Self-Heating Cup

ECE 445 Design Document

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1 Introduction

1.1 Objective

Coffee and tea culture are long living both in the east and the west. Either of them require warm or hot water to make. These days, although cafes like Starbucks or even the Daily Byte in ECEB are everywhere in the United States, the temperature of the coffee or tea usually does not hold for a long time. Especially for people who work in the office, they don’t want to walk in and out to reheat their drinking. Scenarios like a long meeting and your coffee was totally cold after one hour and you don’t have access to a microwave at that awkward moment. Therefore, our objective is to always keep your coffee or tea warm whenever you drink it with our designed mug with a self-heating coaster.

1.2 Background

Our design is specific for people who work in offices and probably will spend much time in their seats. As we briefly explained above, there are for sure products that could heat your beverage like a microwave. However, they are not everywhere. The microwave in ECEB was located in the lounge on the 3rd floor. We do see some professors heat their beverage occasionally but more often they don’t want to walk up and down stairs to just heat their coffee. The first point of our design is to allow people to stay focused on their stuff and don’t have to walk around when working.

The previous project idea Electric Thermos Box, contributed by Celine Chung, Tingfeng Yan and Zerui An is a good approach for solving this problem, but we think that it is still too large to prevent more convenient usage. Their design looks like a small scale microwave, which like we explained above, you mostly don’t want to bring a microwave in scenarios like in-person meetings and etc.. This comes with our second point that makes the design portable.

There’s also a similar product on the market called Ember[1], which is a self-heating mug that has a fully-integrated design. But it also has several problems: according to user reviews, it suffers limited heating ability and also potential failure due to integrated design in one mug. Putting the battery, sensors and controllers underneath the hot mug may not be a safe and efficient approach. Based on that, we decided to use a constant power supply since the heating part is only the coaster instead of the mug.

Our design will consist of two parts: a cup for heating and drinking as well as a coaster that provides the power for the cup. For one cup, we can have several coasters in different areas for more portable heat-and-drink experience. The coaster can provide some functionalities like power and controlling, to help simplify the cup's design that makes it safer and more reliable.

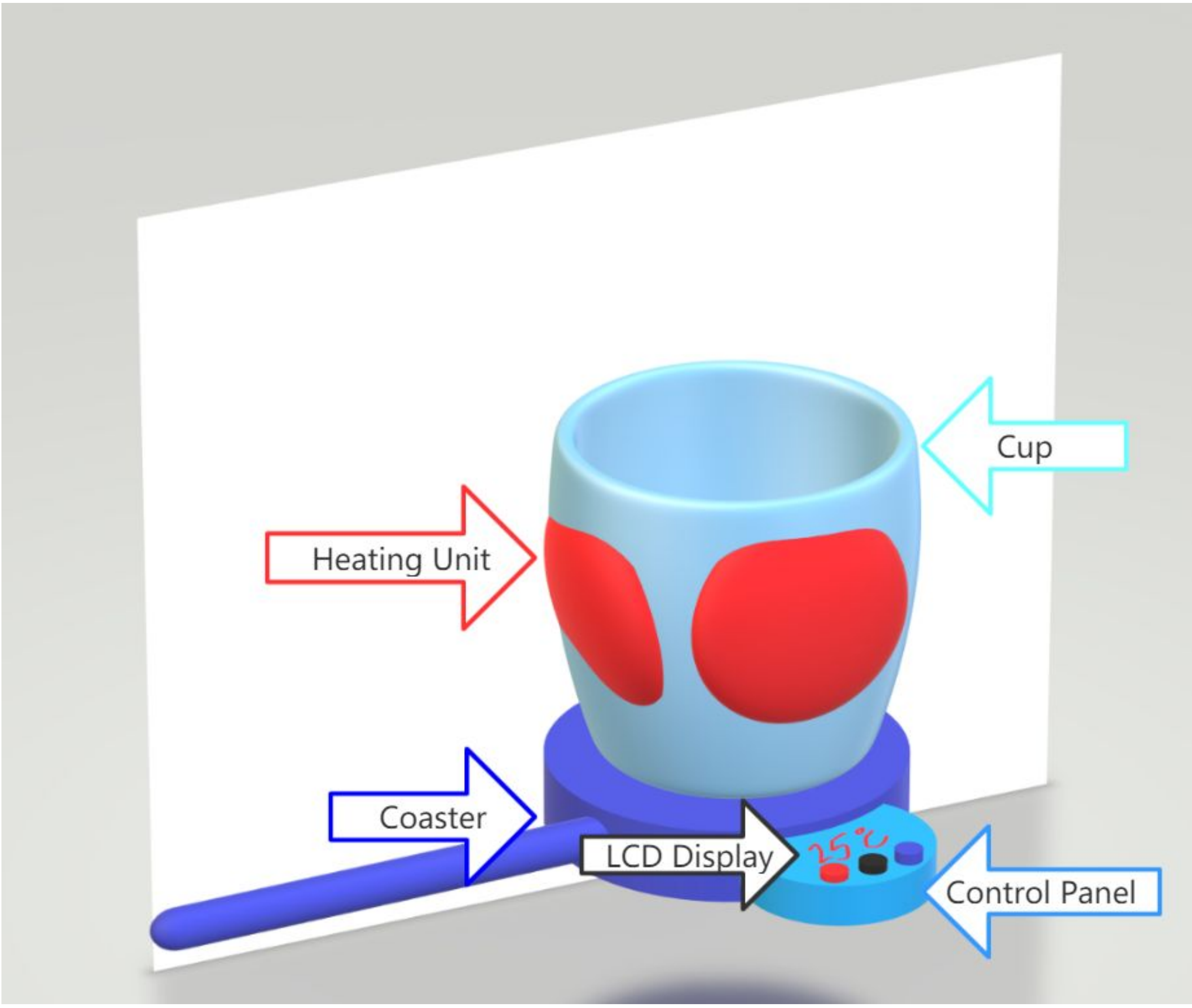

Figure 1. Physical Design for Self-Heating Cup

1.3 High-level Requirements

- The heating process within 10 mins to heat the liquid to a certain temperature.
- The difference between the temperature we set and the temperature of the liquid after heating should be less than 5 Fahrenheit.
- The whole design should be fit in a bag and can be carried to anywhere conveniently.

2 Design

High level description of the design

Our design is located heavily on the heating coaster, which requires a power supply, a heating unit and a control unit. The power supply takes in the standard 110V voltage input and powers the rest of the design using several linear regulators. The heating unit will heat the mug to a comfortable temperature to use. The control unit takes the responsibility to monitor display the temperature measurements and communicates with the control panel, temperature sensors and the heating unit.

Block Diagram

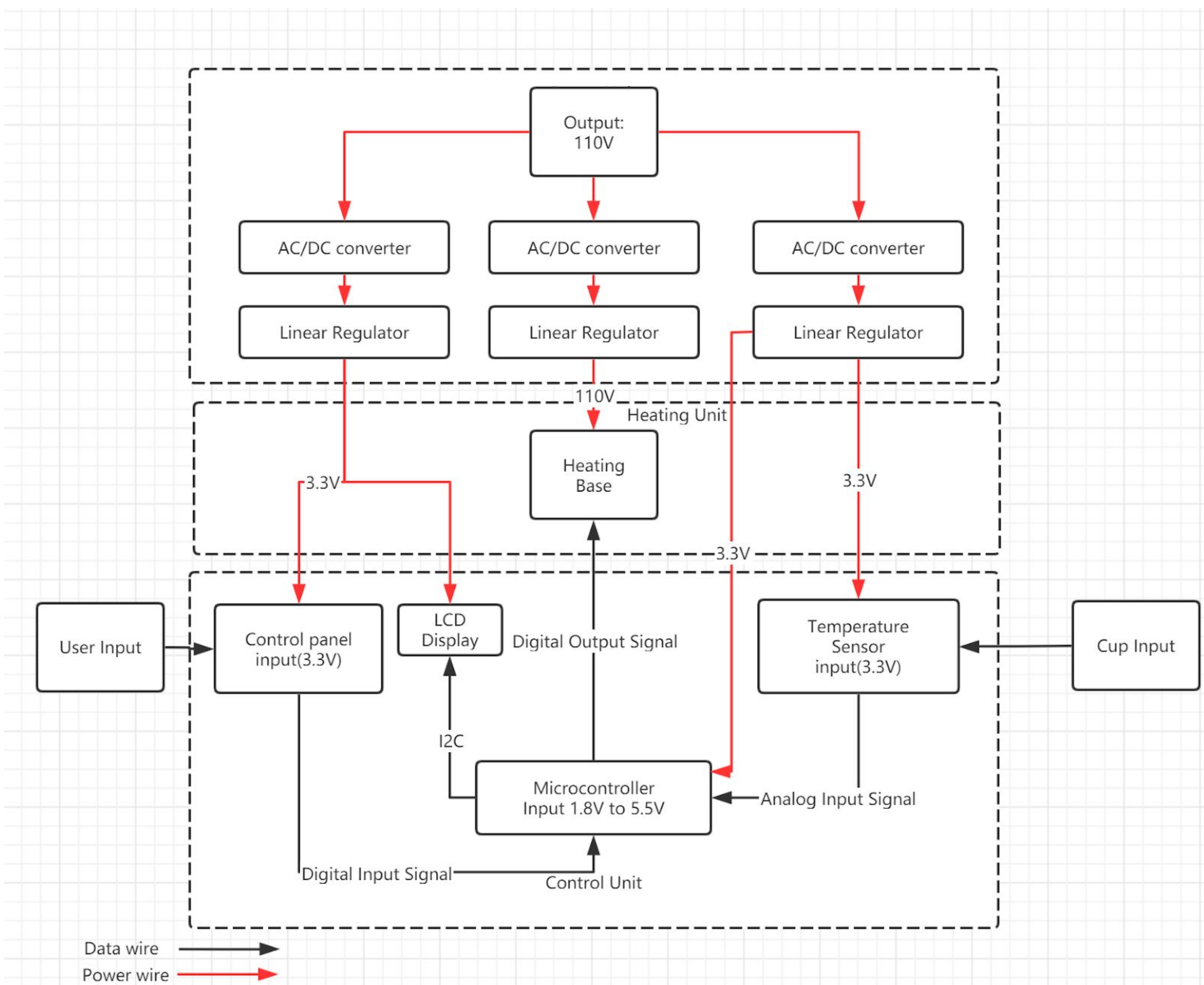

Figure 2. Block Diagram for Self-Heating Cup

State Machine

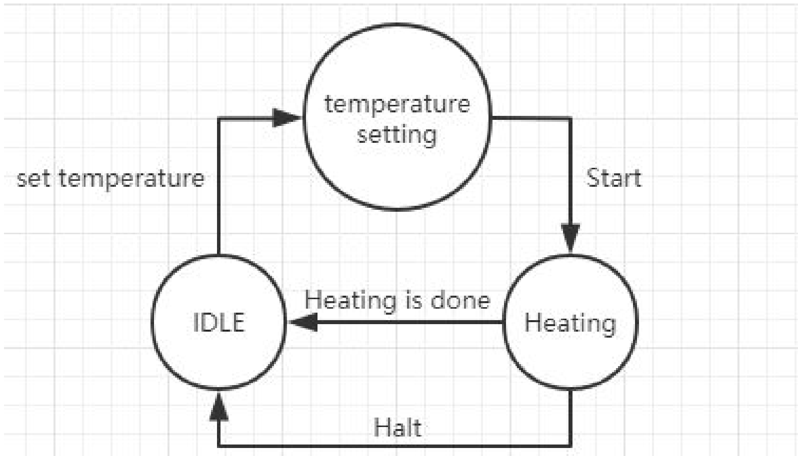

Figure 3. State Machine

2.1 Power Unit

2.1.1 AC/DC converter

This is used to convert standard AC input to DC input to other subsystems.

Requirement	Verification
Converting the standard 110V AC input to 110 V DC input using a rectifier circuit.	**Step 1:** Use a digital multimeter to measure both AC and DC output, which should be both ~110V.

2.1.2 Linear Regulator

This is used to regulate the 110V DC input voltage to desired input voltage to other subsystems.

Requirement	Verification
The linear regulator should regulate the DC output voltage from the AC/DC converter to desired input voltage to the Control panel(~3.3V),	**Step 1:** Use a digital multimeter to measure the DC output voltage from all the linear regulators.

microcontroller(1.8V~5.5V) and Temperature sensor(~3.3V).	Ranges should be matched with that specified in the requirement.

2.2 Heating Unit

2.2.1 Heating

This is the heater we use to heat the cup and the input of the heater should be 110V.

Requirement	Verification
1. The coaster should heat 200 ml beverage to ~40(less than 50 celsius) celsius in ~15 minutes. 2. The error should be less than 5 Celsius.	**Step 1:** Place 200ml water in the cup; send the start signal to the heating unit. **Step 2:** Use a thermometer to ensure that the temperature of the coffee reaches around 40 celsius (less than 50 celsius) in ~15 minutes. **Step 3:** Compare the reading value from the thermometer and the temperature we set, make sure the difference is less than 5 Celsius.

2.3 Heat insulator

2.3.1 Insulator layer

There is a heat insulation layer around the handle of the mug to prevent the user's hands from overheating.

Requirement	Verification
Users can hold the cup safely when the liquid in the coffee cup is around 50 celcius.	**Step 1:** Put a thermometer in the cup to get the temperature of the coffee. **Step 2:** Use the heater to heat the cup until the thermometer shows that the temperature of the coffee reaches 50 celcius, which is our maximum operating temperature.

	Step 3: Touch the handle to see if the handle is safe to hold for humans.

2.4 Control Unit

2.4.1 Control panel

There is a screen to show the current temperature and the temperature set by the user. There are four buttons: the first one is to raise the temperature, the second one is to lower the temperature, the third one is to begin the heating process, the fourth one is to stop the heating.

Requirement	Verification
There are 3 buttons on the control panel. One button is for implementing “start” and “halt” for the heating process. The other two will implement the temperature changes up and down.	**Step 1**: Put a 200ml water filled cup and press the start/halt button. **Step 2:** Set to 30 Celsius degrees and wait for it to be heated. **Step 3:** Measure the water temperature and make sure the water temperature range only has +-5 Celsius degree error. **Step 4**: Set to 50 Celsius degrees and wait for it to be heated. **Step 5**: Measure the water temperature and make sure the water temperature range only has +-5 Celsius degree error.

2.4.2 LCD Display

This is used to display the power on/off and temperature modification.

Requirement	Verification
1 The LCD display can connect with the microcontroller over I2C bus.	**Step 1**: Connect the LCD display to the ATmega328p via I2C bus.

	Step 2: Upload the test driver code to ATmega328p and execute. **Step 3**: Verify that LCD display will have the desired output. .

2.4.3 Temperature sensor

This sensor is used to monitor the temperature of the cup.

Requirement	Verification
The temperature sensed by the sensor on the base should not be too different from the real temperature of the liquid (less than 5 celcius)	**Step 1:** Put a thermometer in the cup to get the temperature of the liquid. **Step 2:** Connect the temperature sensor to the microcontroller. **Step 3:** Use the heater to heat the cup until the thermometer shows that the temperature of the coffee reaches 40 celcius. Verify the microcontroller can read the sensor's analog value. **Step 4:** Verify that the difference between the temperature sensor on the base and the thermometer should be less than 5 celcius.

2.4.4 Microcontroller

Requirement	Verification
1. The microcontroller can communicate with control panel over digital input; 2. The microcontroller can communicate with LCD display via I2C bus;	**Step 1A**: Connect the microcontroller with the control panel via digital input; **Step 1B**: upload and run the test code for reading digital input to see if it reads correctly. **Step 2**: Follow the Verification for LCD Display;
3. The microcontroller can communicate with the temperature sensor via analog input;	

4. The microcontroller can send the digital output. 5. The microcontroller will operate during the whole heating process; it won't fail due to overheating.	**Step 3**: Follow the Verification for Temperature Sensor; **Step 4A:** Connect the microcontroller with the digital output, which is connected to an external voltmeter. **Step 4B:** Use the voltmeter to verify the output is what we need. **Step 5A:** Set up a 75 °C environment, verified by thermometer, to simulate our 50 °C max operating temperature + 25°C buffer temperature. **Step 5B:** Test if the microcontroller will still be functional.

2.5 Risk Analysis

The heating unit is the major risk inside our design since we want to keep a high power within a relatively small coaster. Also, the heating unit is the part that communicates with parts that are in the microcontroller. Therefore, problems like overheating during the heating process should be considered seriously. Since our design will deal with liquid like coffee, making sure that spilled liquid won't affect the full functionality and lead to potential fire.

On the other hand, the temperature measurement could be another risk in that usually mugs are made of ceramics. The reason for that is ceramic retains heat better than materials like glass both in terms of conduction and convection. (i.e. two major ways of heat loss) [2] However, in the case of heating ceramic mug using microwave, the top side of the mug is usually very hot while the bottom side is still cold and hence the temperature measurement in our design is crucial to maintain the mug comfortable to use and temperature-accurate in a range. (i.e. 30 celsius ~ 40 celsius is acceptable).

2.6 Tolerance Analysis

The core of our project is the heating unit. We want to heat the ceramic cup within around 10 mins. We decided to use a silicone rubber heater pad[7] to cover the cup to ensure uniform heating. The ideal power of the silicone rubber heater pad is 30W/ in^2 (4.65W/ cm^2). We will assume the size of the cup with 3.5inch in height and 1.5 inch radius.

Therefore, we anticipate the width and height of the heater pad are:

Width: 2π * 3.5 inch = ~ 9 inch
Height: 3 inch

The area of the whole heater pad and expected power then will be:

Area = Width * Height = 27 in^2
Power = Area * Power per in^2 = 27 in^2 * 30W/ in^2 = 810 W

We assume using 200ml(0.2kg) water to be heated and the heating time of water is as follows[8]:

$$\frac{Amount\ of\ water\ in\ kg * (end\ temperature\ in\ ℃ - start\ temperature\ in\ ℃) * (4168\ J/kg/℃)}{heating\ power\ in\ Watts}$$

Theoretically, using 0.2 kg normal tap water with a starting temperature of 7℃ and heat up to 50℃ will get the lower bound of the time heating process:

$$\frac{0.2\ kg * (50℃ - 7℃) * (4168\ J/kg/℃)}{810W} = 442.5 \text{ secs} = 7.38 \text{ mins}$$

In practice, we have to take the heat efficiency into consideration:

1. It takes ~3 mins to heat the heater pads to desired heating temperature.
2. There is part of the heat loss into the air. However, this could not be done in paper work at this point so we anticipate 50% efficiency of our heating process.

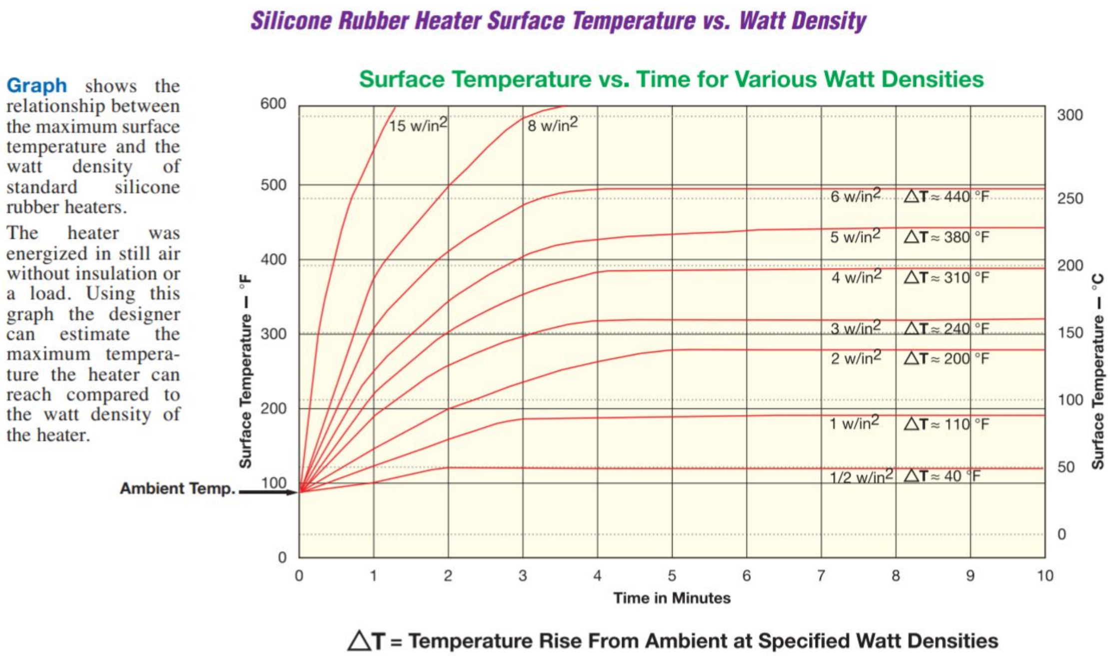

Figure 4: T vs Watt graph (from Silicone Rubber Heater Datasheet) [9]

2.7 Project Differences

2.7.1 Overview

Both the original solution and our solution are trying to address the problem of conveniently drinking with desired temperature in our daily life. The original solution proposes to use a heating box that people can put mugs into to heat the liquid. The box will behave similar to an oven that uses heated/cooled air inside the box to conduct the generated heat to the liquid. In their design, while the mug can be some ordinary one, all the logic and PCB layout are built into the heating box.

In our design, we will design a coaster with a digital controlling circuit with the mug having the heating unit. The coaster will have a microcontroller and the necessary power converters that drive the basic controlling unit; the mug will contain the heating unit that will directly heat the liquid underneath the mug.

The major differences between our design and the original design:

- **Reduced size.** Since our design only has a coaster and a mug for a whole system, the reduced size will have more convenience to use in daily life.

- **Tradeoff**: reduced size requires more complexities in designing the mug and the coaster; also have to pay more attention to safety issues like overheating or waterproof problems.

- **Different heating techniques.** Instead of heating the liquid via the air inside the Heating Box, we will drive the heating unit inside the mug itself to have a more direct access for heating, thus reducing the waste of energy.
  - **Tradeoff:** the heating process will be more efficient for our design. However, it requires connection to be safe for heating, including waterproof connectors

2.7.2 Analysis

Our design aims to increase the convenience. The size of the previous project is still impossible to carry around for individuals. However, our project can let users carry conveniently like going to work. The mug and coaster can be perfectly fitted in a backpack. Our heating process lets the heating layer directly contact the liquid which will largely save time and the energy compared to the previous project which has the air as the medium between the cup and heater. According to the previous calculation, it only takes about 15 min to heat the liquid to 40 Celcius.

2.8 Calculations

2.8.1 Labor Cost

Member	Hourly wage	Weekly hours	Weeks	Multiplier	Cost
Chengyao Zou	$50	12	12	2.5	$18,000
Peiming Wu	$50	12	12	2.5	$18,000
Haonan Wang	$50	12	12	2.5	$18,000

2.8.2 Parts Cost

Part	Cost(prototype)
AC/DC rectifier PCB	$ 10

Linear regulator PCB	$ 2
3 inch * 9 inch Silicone Rubber Heaters	$ 30
3.5 inch height Ceramic cup	$ 5
Control panel (includes buttons)	$ 2
Microcontroller (ATmega328p)	$2.08
JANSANE 1602 LCD Display Screen Blue	$5
Heat insulator	$ 5
Total	
Grand Total	

2.9 Schedule

Date	Chenyao Zou	Haonan Wang	Peiming Wu
4/20-4/24	PPT for Review	PPT for Review	PPT for Review
4/27-5/6	Final Report	Final Report	Final Report

3 Safety and Ethics

For our project, we have to guarantee safety while using our design to drink. While it involves both powering and heating in a relatively small space, there are several potential safety issues that we need to pay attention to.

The first issue is about heating: while heating the liquid, the extra heat could not only interrupt the functionality of our design but also could destroy other parts if it exceeds the thermal limit. For example, the ATmega328p’s operational temperature has a maximum of 85 °C [3]. During our design and building process, we will closely monitor the heating temperature, isolate or dissipate these extra heat as much as we can to prevent thermal issues from happening. We can also set a software temperature barrier using the internal temperature sensor in ATmega328p to cut off the system if it is alarmingly overheated.

The second issue could come from the potential hazard from the liquid, that could cause the water damage to the system. Our solution is to solidify our system, including PCB, to be water-resistant from hot water and moisture. Some post-processing of the PCB can make it waterproof up to IP48 protection level. We will aim for the IP48 protection level, as we should also be safe in events like spilling water accidentally over it. The PCB will be mainly on the heating coaster, so water-proof is mainly about the heating coaster and the connections, while the cup itself would be a fully-integrated design.

As safety comes first in our design, it also corresponds to the first goal in IEEE Code of Ethics: " hold paramount the safety, health, and welfare of the public..." [4] We will always put safety as our top priority for our project. It also corresponds to the ninth goal in IEEE Code of Ethics, "to avoid injuring others, their property, reputation, or employment by false or malicious action;" [5], that we will eliminate the possibility of injuring others by false.

We will share our design document and open-source all materials needed for this project. This is also aligned with the tenth goal in IEEE Code of Ethics, where it states that "to assist colleagues and co-workers in their professional development and to support them in following this code of ethics." [6]. Thus, we encourage students to learn, share and improve this project further in the future.

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