SMART MEAT DEFROSTER

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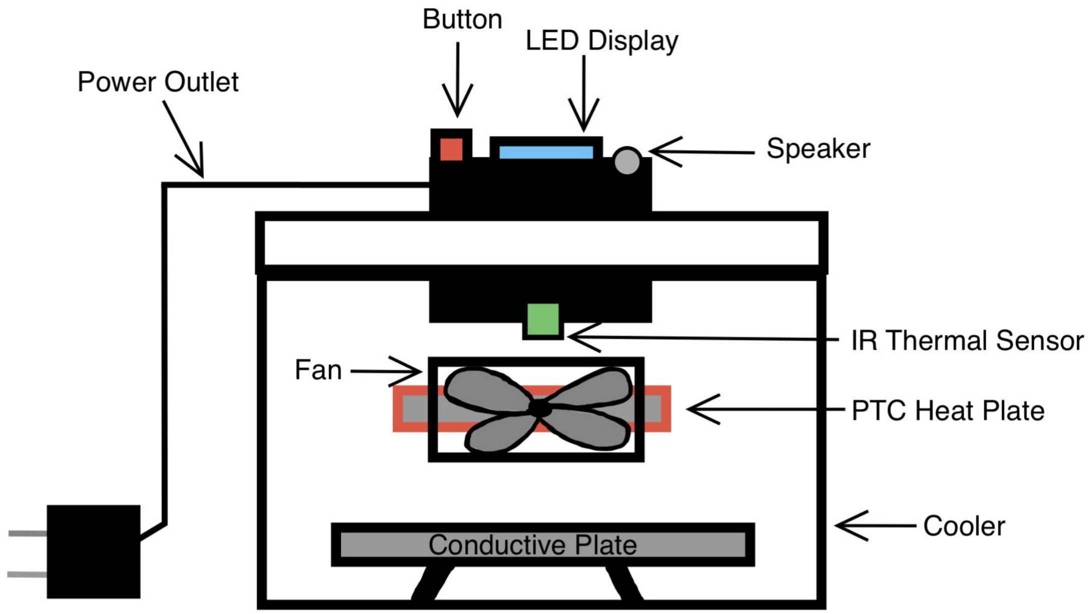
Problem:

Defrosting frozen meat is a very tedious process. There are a few common thawing techniques, each with its own issues. One, you can leave the meat in the fridge to thaw, but that takes around two days. Next, you could also heat your meat in the microwave, though this results in extremely uneven heating. The meat usually ends up being partially cooked and still frozen in some parts. 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.

Solution:

We propose a meat defrosting container that uses a heating element to quickly defrost meat. It will be designed to defrost food very quickly and evenly without cooking it. The device will be extremely easy to use and provide a hands-off experience by turning off automatically once the food has finished defrosting. The container will use a heating device above and a conductive plate beneath to defrost the meat, while a thermometer measures the meat's temperature to detect when it has fully defrosted. This allows for a hands-off, quick, and versatile approach to defrosting meats.

Visual Aid:



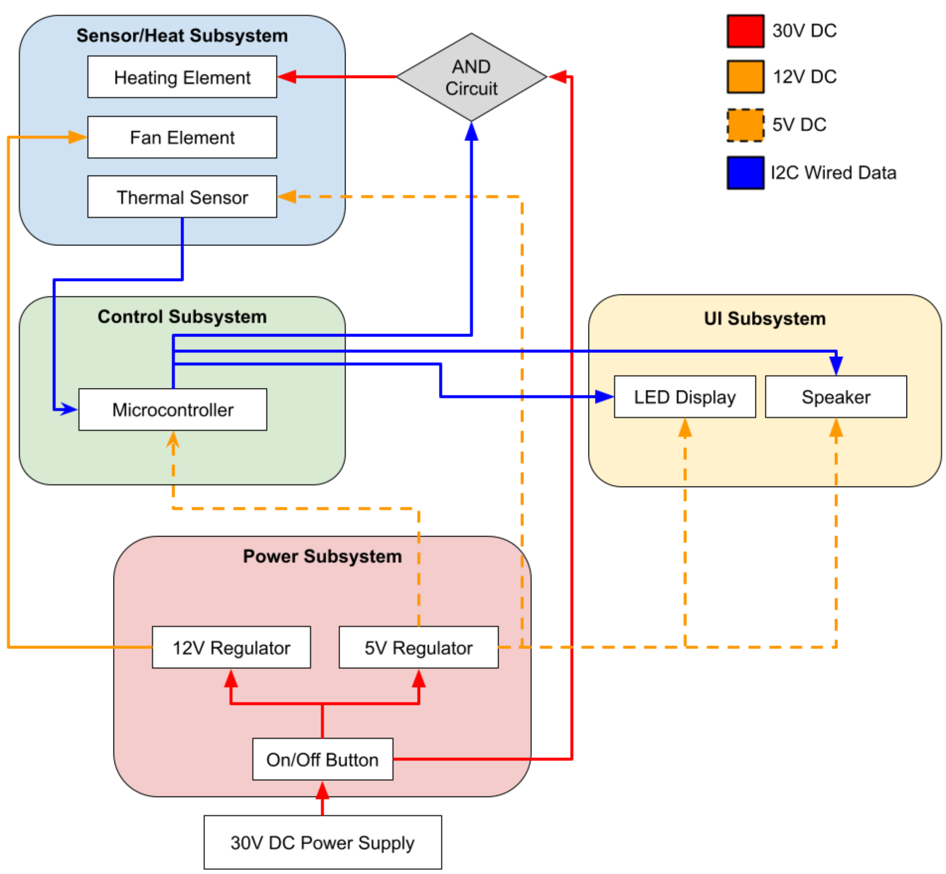
Side View

High-level Requirements List:

- 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 percent 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.

Design:

Block Diagram:



Subsystem Overview:

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.

Requirements:

- Receive temperature data from the thermal sensor, and pass this through the microcontroller to the LED Display
- Microcontroller sends a signal to disable the heating element once the meat temperature reaches 35 degrees F
- Microcontroller sounds a defrost completion alarm

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 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 I^2C data needed to adjust the other subsystems.

Requirements:
- Detect internal temperature with an accuracy of +/- 2 degrees C (will need to run trials to calibrate this)
- Maintain an internal air temperature between -40 and +80 C, the operating temperature range of the thermal sensor
- Ensure the voltage does not fluctuate more than the allowed 0.5 V

User Interface Subsystem

The display and audio subsystem gives feedback to the user in order for them to be aware of how far along the meat is in the defrosting process. The LCD Display shows the current temperature of the meat for the entirety of the meat in the container. The audio will beep once the meat’s internal temperature hits above 2°C to notify the user the meat is defrosted. If the meat is kept in the container after defrosting, then the audio will beep more frequently as the internal temperature approaches the bacteria-growing temperature of 5 °C.

Requirements:

LCD Display:
- Able to send input for hex display
- 3 hex digits

Audio:
- Speaker that can beep at an adjustable rate

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. We will use a wall outlet AC/DC converter as our main power supply, this will convert 120V AC to 30V DC. The 30V is what is required for the heating element and then we will need to use voltage regulators to step down the power for the necessary voltage levels of the other subsystems. The fan will require 12V and the rest of the subsystems (control, sensor, and UI) will be powered with 5V.

Requirements:
- Controllable by On/Off button
- Maintain an output voltage between 4.5 and 5.5V
- Provide an output voltage of 12V to the fan (this will require a large power dissipation that could produce unsteady voltage but this is alright for the fan)
- Stop supplying power to the heating plate once the HEAT_ON signal has been set low by the microcontroller (plan on using a MOSFET with 30V DC and the HEAT_ON signal)

Heat Subsystem

The Heat Plate and Fan are 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 by a 3-AND circuit with the heat plate voltage, fan voltage, and a signal from the microcontroller. We found that PTC Heaters are self-regulating. 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. 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. The equations below are how we decided on a 30W heat plate.

Heat loss of cooler:

$Q = A*U*(To - Ti)$

- Q = Total hourly rate of heat loss through walls (BTU/hr)
- A = Net Area of walls (ft^2)
- U = Overall heat transfer coefficient of walls (BTU/hr/ft^2)
- To = outside temperature (°F)
- Ti = inside temperature (°F)

Heating container through convection:

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

- Q = Heat energy required (W)
- V = Volume space (m^3)
- p = Air density (kg/m^3)
- c = Specific heat capacity of air (J/kg/°C)

- ΔT= Temperature difference desired indoor and outdoor temperatures (°C)
°C,°F conversion: (°F-32)*(5/9) = °C
BTU/hr, W conversion: 1W = 3.41 BTU/hr

Requirements:
- Does not burn the container
- Does not damage other subsystems
- Container air temperature consistently at 38$\pm$2 °C
- Container air temperature takes less than 15 min to reach 38 °C

Tolerance Analysis:

One aspect of our design that we are heavily relying on to be accurate is the temperature sensor. Since our goal is to have the internal temperature of the meat reach 2°C ($\pm$ 2°C), and we are only gathering the external temperature of the meat, we must spend a large amount of effort and time on calibrating the device after construction. This calibration will involve us running tests on a variety of different-sized chicken breasts and comparing the temperature that our thermal sensor reads with the value gathered through a heat thermometer. Additionally, since our thermal sensor is rated at an accuracy of $\pm$1.5°C, only slightly below our desired accuracy, we need to ensure that this reading is not influenced by the heat produced by the heating element. To accomplish this we will need to experiment with the placement of the heating element and sensor, ideally spacing them out as much as possible and placing the sensor as close to the meat as possible.

We also need to provide a steady voltage to the microcontroller, sensor, fan, and UI subsystem. We are limiting fluctuations by using voltage regulators to step down and modulate the voltage from the power supply. We have calculated the amount of power that each regulator will dissipate and verified that this falls under the maximum amount specified on the datasheet. Since the microcontroller, infrared sensor, and UI components draw a very small amount of current, we are able to use the same 5V regulator to power each.

For our heating element to function properly, we will need to ensure a 30V power supply. This will be achieved by wiring it directly to the power source since the heating element is self-regulating and doesn't require a designated voltage regulator.

We must also dedicate resources to ensure the effectiveness of the container and seal to keep water from spreading into the electrical components since our product will need to be used in the kitchen and washer periodically.

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.

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].