linear Regulator

Output: I2C synchronous data stream to microcontroller

The Omron D6T-1A-02 infrared thermal sensor measures the surface temperature of the meat. This is used to track the defrosting process and supply the microcontroller with the data needed to adjust the other subsystems.

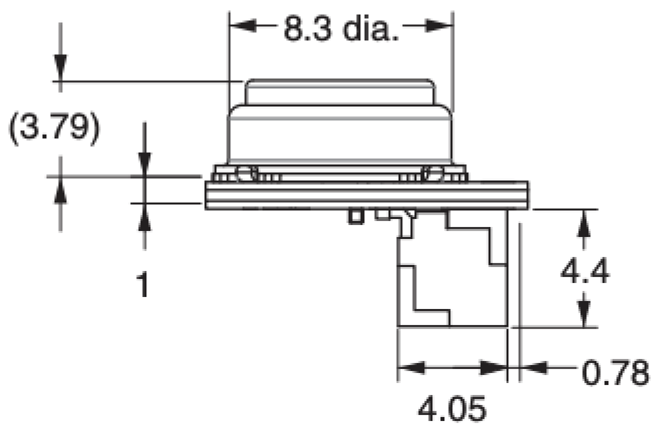
It will receive a steady source of power from the wall outlet, stepped down by a voltage regulator to the necessary 5 volts (it usually operates at 3.5 mA). The thermal sensor has a minimum operating temperature of -40 C and a maximum operating temperature of +80 C [9]. Since the defroster is designed to sit at room temperature we can provide a reasonable guarantee that the sensor will never go below its minimum operating temperature. Additionally, we turn off the heating coils once the meat reaches a temperature of 1°C and will keep the temperature of the air in the device below 70 C to avoid cooking the meat. This will ensure that the sensor doesn't reach a temperature above its maximum operating temp.

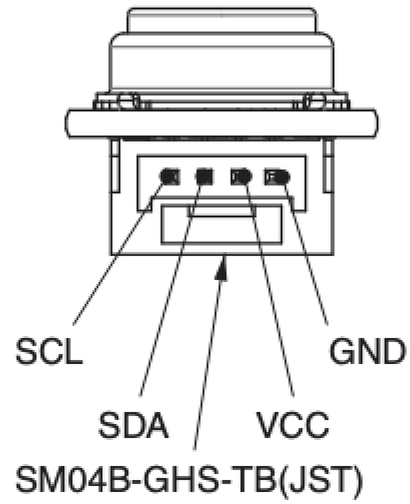
For I2C data transfer to the microcontroller, we will be using the *653-D6T-HARNESS-02*, as recommended in the Omron D6T datasheet. This is compatible with the sensor and connects to any standard I2C port.

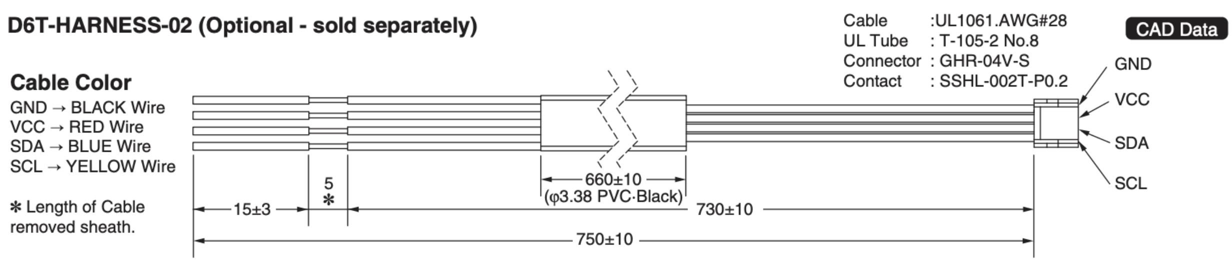
Requirements:

Requirement	Verification
Calculate the internal temperature with an accuracy of $\pm$2 C.	Run calibration trials with various meat. At intermittent intervals, take out the meat to perform a heat check with a thermometer. Compare this to what we expect the internal temperature to be based on our thermal reading and calculation.
Maintain an internal air temperature between -40 C and +80 C.	During internal temperature tests (as described above), take readings of the air temperature to ensure that it has not gone

	outside of the acceptable range.
Ensure voltage does not fluctuate more than the allowed 0.5 V.	Hook up an oscilloscope to the output of the Linear Voltage Regulator (input of the thermal sensor) during trial runs to track input voltage.







2.4 Heat Subsystem

2.4.1 Heating Element (DBK HP03-1/08-24)

Input: 30VDC from the Wall Mount Power Supply

Output: 30W

2.4.2 Fan (OD4010-12HSS)

Input: 12VDC from 12V Linear Regulator
Output: 1.2W, 6.7CFM

The DBK HP03-1/08-24 PTC Heat Plate and OD4010-12HSS Fan is controlled by the microcontroller to consistently blow hot air to create a 38°C air temperature within the cooler. The microcontroller will also turn off the heating subsystem once the internal temperature reaches above 0°C via a MOSFET connected to the heat plate and fan. We referenced one project found online [9] and a heating container through convection equations to come to a conclusion of a heat plate that outputs 30W of power that will result in the container temperature being around 38°C. The project was an incubator, a 220V,60W PTC Heat Plate and 12V,2W Fan is used. It was mentioned that in order to reach a temperature of 38°C within a 2’ x 2’ x 2’ box two 60W PTC Heat Plates would be needed. Based on our cooler being around 4 times smaller in volume, 18”x12.02”x15.28”, a 30V,30W PTC Heat Plate would be sufficient. Also, we found that PTC Heaters are self-regulating. Also, we used an equation that calculates the heat energy required to heat a container through convection. This equation is shown below.

Convection Heating equation: $Q = V * p * c * \Delta T$

Q: heat energy required (J)

V: volume space (m^3) = 0.2755 m^3

cooler’s interior dimensions: .2286m x .38735m x .31115m (L x W x H)

p: density of air (kg/m^3) = 1.204 kg/m^3

c: specific heat capacity of air (J/kg/C) = 1870 J/kg/°C

ΔT: difference in temperature between inside and outside of cooler (C) = 37.78 °C

inside temperature = 37.78 °C (100 °F)

outside temperature = 20 °C (68 °F)

$Q = 0.2755 * 1.204 * 1870 * 37.78 = 1102.86$ J

Take around 30 sec to heat up: $1102.86 / 30 \approx 30$W

Another way of decreasing the defrost time is by the meat sitting on a conductive plate. The plate conducts the air temperature onto the meat, and the meat temperature migrates into the plate lowering its overall temperature similar to current defrost plates on the market. Conduction will be our main source of defrosting, so the fan will run at a low speed. Currently, defrosting plates take approximately 40 min to dethaw a chicken breast at room temperature. With the combination of the container being above room temperature and the conductive plate will result in a decrease in defrost time compared to other defrosting methods.

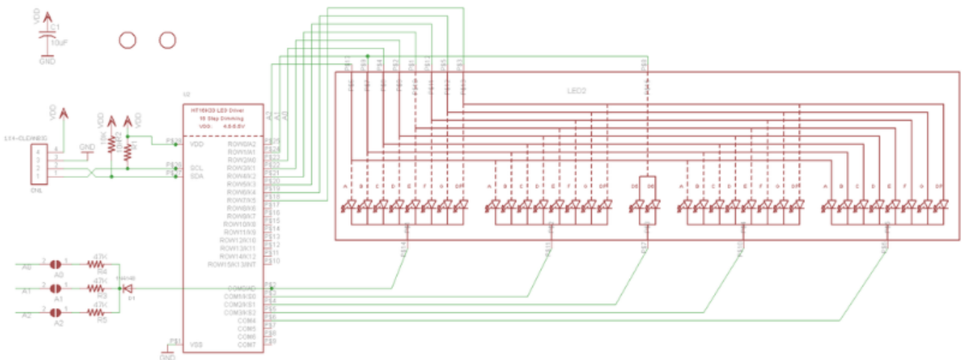
Requirements:

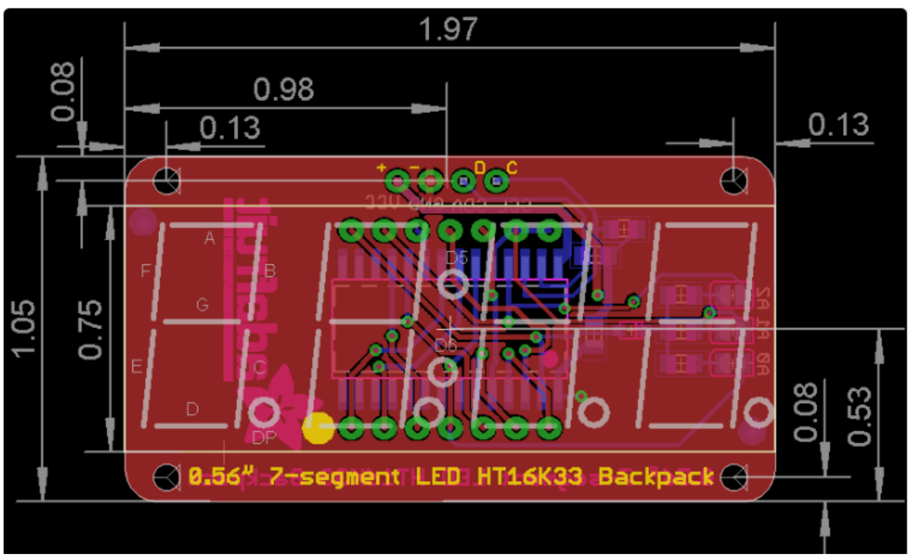
Requirement	Verification
Container air temperature consistently at 37.78 $\pm$2°C	Periodically check the temperature of a thermometer inside the container
Container air temperature takes less than 15min to reach 37.78°C	Measure the length of time it takes for a thermometer inside the container to reach 37.78°C

2.5 User Interface Subsystem

The Adafruit 4-Digit, 7-Segment Display with I2C Backpack will be used for our User Interface Subsystem. This will conveniently display the meat's current temperature for the user to get an idea of how far along the defrosting process is at any time. This product will work well with our microcontroller as it can be controlled through the I2C communication protocol and be powered with 5V DC.

Quad 0.56" 7-Segment Original





This schematic shows how the backpack allows us to use I2C data transmission to have easier control over the seven-segment displays, as opposed to us manually controlling each individual LED.

Also in the User Interface subsystem will be our audible defrosting complete alarm. We will use a Piezo buzzer to make noise once our meat has fully thawed and will continue to buzz until the device is turned off as explained in the microcontroller section. The TDK PS1440P02BT has a listed operating voltage as 3V but maximum supply voltage of 30V so we should be able to use 5V to power this device or use an output from the microcontroller. The audio will beep once the meat’s internal temperature reaches 1°C to notify the user the meat is defrosted. If the meat is kept in the container after defrosting, then the audio will continue to beep as the internal temperature approaches the bacteria-growing temperature of 5°C.

Requirements	Verification
LED Display Shows Current Temperature	- Link the I2C output of the microcontroller to the quad seven segment display - Ensure the display shows the current meat temperature throughout the thawing process
Buzzer Plays Audible Tone at defrosting completion	- Verify that the buzzer can be controlled by the microcontroller - Ensure the buzzer sounds once the temperature has reached 35 degrees, and resounds for every degree increment until 40 degrees where the buzz stays constant

2.6 Power Subsystem

The power subsystem will be button controlled and in charge of supplying all power that is required by the defroster. It will also provide a stable voltage as required by each component. The voltage will be supplied to the display subsystem, control subsystem, sensor subsystem, and heat subsystem. Both the control subsystem and sensor subsystem require the same voltage level and tolerance (4.5V - 5.5V) so they will share the same linear voltage regulator. The other components each will require their own respective voltage source.

Requirement	Verification
Maintain an output voltage between 4.5 and 5.5 V (for microcontroller and thermal sensor)	Connect the oscilloscope to the output of this element during trial runs and verify that the voltage stays consistent
Provide an output voltage of 12 V to the fan	Connect the oscilloscope to the output of this element during trial runs and verify that the voltage stays consistent
Stop supplying power to the heating plate once the *HEAT_ON* signal has been set to 0	Record the point in time that this signal is sent to the voltage switch circuit, and verify via oscilloscopes that the voltage of reaching the heater
All power controllable with On/Off button	Measure the power at all components when the device is plugged in but switched off. Verify that

	this is 0V. When the device is switched on, probe all components and check against expected results.

2.6.1 30 VDC Wall Mount Power Supply (PERFEIDY 30V 1A 0.5A Charger) [12]

The 30VDC Wall Mount Power Supply will connect directly into the wall outlet. The power from this will be wired to the necessary voltage regulators as well as the heating element. The heating element requires a much higher voltage than the rest of the components and is self-regulating, meaning it does not need to be moderated by a regulator. Therefore the power used by the heating element will come directly from this component.

2.6.2 5V Voltage Regulator (LM7805)

Input: 30VDC from the Wall Mount Power Supply

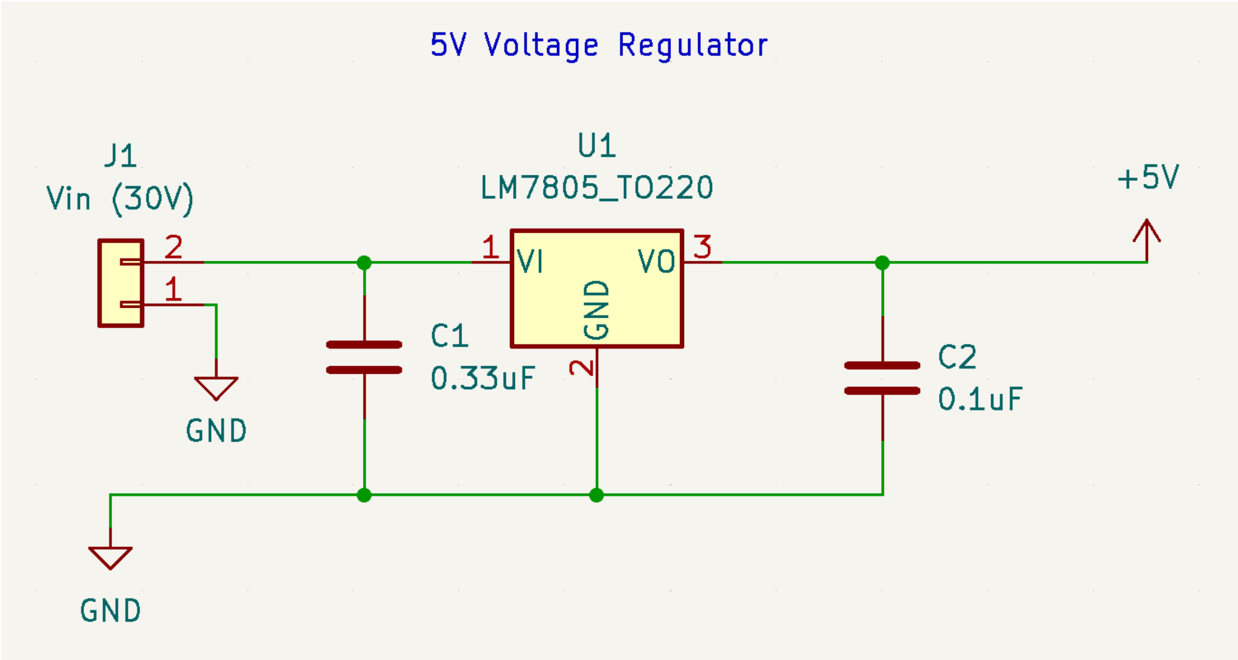
Output: 5VDC (rated at $\pm$0.2 V)

The LM7805 voltage regulator will take an input of 30VDC and regulate/step down to 5 VDC. The thermal sensor operates at 3.5 mA and the microcontroller operates at 0.5 mA. This will cause the LM7805 to dissipate…

$$Power\ Dissipation\ =\ (V_{in} - V_{out}) * I_{out}$$

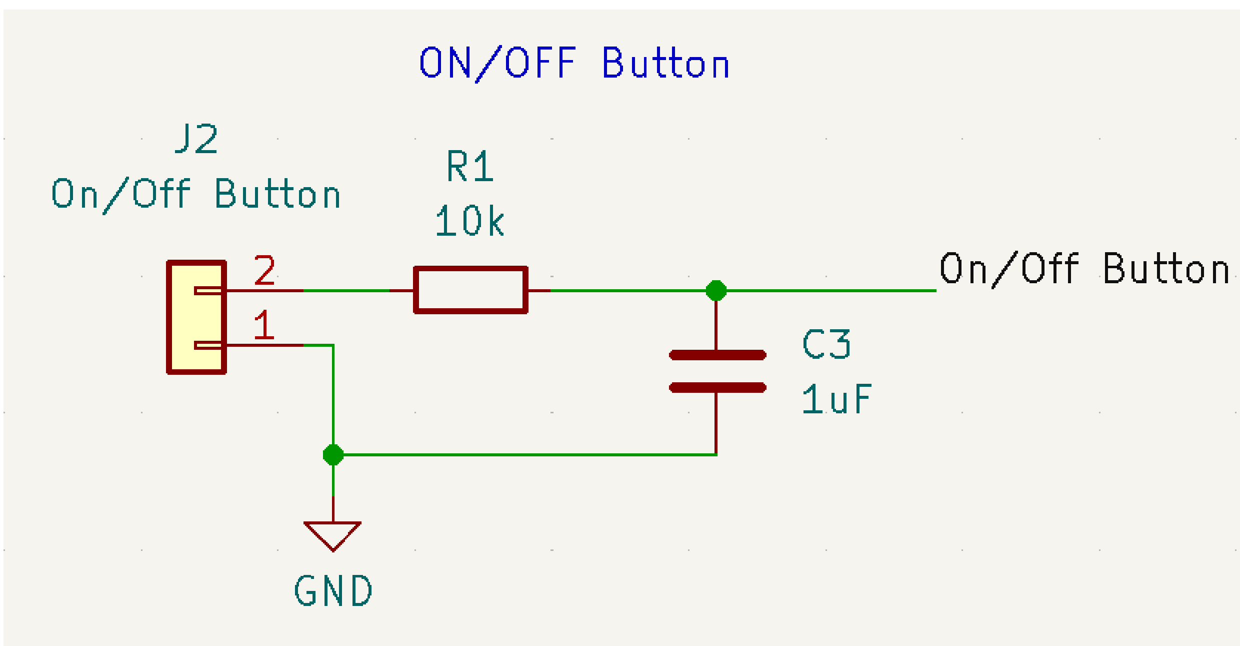
$$(30\,VDC\ -\ 5VDC)\ *\ (3.5mA\ +\ 0.5mA)\ =\ 0.1W$$

Since the LM7805 has a maximum power rating of 2.2W, we can safely use this without a heat sink.



2.6.3 On/Off Button

The ON/OFF button, when pressed, should provide a debounced high voltage signal to the Power Supply. This signal will control whether the voltage is supplied to the rest of the subsystems by sitting between the power supply and the rest of the circuit.



2.6.4 12V Switching Converter (R-78C12-1.0)

Input: 30VDC from the Wall Mount Power Supply

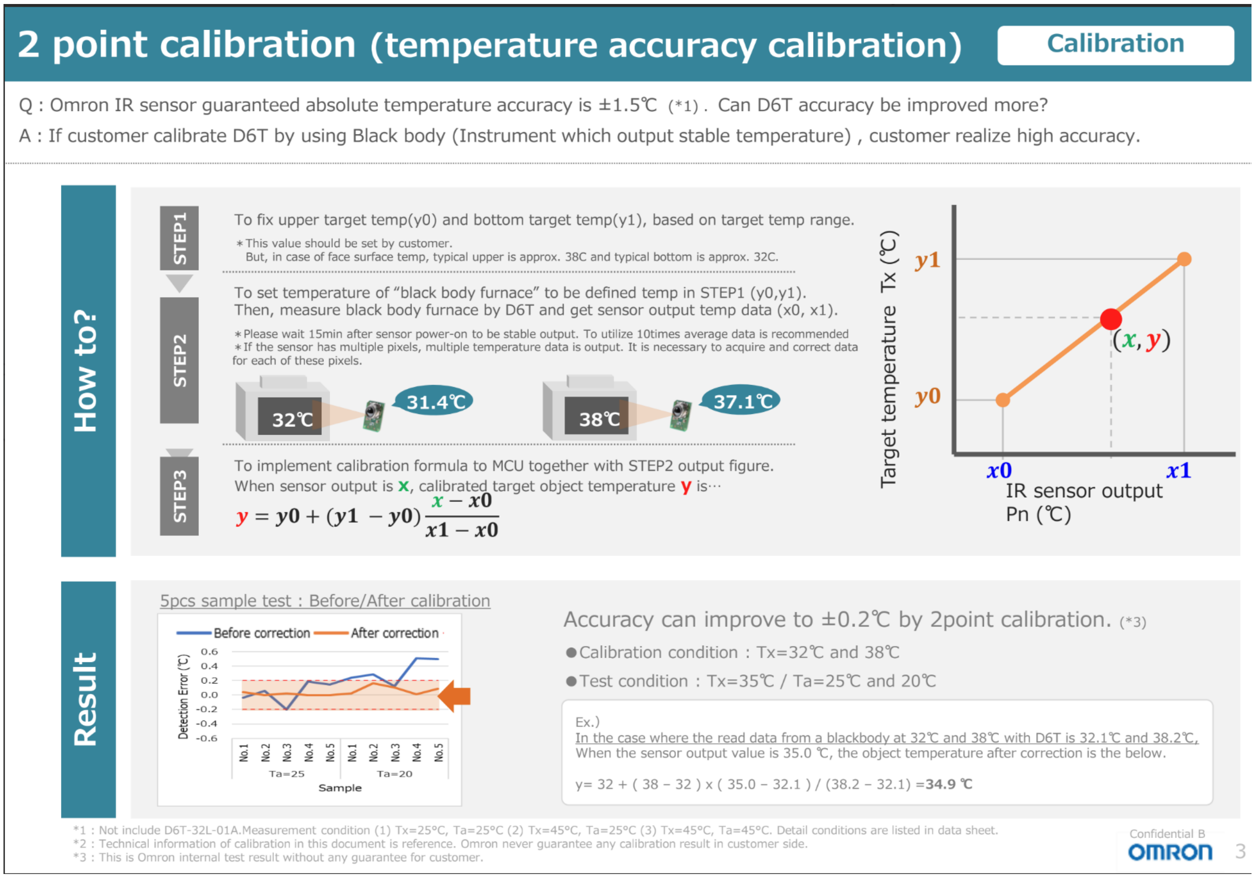
Output: 12VDC (rated at $\pm$2%)

The R-78C12 switching converter will take an input of 30VDC and step down to 12V DC. The benefit of using a switching converter in this context is that the heat dissipation will be minimal. The IC promises efficiency of >90%, allowing us to draw larger amounts of current without the need of a heat sink.

2.7 Tolerance Analysis

One aspect of our design that we are heavily relying on is the accuracy of the temperature sensor. Since we are only gathering the external temperature of the meat and our goal is to estimate the internal temperature of the meat $\pm$2°C, we must spend a large amount of effort and time on calibrating the device after construction. Our thermal sensor is rated at an accuracy of $\pm$ 1.5°C, so we must minimize this as much as possible in order to account for our inaccuracy when estimating the internal temperature. We also must be wary of the heating device affecting the thermal sensor's readings. By using 2 point calibration, we can increase our accuracy to $\pm$ 0.2°C. First, we fix the lower (y0) and upper (y1) target temperatures based on our needed range. Next, use the thermal sensor to measure a black body furnace at those two target temperatures and record output (x0,x1). Lastly, we use the sensor output (x) to receive the calibrated temperature(y) using the following equation:

$$y = y0 + (y1 - y0)\frac{x - x0}{x1 - x0}$$



Another factor is having a constant temperature of 37.78 ±2°C within the container. If the temperature becomes too cold then it will impact the defrost time, or if the temperature is too hot then it will impact the moisture level within the chicken breast and increase the possibility of reaching the bacteria growth temperature. We factor for this by ensuring our heating device wattage can accurately reaches 37.78. Our equation for convection heating in a container, previously mentioned in the Heat Subsystem section, gives a close wattage for what is needed to reach 37.78°C. The equation is below:

$$Q = V * p * c * \Delta T$$

Q: heat energy required (J)

V: volume space (m^3)

p: density of air (kg/m^3)

c: specific heat capacity of air (J/kg/°C)

ΔT: difference in temperature between inside and outside of cooler (°C)

3 Cost and Schedule

3.1 Cost Analysis

Labor			**Cost**	**Count**	**Total Cost**
Computer Engineer			$12,156	3	$36,468
Parts					
Type	**Manufacturer**	**Number**			
Cooler	Walmart	----------	$21.88	1	$21.88
Temperature Sensor	Omron	D6T-1A-02	$7.09	1	$7.09
Beeper	TDK	PS1440P02BT	$0.75	1	$0.75
Button	TE Connectivity	1825910-2	$0.15	1	$0.15
LED Display	Adafruit	878	$9.95	1	$9.95
PTC Heat Plate	DBK	HP03-1/08/24	$16.79	1	$16.79
Microcontroller	Microchip	ATMEGA328PB-ANR	$1.87	1	$1.87
5V Voltage Regulator	Jameco	LM7805	$1.19	1	$1.19
Fan	Orion	OD4010-12HSS	$7.71	1	$7.71
Power Supply	Perfeidy	------------	$18.99	1	$18.99
Plastic Enclosure	Polycase	LP11F	$3.20	1	$3.20
12V Switching Converter	RECOM Power	R-78C12-1.0	10.63	1	10.63
				Part Total	$100.18
				Total	$36,568

3.2 Calculations

According to data from the 2020-2021 graduating class, the average starting salary of a UIUC graduate is $105,352 for computer engineers. One may work around 2080 hours per year (40 hour week * 52 weeks). We will be working on our project for 12 weeks and expect around 10 hours of work per week since it is a 4 credit hour course. Also, we apply a 2 overhead multiplier to account for unexpected costs. Labor cost per partner would total to:

$$\frac{\$105{,}352}{1\ year} * \frac{1\ year}{2080\ hours} * \frac{10\ hours}{1\ week} * 12\ weeks * 2 = \$12{,}156\ (per\ Computer\ Engineer)$$

The part list shown above only accounts for creating one product. Bulk purchasing and number of products made will alter the price of the individual parts.

3.3 Schedule

Week	Ben Civjan	Brad Palagi	Payton Thompson
2/27/23	Discuss voltage and power management of subsystems with Jason or Matthew (step downs/AND gates)	Research microcontroller, understand capabilities of ATmega, how we will program it	Discuss container dimensions, heat placement with Machine Shop
3/6/23	Order power system components including AC/DC converter and regulators	Begin ordering initial parts for control, UI and sensor subsystems	Order heating element, submit plans to machine shop with selected cooler and polycase
3/13/23	HAVE	SAFE	FUN!
3/20/23	- Breadboard Power Subsystem - Update PCB with new parts	- Get s upplies to Machine Shop - Breadboard Control Subsystem	- Order final parts - Reevaluate capacitor/resistor values for PCB
3/27/23	- Breadboard Power Subsystem - Order new PCB	- Breadboard Control Subsystem - Breadboard UI Subsystem	- Get Final supplies to Machine Shop - Breadboard Heating Subsystem - Solder PCB 1
4/3/23	- Breadboard entire System	- Code microcontroller	- Breadboard Sensor Subsystem
4/10/23	- Solder PCB 2	- Code microcontroller - Connect PCB to	- Breadboard entire System

		cooler	
4/17/23	- Final Implementation - Test Power Subsystem - Test UI Subsystem	- Final Implementation - Test Control Subsystem	- Final Implementation - Test Heating Subsystem - Test Sensor Subsystem
4/24/23	- Resolve Bugs - Final Report	- Resolve Bugs - Final Report	- Resolve Bugs - Final Report
5/1/23	- Finishing Touches - Final Report	- Finishing Touches - Final Report	- Finishing Touches - Final Report

4 Ethics and Safety

According to section 1 of the IEEE code of conduct, it is essential “to hold paramount the safety, health, and welfare of the public” [6]. As this is a product that assists in making food for human consumption, the system must be food-grade. This means that we will need to use high-quality components to provide a safe, reusable product. We will thoroughly test our product under a variety of conditions that could be experienced in the kitchen, where our device will be used. Throughout our engineering process, we will focus heavily on making sure our components are functioning properly and do not show signs of overheating, inaccuracy, etc. Additionally, since our device uses a heating element, we include warnings of this and instructions on how to use the product safely.

Sections 1.2 and 1.3 of the ACM code of conduct state that a computing professional should “avoid harm” and “be honest and trustworthy” [5]. In the case of a device that will generate heat and be in contact with food, it is crucial for us to maintain full honesty in our design process. This will allow others to verify that we are taking proper precautions, which will generate the best and safest possible product. Additionally, one of the ACM guidelines is to build things that are “robustly and usably secure” [5]. This means our design should not be able to be tampered with maliciously easily. To accomplish this we must securely wire our components (i.e. not make them easily accessible), and securely program our microcontroller to maintain proper functionality.

5 References

[1] “Amazon.com: Evelots meat thawing tray for frozen meat.” [Online]. Available: https://www.amazon.com/Evelots-Rapid-Defrosting-Frozen-Naturally/dp/B01K3A5X26.

[2] “What Is a Defrosting Tray and Does It Really Work?” [Online]. Available: https://www.thespruceeats.com/what-is-a-defrosting-tray-4782382.

[3] “ATMEGA328PB.” [Online]. Available: https://www.microchip.com/en-us/product/atmega328pb

[4] “The Big Thaw — Safe Defrosting Methods | Food Safety Inspection Service.” [Online]. Available: https://www.fsis.usda.gov/food-safety/safe-food-handling-and-preparation/food-safety-basics/big-thaw-safe-defrosting-methods.

[5] “ACM Code of Ethics and Professional Conduct.” [Online]. Available: https://www.acm.org/code-of-ethics [Accessed: Feb.9, 2023].

[6] “IEEE Code of Ethics”, IEEE. [Online]. Available:https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed: Feb.9, 2023].

[7] S. Pelonis, “What you need to know about PTC heaters,” *Pelonis Technologies, INC.* [Online]. Available: https://www.pelonistechnologies.com/blog/what-you-need-to-know-about-ptc-heaters.

[8] “D6T Thermal Sensors Datasheet.” [Online]. Available: https://www.mouser.com/datasheet/2/307/en_D6T_catalog-1633759.pdf

[9] “How to Install PTC Heater in an Incubator.” [Online]. Available: https://www.youtube.com/watch?v=13modlI5Zew.

[10] “Adafruit 0.56" 4-Digit 7-Segment Display with I2C Backpack.” [Online]. Available: https://www.adafruit.com/product/878.

[11] “PERFEIDY 30V 1A Universal AC Adapter.” [Online]. Available: https://www.amazon.com/PERFEIDY-Switching-Regulated-Transformer-Interchangeable/dp/B0B2RLKLMH/ref=sr_1_6?crid=SEQ750XDWWP&keywords=30v+power+supply&qid=1677196116&sprefix=30v+power%2Caps%2C158&sr=8-6.

[12] “LM7805CT 5V 1A Positive Voltage Regulator.” [Online]. Available: https://www.digipart.com/part/LM7805.