Bluetooth Burner Project Proposal

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Team 63

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1. Introduction

(a) Problem

Each day, millions of people drink warm coffee, tea, or soup. However, one common challenge faced is maintaining the ideal temperature over time, especially in large sit-down environments or during extended periods of consumption. Moreover, traditional methods like reheating in microwaves can degrade the quality of the drink or food, while passive insulating containers often fail to maintain the desired temperature for long. The repeated process of reheating can be time-consuming and energy-inefficient, making it a less than ideal solution for both home and office settings. This results in a compromised experience, as the taste derived from hot beverages and soups is significantly tied to their warmth. Currently, the beverage warmer market only focuses on two main targets, high-end and low-end, leaving no options for a quality, yet affordable warmer.

(b) Solution

To address this issue, we propose to make a heating pad with Bluetooth capabilities so that users can adjust temperature to three settings. This allows users to change the heating pad to their ideal temperature to the requirements of the beverage or soup. Integration of Bluetooth allows for a convenient and remote control, enabling users to adjust settings directly from their smartphones. The pad will be energy-efficient and durable, suitable for both home and office use. It will also feature a smart timer function for automatic temperature adjustments or shutdown, promoting convenience and energy savings. Our design prioritizes eco-friendliness by using sustainable materials, aligning with consumer demand for environmentally responsible products. The surface is designed to accommodate a variety of cup and bowl sizes, making it versatile for different beverages and soups. A companion app will offer control over the pad and provide hydration reminders and optimal consumption prompts. Our solution aims to bridge the market gap with a quality, affordable product, enhancing the hot beverage and soup experience.

(c) Visual Aid

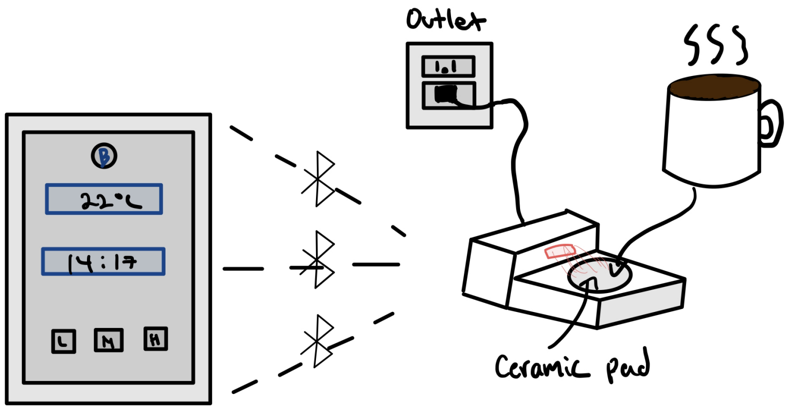

Figure 1: Visual Aid

(d) High-Level Requirements

1. The heating pad should have temperature capabilities of $30 - 60^o$ C for heating and reach at least -10^oC for cooling.

2. The infrared sensor observing the heating pad should be able to identify pad temperature within $1^{o}C$
3. The device should communicate and receive information such as change in temperature via an iPhone app in a range of at least 10 - 20 meters.

2. Design

(a) Block Diagram

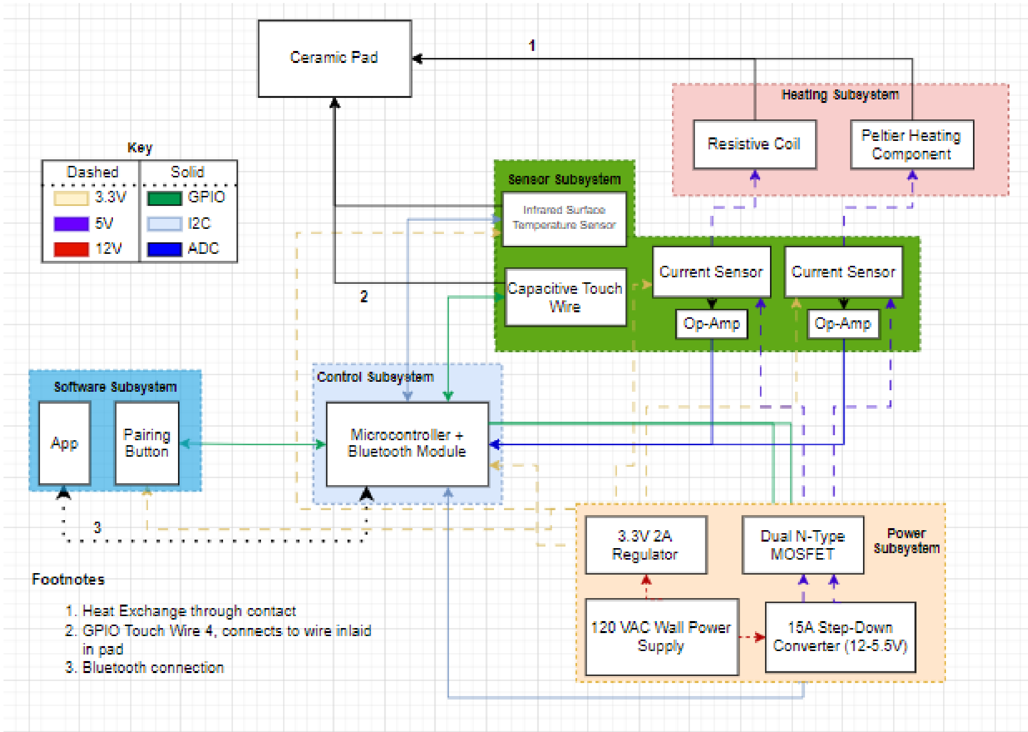

Figure 2: Block Diagram

(b) Subsystem Overview & Requirements

i. **Software**

The software subsystem of the Bluetooth Burner serves as the graphical user interface for interacting with the device, providing a seamless and intuitive experience. Moreover, the primary function of the software subsystem is to enable users to initiate the Bluetooth pairing process, adjust temperature settings, and monitor the status of their Bluetooth Burner in real time. At the heart of the subsystem lies the bluetooth communication facilitated by the ESP32's onboard module, which bridges the gap between the user's commands and the device's operational logic in the control subsystem. By using ESP32 communication protocols, the software subsystem is able to send and receive data, which will utilized for visual indicators of the device's current state and providing feedback on system statuses as detected by various subsystem.

Requirements:

A. Software subsystem must be able to communicate with the control subsystem to change the temperature to three pre-set settings, and a single cooling, with a precision of $1^{o}C$ for each setting.
B. Phone app must be able to connect to device within 10 - 20 meters of it
C. Pairing button must initiate pairing search for Bluetooth devices and successfully connect within at most one minute

ii. **Control**

The control subsystem serves as the central processing unit of the Bluetooth Burner, powered by an ESP32-WROOM-32E-H4 equipped with a Bluetooth module. Its primary functions include controlling the heating/cooling devices, monitoring the burner's status, and facilitating communication with the user's device via Bluetooth. It receives input from the sensor subsystem, which includes an infrared temperature sensor and a current sensor, the former using I2C connection while the latter uses ADC pins. Additionally, the control subsystem links with the software subsystem, which allows users to interact with the burner through a dedicated application. The ESP32 also connects to a button that initiates the Bluetooth pairing process. This subsystem is also responsible for operating the power relay, which switches the MOSFETS responsible for the Peltier module and the Resistive Coil.

Requirements:

A. The ESP32 must initiate the Bluetooth pairing process within 30 seconds upon user command through the pairing button, ensuring a quick and seamless connection with the user's device.
B. The ESP32 must consistently read data at a rate of 2.2 MHz from the infrared and current sensors via the I2C communication protocal and ADC pins, ensuring accurate and timely monitoring of the burner's temperature and electrical current.
C. The control subsystem should control power relay, enabling the device to toggle the heating in response to the app's commands and the sensor's feedback.

iii. **Sensor**

The Sensor Subsystem serves to provide real-time monitoring and data collection regarding the operational status of the burner. It includes two current sensors, a capacitive touch sensor, and an infrared surface temperature sensor. These sensors that comprise the subsystem are essential in ensuring the safety, efficiency, and effectiveness of the heating process, each serving a unique purpose. The two current sensors are connected to the power lines for the heating subsystem to monitor the power output, while the GPIO capacitive touch pin helps to detect human contact through the inlaid wire on the ceramic pad, and the infrared surface temperature sensor provides temperature control to prevent overheating. The sensor subsystem communicates relevant information to the controller and power subsystems using I2C for the IR sensors, and GPIO-ADC pins for the MOSFETS and the current sensors respectively. In the case of the ADC pins connected to the current sensors, the output of our current sensors goes through an amplifier to take it from a range of 0-110mV to a readable range on the ADC pin.

Requirements:

A. Infrared sensor must accurately measure the surface temperature of the heating path with a precision of $\pm1^{\circ}$C, providing feedback to the control unit to ensure the user set level is maintained
B. The current sensors should have an accuracy of $\pm0.5\%$ of the measured value to ensure precise monitoring of electrical consumption and to detect any unusual current draw.
C. The GPIO capacitive touch wire should make sure to respond within 0.1-0.5 seconds of a human touch to protect users from any heat damage
D. Both the current and infrared sensors must be able to read the data of their respective purposes despite negligible obstacles or noise

iv. **Heating**

The heating subsystem is responsible for heating and cooling the pad upon which our user can place items. The heating device we are using is a Resistive Coil using Nichrome wire. Our cooling device is the CP40236 Peltier Module. The two heating elements will be powered using 5V from our 12V-5V Step-Down Buck Converter. The ESP32 is in control of turning the heating elements on/off. The pad we are using will be made of ceramic and go on top of the heating subsystem. The IR Temperature sensor will relay the surface temperature of the pad back to the ESP32 so it can better control the heating elements. Requirements:

A. Resistive Coil must be able to go up to 65^{o}C.
B. Resistive Coil must be able to impart (heat energy transfer) at least 11J $\pm$ 2J per minute.
C. Peltier module must have a lower-bound temperature for T_C (cold-side temperature) of -10^{o}C.

v. **Power**

This subsystem is responsible for powering the control subsystem, the heating subsystem and the control subsystem. The Power subsystem takes in 12V from an AC/DC wall-adapter. This 12V is stepped down by the TPS540A50 Buck Converter to 5V to be used by the heating subsystem. The 12V is also Vin for the 3.3V AP62200WU Converter that powers the Control and Sensor subsystems. The 5V for the heating subsystem is also controlled by a Dual N-type MOSFET with the gate's connected to GPIO pins on our ESP32. These MOSFETS are able to provide our desired power to the heating subsystem and has a P_{max} of $48W$. Requirements:

A. The power subsystem must provide 3.3V $\pm$ 0.1V to the control subsystem and sensor subsytem.
B. The power subsystem must provide 5V as output from the Step-Down Buck Converter.
C. The power subsystem must provide up to 15A as output current from Buck Converter.
D. MOSFETS must be capable of switching to allow 5V to heating subsystem.

(c) Tolerance Analysis
When looking at our device, the first section that we wished to analyze was the heating

of the ceramic pad. Using small estimates of 10cm x 10cm x 2mm for the pad itself we can calculate how much energy we would need to transfer from the resistive coil using the specific heat capacity formula (with an estimate 100 J/kg^oC specific heat, and $2500kg/m^3$ ceramic density).

$$\text{Area} = L \times W = 0.1\,\text{m} \times 0.1\,\text{m} = 0.01\,\text{m}^2$$
$$\text{Volume} = \text{Area} \times \text{Thickness} = 0.01\,\text{m}^2 \times 0.002\,\text{m} = 0.00002\,\text{m}^3$$
$$m = \rho \times \text{Volume} = 2500\,\text{kg/m}^3 \times 0.00002\,\text{m}^3 = 0.05\,\text{kg}$$
$$Q = mc\Delta T = 0.05\,\text{kg} \times 1000\,\text{J/(kg°C)} \times 30\,°\text{C} = 1500\,\text{J}$$

To get the 1500J we have to check the power requirements from the resistive coil. We get

$$P = \frac{1500\,\text{J}}{30\,\text{s}} = 50\,\text{W}$$
$$I = \frac{50\,\text{W}}{5\,\text{V}} = 10\,\text{A}$$

, using the equations:

$$P = \frac{E}{t}, t = 30sec$$
$$I = \frac{P}{V}, V = 5V$$

Looking at the equations above we would need 5V and 10A, which our TPS540A50 is capable of reaching, as well as the MOSFETS we are using to control them.

Another aspect of our project that poses a potential risk is making sure that our heating pad works accurately and reliably. With various different bowl/cup sizes and materials, it may prove challenging to maintain the desired temperatures precisely. Below are some examples of different heat levels we may use and different materials of the containers. For each of these temperature ranges, using the Heat transfer calculation, we have rep-

Table 1: Tolerance Range

Temperature Range (^{o}C)	**Heat Transfer**	$\sim U$
Low (40-50°C)	U x 0.03 x 25	Approx 1.33 ± 0.2 W/m²°C
Medium (50-60°C)	U x 0.03 x 30	Approx 1.11 ± 0.2 W/m²°C
High (60-70°C)	U x 0.03 x 35	Approx 0.95 ± 0.2 W/m²°C

resented an ideal heat coefficient of the material that would be suitable for temperature maintenance at the desired levels, with a ± 0.2 to account for using the average surface area of our container being 0.03 m. When using the calculations from above we can see there is than enough power and current coming from the Nichrome coil that it will be able to transfer the necessary heat.

(d) Safety & Ethics

As our product is something that will be heated, we will make sure to have ethical and safety precautions that can help avoid burning the users or other objects within a close vicinity. As the team developing the project, we are also aware of the precautionary measures required as we work in the lab, and we will make sure to be as careful and responsible as possible to avoid any misuses of any potentially harmful materials. Our product also contains a bluetooth aspect, so we will make sure to respect the user's privacy when connecting their device.

As per the context of IEEE Code of Ethics I-2, we will make sure that users of our product understand the correct methods of usage of our product, specifically that it is not meant in any way, shape, or form to harm others or burn other items. Our team will emphasize that the heating pad may still be warm after it is turned off for a bit of time, and there will be a temperature limitation to mitigate risk of overheating.