Electric Thermos Box

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1 Introduction

1.1 Objective

Thermos cups are very useful tools for our way of living and also for the environment. However, it is not easy to drink the liquid inside the cup at the temperature we want. We often find the liquid too hot or too cold when we are using the normal thermos cups. Electric Thermos Box can help us to heat up or cool down the drink inside by simply pressing a button.

1.2 Background

Although some companies (Ember, etc.) have been developing a temperature controllable mug, most of the existing thermos cups only have functions of heating the liquid, and they could take as long as an hour to get the drinks ready according to user reviews[1]. Also, there is a possible problem with burning users' hands since the heating modules are usually exposed to air.

The device we are developing would not only be able to heat up drinks but also to cool them down. Furthermore, we expect our device to be much more efficient than the ones currently on the market.

1.3 High-level Requirements

- Our product should be able to bring 250g of water to any desired temperature within the range 0-50℃ starting from room temperature(20-30℃).
- The entire process should take no more than 20 minutes.
- The final temperature should have an error of at most +-5C compared to the desired temperature.

2 Design

2.1 Block Diagram

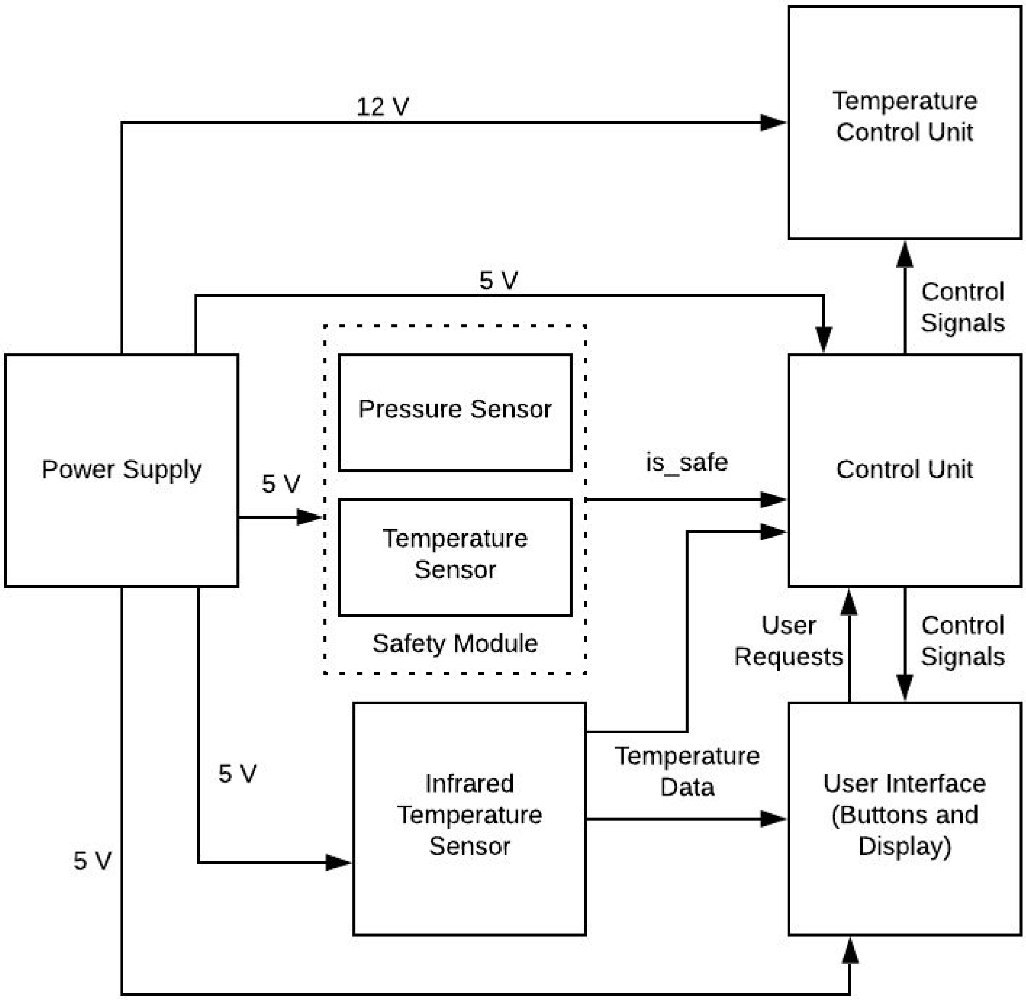

Figure 1. High Level Block Diagram

As shown in figure 1, once the user sets the desired temperature by pressing the buttons, the control unit would compare it with the current temperature, and send control signals to the temperature control unit to perform either heating or cooling.

2.2 Physical Design

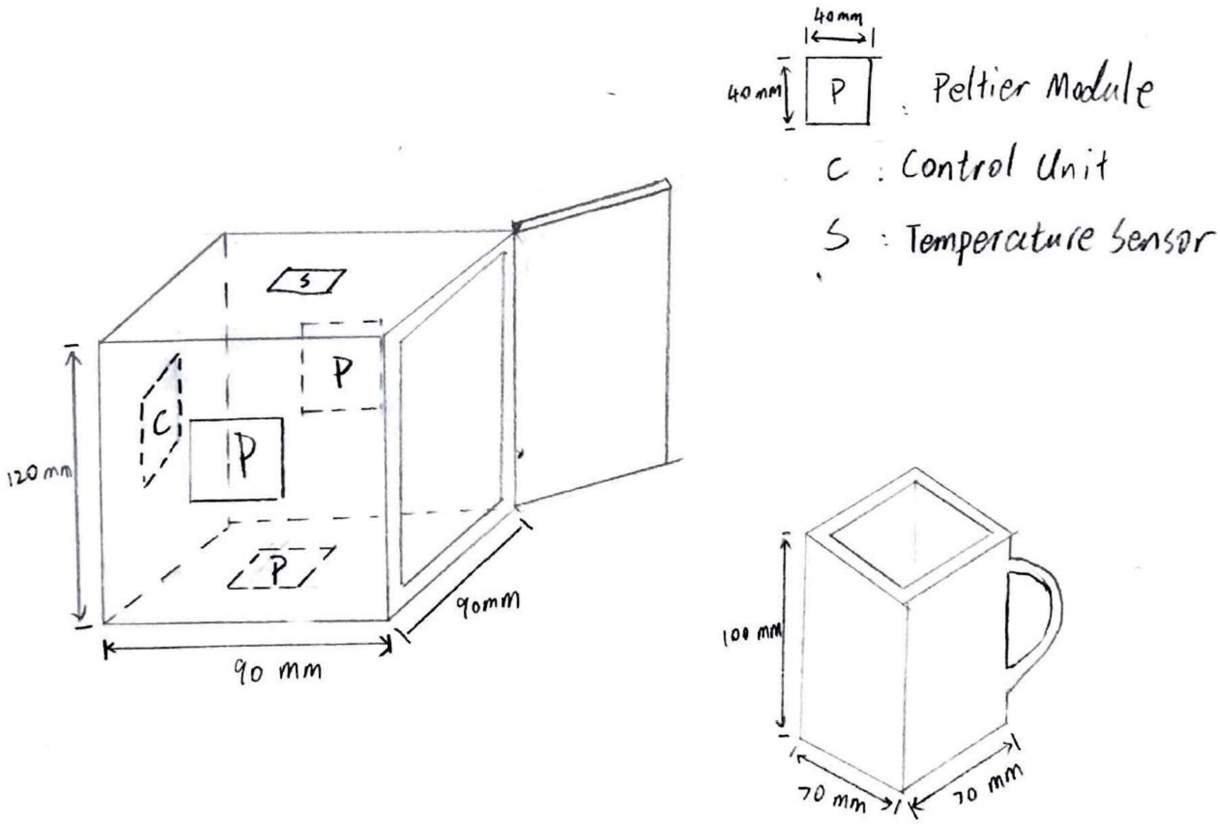

Figure 2. Physical Design

We plan to design a box-shaped heater/cooler and a cup of the same shape. To heat or cool the drink, the user must first place the cup inside the box, then use the buttons to set a desired temperature. We plan to put all the electronics on the box. Therefore, this box should ideally work with any container that fits in the box, but with lower efficiency compared to our original cup.

2.3 Block Descriptions

2.3.1 Temperature Control Unit

Power: 12V, 10-15A
Input: control signals from Control Unit
Outputs: none

The temperature control unit has 3 modes: “heat”, “cool”, “idle”, corresponding to when it’s heating/cooling the liquid or doing nothing. The mode is controlled by the control unit. We plan to use Peltier modules from the TEC1 family. We will use the same set of modules to perform both heating and cooling. We will use H-bridges to achieve this.

The Temperature Control Unit is supposed to generate enough heat in heating mode and be cold enough to absorb heat fast in cooling mode. It should be able to raise the temperature of 250 ml liquid by 10℃ within 5 minutes or lower the temperature of 250 ml liquid by 10℃ within 7 minutes.

Requirement	Verification
1. Able to raise the temperature of 250 ml of water by 10℃ within 5 minutes. 2. Able to lower the temperature of 250 ml of water by 10℃ within 7 minutes.	1. Add 250ml of room temperature water to a container, then attach our module to it. 2. Use switches to simulate the inputs from the control unit. Send “heat” or “cool” signal to the module. 3. Monitor the temperature of water using a thermostat. Record the time it takes for the water to raise or drop by 10℃

2.3.2 Control Unit

Power: 5V, low current
Inputs: Temperature data, User requests, and is_safe
Outputs: Control signals to temperature control unit and user interface

The Control Unit takes 3 inputs, 2 of which are used in temperature control: “desired temperature” from user inputs, and “current temperature” from the sensor. After comparing these two temperatures, the control unit then sends a signal to the temperature control unit to perform the corresponding task.
The control unit also takes an input (“is_safe”) from the safety module. This signal indicates if the system is operating normally. If not, the control unit would stop any ongoing process until the system is back to a normal state.

The Control Unit should be able to stop all activities of the Temperature Control Unit when receiving “0” from the Safety Module.
When receiving “1” from the Safety Module, the Control Unit should correctly compare the current temperature and the desired temperature, and then send a proper signal to the Temperature Control Unit and let it switch into the right mode.

The Control Unit outputs 2 bits, where “0x” means “idle”, “10” means “heating” ,and “11” means “cooling”.

Requirement	Verification
1. (Top priority) If Safety Module output ('is_safe' signal) is 0, output should be the 'idle' signal. 2. When the current temperature is at least 2℃ below the desired temperature, output should be the 'heating' signal. 3. When the current temperature is at least 2℃ above the desired temperature, output should be the 'cooling' signal.	1. Use switches to simulate the inputs from the Safety Module. See if the Control Unit outputs the "idle" signal. 2. Set the desired temperature to 2℃ above the current temperature. Check if the Control Unit outputs the "heating" signal. 3. Set the desired temperature to 2℃ below the current temperature. Check if the Control Unit outputs the "cooling" signal.

2.3.3 Infrared Temperature Sensor (Thermostat for Water)

Input: 5V from power supply
Outputs: 8-bit temperature data for control unit and user interface

This module measures the temperature of water (or any other liquid inside the container), converts the measurement to an 8-bit integer, and sends it to the control unit. We are planning to use an infrared sensor for this module.

The output should be an 8-bit integer.

Requirement	Verification
1. The error should be within 3℃ (compared to a thermostat measuring the water directly).	1. Place the infrared sensor at least 5cm above the surface of a cup of water, also place another thermostat inside the water. Compare their readings. Repeat this process using cold, room temperature, and hot water.

2.3.4 User Interface

Inputs: 5V from power supply, temperature data from Thermostat for water, and control signals from Control Unit
Output: User requests to control unit

We plan to have the following features on our product:
An on/off switch that controls the power supply.

A pair of +/- buttons to allow users to set the desired temperature freely (within the range 0-50℃). (Allow the user to change the temperature quickly by holding the button; default step size: 1℃/press)
A stop button to stop any ongoing process (and clears desired temp.)
A 7-seg display for desired temperature, another 7-seg display for the current temperature.
A 3-color LED indicating the current state(red for heating, blue for cooling, and green for task_completed)

The Power Supply should be turned on after the On/Off button is pressed when the system is off.
All units should come to a stop after the On/Off button is pressed when the system is on.
The desired temperature should change immediately by 1℃ after the +/- button is pressed and should continue changing if the button is held.
When the desired temperature is higher than the current temperature, the status LED should be red.
When the desired temperature is lower than the current temperature, the status LED should be blue.
When the desired and current temperatures are equal, the status LED should be green.
When the system is not heating/cooling the liquid, the status LED should be off.

Requirement	Verification
1. Current temperature display should be 2-digit decimal integer, and equal to the measurement rounded down. 2. Desired temperature should be displayed as a 2-digit decimal integer between 0-50.	1. Connect LEDs to the binary output of thermostat; compare the integer part to the display (should be equal)

2.3.5 Power Supply

Outputs (power): 5V for control unit, thermostat for water, user interface, pressure sensor and temperature sensor in safety module, and 12V 15A for temperature control unit

Supplies 12V for each Peltier module; 5V for other modules. We are planning to use a fuse wire in our power supply module, so that power can be cut off when current is too high.

Requirement	Verification
1. The power supply must provide an	1. Use an oscilloscope to monitor the

open-circuit voltage in the range of 4.5-5.5V.	output. Check if the voltage always stays in the range 4.5-5.5V.

2.3.6 Safety Module

Power: 5V, low current
Input: none
Output: is_safe signal (0 or 1)

The safety module will include two parts:

(1) A temperature sensor that monitors the temperature of the circuit;
(2) A pressure sensor that measures the weight of items in the box.

When the circuit temperature is too high, or weight is too small (when trying to heat an empty container), the safety module would signal the control unit to enter the stop (idle) state.

The safety module should output a “0” (indicating that it’s not safe to continue heating/cooling) in either of the following conditions:

(1) The circuit temperature (measured using some temperature sensor) is above 60 ℃ (or some other suitable value);
(2) The weight placed in the box (measured using some pressure sensor) is less than {weight of container + 100g}

Otherwise, the output should be “1”, indicating that the system is operating normally.

Requirement	Verification
1. The Safety Module must output a “0” when the circuit temperature is above 60℃. 2. The Safety Module must output a “0” when the weight inside the box is less than the weight of container plus 100g.	1. Load enough weights first to make sure this verification is not affected by requirement 2. Then intentionally short the circuit with low voltage supply to raise the temperature in a controlled fashion and check if the output turns to “0” after the temperature reaches 60℃. 2. Load enough weights to see “1” being output by the Safety Module. Remove the weight and check if the output turns to “0”.

2.4 Schematics

2.5 State Diagram

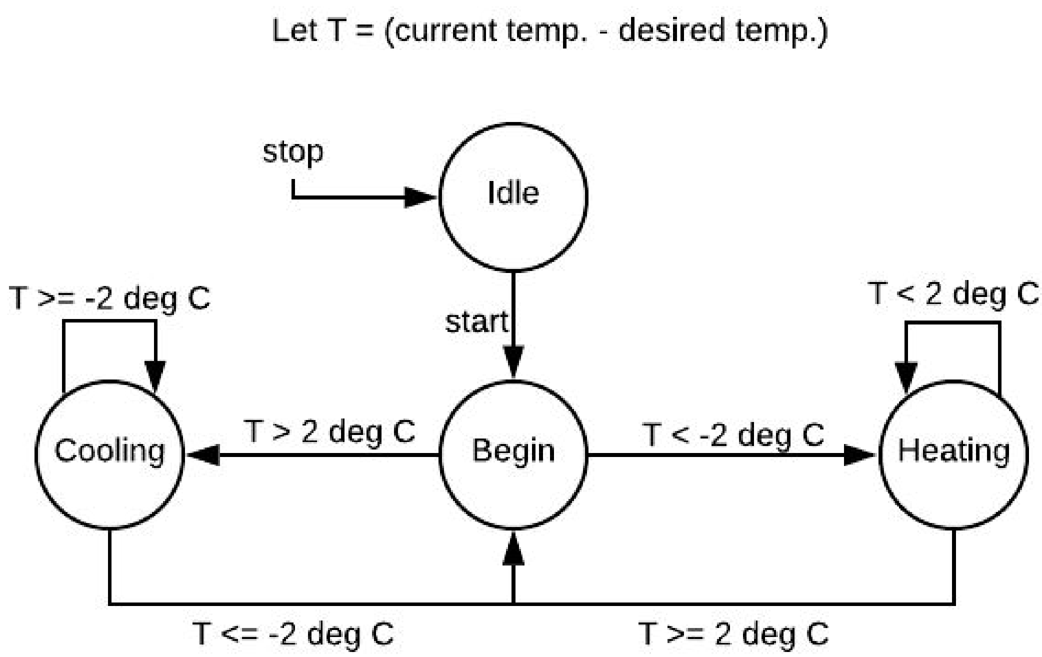

Figure x.y State Diagram for Control Unit

2.6 Calculation and Simulation

Given that water has a specific heat of 4.2kJ/(kg*℃), it takes about 1kJ to heat 250ml of water up by 1℃. Our temperature control module is expected to heat up 250ml of water by 10℃ within 5 minutes, so the required power is 10kJ/300s = 33W. The actual value would be higher since we also need to take efficiency into consideration. According to the datasheets, each piece of TEC1-12706 has 50W power. The overall efficiency should be 22% if we use 3 pieces, or 17% if we use 4.

3 Tolerance Analysis

According to our high level requirement, the final temperature should have an error of at most ±5℃ compared to the desired temperature. This error range is directly related to our control logic and the accuracy of the infrared sensor used to measure water temperature. We plan to have the control logic try to keep the liquid temperature within desired temperature ±2℃, therefore we can tolerate a ±3℃ error in the infrared sensor measurement.

4 Cost Analysis

5 Schedule

6 Ethics and Safety

There are several safety concerns about our project. The Peltier modules we are planning to use require high current (reference datasheet). Currents as large as a few amps could easily burn the circuit if wires are not chosen properly. To avoid such accidents, we would choose our wires based on the AWG standard: use AWG20 wires for 5A paths, and AWG18 wires for 10A paths[2].

Since our product works with liquids, we need to consider the case when the liquid spills out and causes a short circuit. To prevent a short circuit from causing damage, we plan to use fuse wires in the power supply module. When the total current exceeds the max working current, the power supply will be cut off.

The Peltier modules are essentially heat pumps, so overheating would be a big concern in cooling mode. The heat removed from the liquid doesn't just "disappear". Instead, it is simply transferred to the other side of the module. We worry that the accumulated heat might be a threat to our circuit. Therefore, we have a temperature sensor in our safety module, which would prevent the circuit from generating or transferring more heat at high temperatures. We also plan to use extra heat dissipation modules if necessary, like heatsinks and fans.

The high heat capacity of water (4.2kJ/℃) defines the high power nature of our product. Despite that, we still want to avoid wasting energy as much as possible. We do not want the user to heat up or cool down an empty container, so we also plan to add a pressure sensor or some equivalent device to the safety module. The system would not operate unless there’s enough liquid inside the container.

References

[1]M. Simon, “Ember Ceramic Mug and Ember Travel Mug reviews: Smart at home, less so on the road,” *TechHive*, 09-Jul-2019. [Online]. Available: https://www.techhive.com/article/3405525/ember-ceramic-mug-review-ember-travel-mug-review.html. [Accessed: 11-Feb-2020].

[2]“Wire Gauge and Current Limits Including Skin Depth and Strength,” *American Wire Gauge Chart and AWG Electrical Current Load Limits table with ampacities, wire sizes, skin depth frequencies and wire breaking strength*. [Online]. Available: https://www.powerstream.com/Wire_Size.htm. [Accessed: 11-Feb-2020].