Heat-N-Cool Coaster

By

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1 Introduction

1.1 Objective

In order to be fully enjoyed by a consumer, many drinks, like hot coffee, need to be prepared to an optimal temperature. The problem is that the initial temperature of a drink is correlated to the temperature it is stored in, without prior preparation. The storage temperature range can vary from frozen to chilled to normal room temperature. The most common way of changing the temperature of a drink from its storage temperature would be through the use of a refrigerator or microwave, but these appliances are not always affordable and accessible to everyone, as mentioned in the "Electric Thermos Box" project from the Spring 2020 semester [1]. Furthermore, these appliances are not capable of taking user inputs to cool or heat drinks to a desired temperature range.

In order to address the problem of inaccuracy and inefficiency in controlling drink temperatures, we propose a drink coaster that will emit a user-defined temperature range. Users can control the coaster through an external smartphone app connected through Bluetooth in order to heat and cool their drinks to a desired temperature range. We believe that our product would be useful for people who do not own the appliances mentioned above, or for those that want a simple and efficient way to modify the temperature of their drink. In addition, the portable nature of the coaster affords users the luxury of taking it on-the-go to heat and cool their drinks, something that is not afforded by major household appliances.

1.2 Background

The problem that we are trying to solve is important because if hot drinks like coffee are not served at an optimal temperature, the experience of drinking them will not be satisfying. According to a study published in *Nature* journal, there exist TRPM5 sensory channels within our taste buds [2]. TRPM5 receptors are responsible for the varying perceptions we experience when tasting foods and drinks at different temperatures. The reactions of TRPM5 send intense signals to the brain that result in an enhanced ability to distinguish taste when consuming food and drink at higher temperatures. These electric signals sent to the brain are not as intense when consuming lower-temperature foods, like ice cream. In order to make sure that hot beverages can thus be fully enjoyed by our TRPM5 receptors, it is important to define an optimal temperature range that our coaster can warm up a user's drinks to. A study done by MEDLINE defined how hot beverages like tea, hot chocolate, and coffee are frequently served in restaurants within a range of 160-185° F, even though severe scalding of the mouth can occur even with light exposure to these temperatures. By surveying 300 subjects to find the balance between limiting scalding hazards and maintaining the drinks to an optimal temperature at which they are still satisfactory, the study's researchers were able to approximate the optimal drinking temperature to be 136° F [3]. Given the conclusion of this study, we decided to set 136° F as the upper bound of our coaster's heating capabilities in order to ensure that our product will prepare the user's drink to a satisfactory temperature while simultaneously limiting the dangers of burns during consumption.

Though the problem that we are trying to solve is essentially the same as the "Electric Thermos Box" project, our solution differs in two fundamental ways. The first is that we are not proposing a thermos that will encapsulate the drink, but rather a coaster that a user will set their drink upon in order to modify or keep temperature constant. Products made by companies like Ember and Mr. Coffee are temperature-controlled mugs that can only heat up drinks, so our coaster with heating and cooling functionality differs significantly from other products currently found on the market. Secondly, the "Electric Thermos Box" had buttons on the actual device to set the desired temperature to. Due to concerns that our coaster would heat up to temperatures that are not safe for users to directly touch, we plan on instead implementing a smartphone app that can communicate with a microcontroller within the coaster design. On this smartphone app, users will be able to define a temperature range to set their drinks to, and this information will then automatically be sent to the coaster in order to begin heating or cooling. This way, the user avoids any direct contact with a potentially hazardous coaster emitting a lot of heat, and can instead just grab their cup off of the product when their drink reaches the desired temperature.

1.3 High Level Requirements

- A portable drink coaster that includes a temperature sensor, pressure sensor, and power supply that can heat and cool 1 cup (250 grams) of a liquid. LEDs must also be present on the coaster to indicate when the coaster is heating, cooling, or inactive.
- Given the drink is initially at room temperature (~70° F), the coaster must cool or heat it within ± 60° F and must do so in a timely manner, between 10-20 minutes depending on the temperature set by the user.
- A paired smartphone app connected to the coaster via Bluetooth will allow users to set the coaster to a desired temperature.

2 Design

2.1 Block Diagram

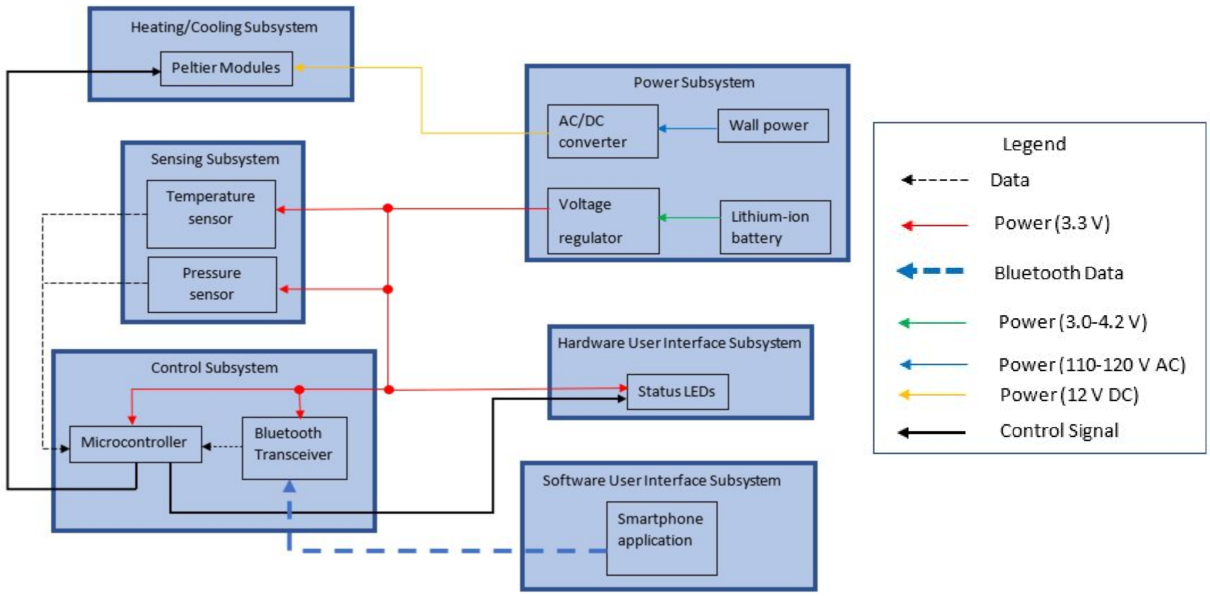

Figure 1. High Level Block Diagram

Our design, as seen in Figure 1, features six subsystems that each serve their own purpose that contribute to the overall function of the coaster. The power subsystem is what is responsible for providing power to the other various subsystems found within the coaster. Since the heating and cooling subsystem requires significantly more power than the other subsystems, we have decided that our coaster will need to draw power from a wall outlet, after which it will be passed through an AC/DC converter so that approximately 12 V DC is passed into the Peltier modules in the heating/cooling subsystem. All other subsystems, excluding the software user interface system, can be powered through a lithium ion battery that is regulated to output 3.3 V. The software user interface subsystem is simply an external phone application that is paired to the coaster via Bluetooth. This subsystem sends information to the bluetooth transceiver within the control subsystem, which will notify the microcontroller that some heating or cooling process must occur. The microcontroller will then send a control signal to the heating/cooling subsystem to initiate the desired process, as well as data to the status LEDs in the hardware user interface subsystem to light up the corresponding LED. While this occurs, the sensing subsystem is polling for data relating to the presence and temperature of the liquid on the coaster, and sends this data to the microcontroller. Once the microcontroller sees that the temperature of the liquid matches that of the inputted temperature, it will send another control signal to the heating/cooling subsystem to notify it to stop its current process, and will send data to the LED in the user hardware interface subsystem to notify the user that the drink is ready.

2.2 Physical Design

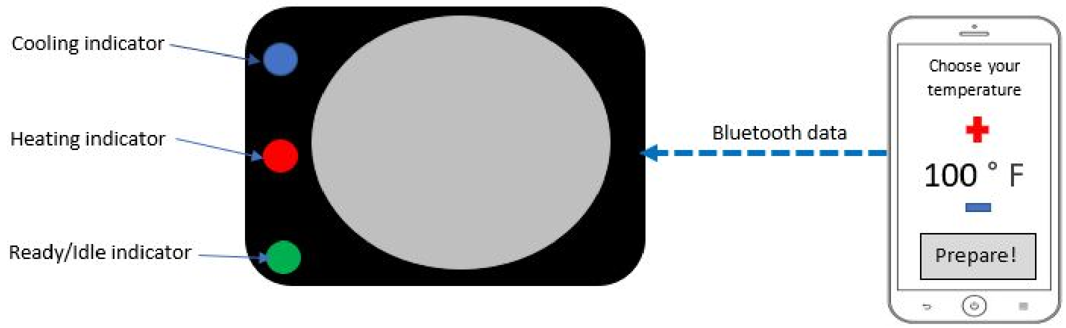

Figure 2. Physical Design of Coaster and Layout of Smartphone Application

Figure 2 depicts what the outer design of the coaster will look like, as well as how the coaster will link to a user's phone via Bluetooth. On the app, users will be presented with a screen where they can either increase or decrease the temperature that they want to set their drink to. After they have selected a temperature and clicked 'Prepare!' the application will send this temperature information to the bluetooth transceiver and microcontroller that are placed inside the coaster. Until this point, the green indicator would have been lit up to signify that the coaster is ready, but the LED will then change to the corresponding information received by the microcontroller. Users will set their drink on the silver pad, and then Peltier modules within the pad will begin to heat or cool the drink, until the temperature of the drink matches that of the user-defined temperature. Once this is done, the microcontroller will light up the green indicator once again. It is important that the LEDs are not placed too close to where heat is being emitted in order to prevent burning them out.

2.3 Power Subsystem

A source of power will be needed to supply the sensing, heating/cooling, control, and hardware user interface subsystems. All of the subsystems mentioned here except for the heating/cooling subsystem can be powered by a lithium-ion battery, which will have its voltage regulated by a voltage regulator to pass 3.3 V to power the rest of the subsystems in the design. As mentioned earlier, the heating/cooling subsystem requires significantly more power than a lithium-ion battery can provide, which is why it will need power from a wall outlet that is passed through a AC/DC converter to supply 12 V to power the Peltier modules.

2.3.1 Lithium-ion battery

The lithium-ion battery will be used as the source of power for everything except the Peltier modules, providing the coaster's sensors, microcontroller, and LEDs with continuous power to allow for uninterrupted use. These subsystems must be powered by the lithium-ion battery for an extended period of time. Once the lithium-ion battery has run out of power, the coaster design must allow for easy removal and replacement of the battery.

Requirement 1: Must supply 3.0 - 4.2 V to all components not part of the heating/cooling subsystem for 4-6 hours on full charge.

Requirement 2: Must be easily replaceable by the user after the battery is drained.

2.3.2 Voltage Regulator

Since the voltage range of the lithium-ion battery fluctuates between 3.0-4.2 V, there will be a voltage regulator connected to the lithium-ion battery that will be used to provide a constant 3.3 V supply of power to all subsystems, excluding the heating/cooling subsystem.

Requirement 1: Must supply and maintain a constant 3.3 V (±5%) to all of the specified subsystem components mentioned above.

Requirement 2: Must operate between 0-300 mA and supply sufficient current for the specified design components.

2.3.3 Wall Outlet Power

Specifically for the Peltier Heating module, we will include wall outlet power to provide power with a higher voltage and current output. This will be utilized by using an AC/DC converter to then power the Peltier modules.

Requirement 1: Must supply 110-120 V AC power that can be routed to an AC/DC converter.

2.3.4 AC/DC Converter

Due to the high power requirement of the Peltier Heating module there is the need for an additional power source with a higher voltage and current output. Implementing wall outlet power is the simplest and cheapest way to achieve such power ratings, however, this will require an AC/DC converter to bring outlet power down to a manageable 12 V required for the Peltier.

Requirement 1: Must supply constant 12 V at over 1 A to the Peltier modules.

2.4 Sensing Subsystem

The sensing subsystem of the coaster will include a temperature sensor and a pressure sensor to measure the amount of fluid and the initial temperature of the fluid. This data will be sent to the control subsystem to determine when the coaster should halt the heating/cooling process and send this information to the control subsystem.

2.4.1 Temperature Sensor

The temperature sensor will be used to measure the initial temperature of the drink before heating/cooling, and continuously monitor this temperature during the process, sending this information to the control subsystem, which will halt the process once the temperature reaches the temperature defined by the user on the application.

Requirement 1: Must accurately detect the temperature of a drink inside of a cup within ± 2° F.

Requirement 2: Must be able to gather and send the drink's temperature information to the microcontroller.

2.4.2 Pressure Sensor

The pressure sensor will be used to measure the amount of fluid in a drink. Assuming the use of a standard coffee mug that weighs approximately 14 ounces (~400 grams), the information collected by the pressure sensor will then be used as one measurement to determine how much heating/cooling is needed to reach the desired temperature set by the user.

Requirement 1: Must accurately determine the amount of fluid in a cup within ± 5 ml.

Requirement 2: Must be able to gather and send information to the microcontroller about the amount of fluid in a cup.

2.5 Heating/Cooling Subsystem

The heating/cooling subsystem will perform the heating/cooling of the drink given information from the sensing subsystem that is fed into the control subsystem, which will then send a control signal to this subsystem to begin heating or cooling.

2.5.1 Peltier Modules

The Peltier module will serve as the primary function to be controlled within the project and should be located on top of the coaster to allow easy contact with the cup on top of it. It is a thermoelectric module that acts as a small heat pump, transferring heat between each side of the device [4]. This gives the ability for an object to be heated/cooled on one side of the device while the other side has the opposite effect.

Requirement 1: Must be easily controllable via the microcontroller's input to the device.

Requirement 2: Can heat the drink placed on top to a user specified temperature specified in the high level requirements.

2.6 Control Subsystem

The control subsystem will include a microcontroller that will be used to receive data from the sensors and use this to send appropriate control signals to the heating/cooling subsystem and status LEDs on the coaster. There will also be a Bluetooth transceiver connected to the microcontroller that will get information from the smartphone application regarding the user's desired temperature.

2.6.1 Microcontroller

There will be a programmable microcontroller that will store data from the sensors and smartphone application. This information will be processed and used to control the heating/cooling of the coaster. It will also be used to activate the proper status LEDs to indicate the state of the coaster.

Requirement 1: Must be programmable to control heating/cooling subsystem and status LEDs.

Requirement 2: Must be able to store data from the sensors and bluetooth transceiver.

2.6.2 Bluetooth Transceiver

The Bluetooth transceiver will be connected to the microcontroller and establish a connection between the coaster and the smartphone. Information about the user's desired drink temperature will be sent from the application to the microcontroller using this Bluetooth connection.

Requirement 1: Must be able to transmit data within a range of 5 meters.

Requirement 2: Must reliably send user's input data from phone to the microcontroller without corruption.

2.7 Software User Interface Subsystem

The software user interface subsystem will include a smartphone application that will send data about the desired temperature of the drink through Bluetooth to the coaster's transceiver within the control unit. This information will then be used by the control unit in conjunction with the sensing subsystem to ensure that the heating/cooling subsystem prepares the user's drink to the temperature specified on the application.

2.7.1 Smartphone Application

The smartphone application will have a user interface as seen in Figure 2 that allows the user to define what temperature they want the drink to be. After a temperature value is set the application will communicate this data to the coaster through Bluetooth.

Requirement 1: Must be Bluetooth compatible to send data to the coaster.

Requirement 2: Must have a basic interface that allows users to easily specify what temperature they would like to prepare their drink at.

2.8 Hardware User Interface Subsystem

The hardware user interface subsystem will have status LEDs that correspond to the different states the coaster might have. This subsystem receives information from the microcontroller regarding which LED to light up during various stages of the heating or cooling process, always ending with the green LED lit to signify that the user's drink is ready.

2.8.1 Status LEDs

The status LEDs represent the different states of the coaster which are 'heating', 'cooling', and 'ready', corresponding to a red, blue, and green LED respectively. They are controlled by a data output from the microcontroller which signals what state the coaster is in, which then activates the respective LED.

Requirement 1: Must be easily visible to the user while the coaster faces upward.

Requirement 2: Must accurately light up respective LEDs according to control signals from the microcontroller.

2.9 Risk Analysis

The subsystem block that will pose the greatest challenge to the successful completion of the project would be the heating/cooling subsystem. This is due to the fact that one of our high level requirements states that the coaster must be able to heat and cool a drink within a specific range centered around room temperature (~70° F). If the subsystem is not able to do so, we would be missing a large portion of functionality for this project to be considered a success. Given the relatively expensive cost of Peltier modules, which will be the main feature of the heating and cooling subsystem, we are limited in how many we can actually implement within our design. The downside of the limit on the number of Peltier modules we can use is that there will be significantly less efficiency in the heat transfer from module to cup. This was also a problem anticipated by the group we drew inspiration for this project, even though their design had even more potential for heat loss since their Peltier modules were not installed directly on the surface with which they were heating or cooling liquids. Since our Peltier modules will be fastened within the heating pad design featured in Figure 2, there will be marginally less heat loss, but still enough to warrant careful consideration on how we can design the coaster's dimensions to minimize heat loss. If we are able to make an informed decision about this, we can maximize the amount of heat being transferred from the module to the cup with liquid in it, while also minimizing the amount of heat lost and energy wasted.

3 Ethics and Safety

There is a potential ethical issue that the durability of the coaster would be compromised in situations that involve direct contact with objects or liquids that may damage or destroy the integrity of the circuit. Our product should "hold paramount the safety, health, and welfare of the public, ... strive to comply with ethical design and sustainable development practices, … [and] disclose promptly factors that might endanger the public or the environment," according to Code #1 of the IEEE Code of Ethics [5]. In order to circumvent this ethical concern, we will need to have a degree of water resistance for the outer structure of the coaster, in accordance with IP66 guidelines. By doing so, we avoid potential issues where the user is shocked when spilling a liquid onto the device, or even further shorting the entire circuit design. Wires becoming exposed within our design are also a safety issue, especially given our design's use of high current to power the heating module. To combat this issue, our coaster's exterior should be composed of a durable and shock-absorbent material like plastic to nullify minor physical collisions that may damage the internal circuit or expose wires within the design.

Another possible damage and safety concern that could arise from the project include the heat generated from the Peltier module. According to the IEEE Code of Ethics #9, "to avoid injuring others, their property, reputation, or employment by false or malicious action" [5], this module must be insulated from the outside world and have clear indication of the high temperature when it is active within the devices. To deal with the safety concern of burning an individual there will be LED indicators for heating modes that are clear and easy to see. Another potential concern here is damage to the surface that the user has placed the device on. For this issue there will be a layer of insulating material between the heating device and the surface it is resting on.

Our coaster will be collecting information from the user's phone regarding the desired temperature. This can lead to an ethical concern over how the user's data is used and where this information is sent to. According to the IEEE Code of Ethics #5, "to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems" [5], the user's data that is currently on their phone will not be accessed by our application. Data that is sent from the user's smartphone to the microcontroller is being stored for the sole purpose of controlling the coaster and no other data will be accessed or sent.

The use of lithium-ion batteries within our design is also another safety issue given the risk of overcharging them. Though lithium-ion batteries are integral to our design given their small size and high power output, their inherent danger is that they are extremely flammable [6]. The course staff recommends fire extinguisher and safety training when handling lithium-ion batteries that may catch on fire if excessively overcharged, discharged, or exposed to extreme temperatures. In addition, our design will incorporate a threshold circuit to ensure that the voltage from the lithium-ion battery does not exceed the range of 3.0 - 4.2 V, as well as a voltage regulator circuit. To ensure that we follow the guidelines set in place by course staff for safe practice with lithium-ion batteries, any of our tests that involve charging and discharging the battery will need to be done when the battery is contained inside of a lithium safety bag. Additionally, two TAs will also need to approve the design of our charging/discharging circuit to make sure that they are not hazardous to others [6].

To ensure that our team has the necessary knowledge to work efficiently and safely within the design lab, it is also imperative that we successfully completed the Lab Safety Training provided to us by the course staff. By having done so, we are acting in accordance with policies regarding Campus Environmental Health and Safety as defined by the University of Illinois at Urbana-Champaign, in order to conduct "university operations in compliance with all applicable laws and regulations … [to provide] a safe and healthful workplace" [7].

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