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

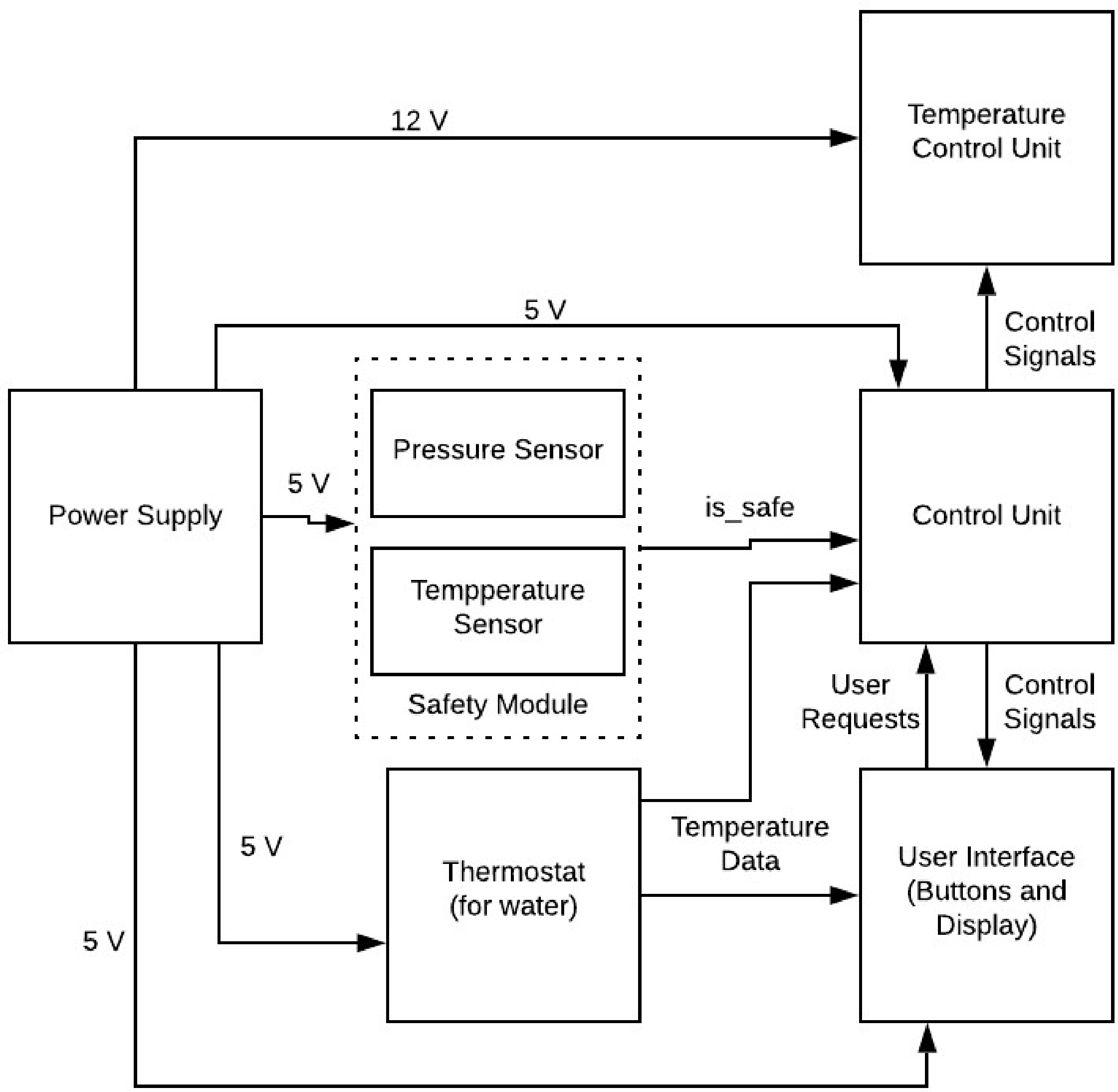

Figure 1. High Level Block Diagram

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, then send control signals to the temperature control unit to perform either heating or cooling.

2.2 Physical Design

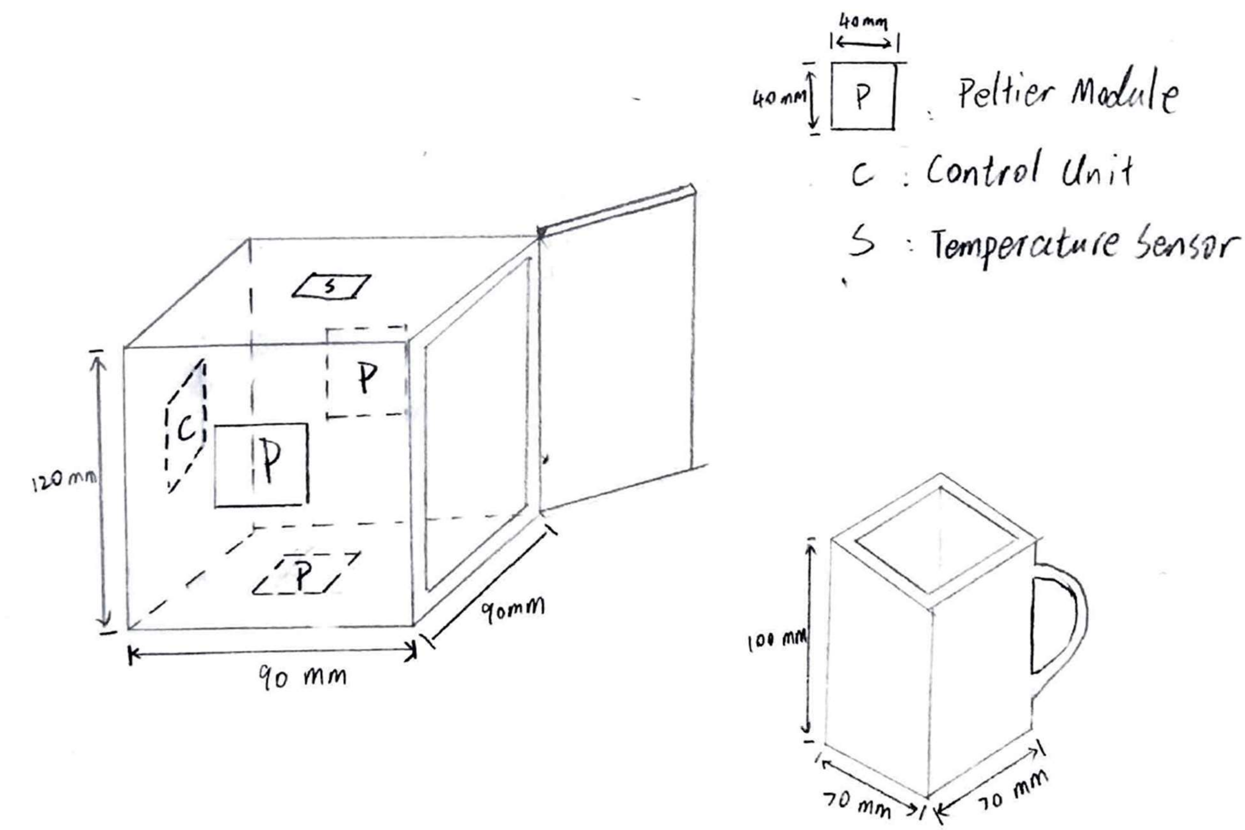

Figure 2. Physical Design

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 Functional Overview

2.3.1 Temperature Control Unit

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. Whether we use the same set of modules to perform both heating and cooling or use different ones to perform different tasks is undecided yet.

2.3.2 Control Unit

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.

2.3.3 Thermostat for Water

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.

2.3.4 User Interface

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)

2.3.5 Power Supply

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.

2.3.6 Safety Module

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.

2.4 Block Requirements

2.4.1 Temperature Control Unit

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.

2.4.2 Control Unit

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.

2.4.3 Thermostat for Water

The output should be an 8-bit integer. The error should be within 1℃ (compared to a thermostat measuring the water directly).

2.4.4 User Interface

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.

2.4.5 Power Supply

The Power Supply should be able to provide a voltage in the range 11-13V for the Temperature Control Unit. It also converts the 12V to a voltage in the range of 4.5-5.5V for all other modules.

2.4.6 Safety Module

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.

2.5 Risk Analysis

We believe the greatest challenge in our project is to make an efficient temperature control unit. Due to the high-level requirement on cost, we cannot use as many Peltier modules as we want.

In order to reach our goal with the limited resources, we will have to think carefully about all the features that might influence the efficiency.

Since the Peltier modules are not directly installed on the cup, transferring heat from the module to the cup, and then from the cup to the liquid inside would certainly result in some heat loss. We need to think of ways to ensure close contact between the Peltier modules and the cup, so that heat loss can be reduced.

Peltier modules also have another efficiency issue due to their small size. Since the hot side and cold side are very close, heat would naturally flow from the hot side from the cold side. To reduce this heat flow, we will need to ensure that the side that is not in contact with the cup must be able to exchange with the environment easily.

3 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].