Smart Mug

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Project No. 56

Abstract

Our proposed project is the development of a smart mug with an advanced temperature control system that maintains the desired temperature of the beverage. The intuitive app interface allows users to conveniently set their preferred temperature for different beverages and monitor their liquid intake. Our smart mug will eliminate the need for time-consuming and wasteful reheating. The device meets high-level requirements such as accurate temperature control up to 100°C, reliable and consistent connectivity, a robust and easy-to-maintain design, competitive pricing, and a safe and user-friendly design. Our design aims to offer superior functionality and affordability compared to existing products, particularly the Embur Mug. Through cutting-edge technology and design principles, our project aims to create a smart mug that offers a superior user experience at an affordable cost.

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1. Introduction

1.1 Problem

Maintaining the perfect temperature of beverages is a common issue that many people face. Drinking a beverage at the correct temperature significantly impacts its flavor and taste. For example, coffee that is too hot can scorch taste buds, while a cold drink can quickly lose its taste. This issue is also relevant in the context of other beverages, such as beer and wine, where incorrect temperature can impact the aroma and flavor of the drink. We researched existing products and found the Ember Mug, which detects the temperature of its contents and maintains them at a desired level. However, the high cost of this product makes it inaccessible to the average consumer. Our mug aims to fix these problems.

1.2 Solution

We developed a new smart mug that will have an advanced temperature control system that will ensure the beverage remains at the desired temperature, eliminating the need for reheating. The user-friendly design will include an intuitive app interface that will enable users to set their preferred temperature for different beverages. Our smart mug will be the ultimate solution to the problem of maintaining the perfect temperature of beverages, providing a superior user experience that is accessible to everyone. With our cutting-edge technology and design principles, we have made this product affordable and practical for the everyday consumer.

1.3 Visual Aid

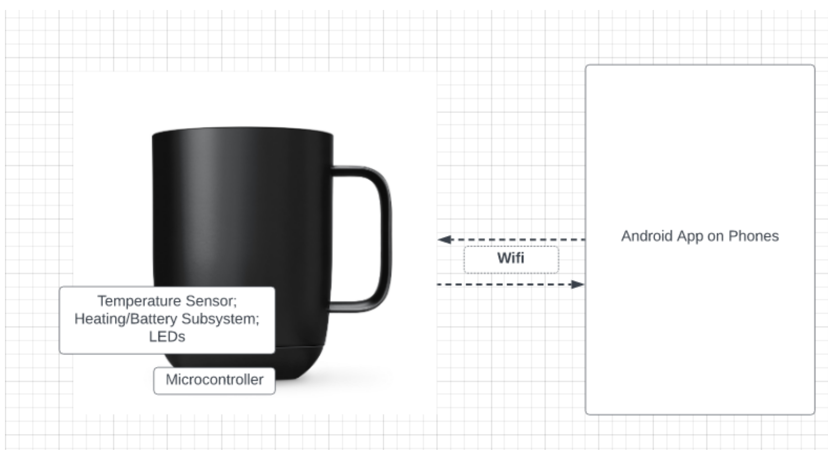

Figure 1: Visual Aid

This diagram presents a high-tech smart mug with six interconnected subsystems. The sensor subsystem, or subsystem 1, detects the temperature of the liquid within the mug. The microcontroller, or subsystem 2, is equipped with a Wi-Fi transceiver that allows the mug to connect to the internet and other devices. The lighting system, or subsystem 3, employs LEDs to indicate the temperature of the liquid or to create an ambient mood. Subsystem 4 is the heating system, which enables the user to heat up the liquid to their desired temperature. The charged battery subsystem, or subsystem 5, provides wireless power to the mug. Finally, the Android application subsystem, or subsystem 6, permits the user to control the mug's settings and receive temperature notifications. By seamlessly integrating these subsystems, the smart mug offers a sophisticated and effortless drinking experience.

1.4 High Level Requirements

Accurate temperature control: The smart mug is able to accurately set the temperatures up to 100°C and control the temperature of the liquid it contains up to 100°C. The heating subsystem and sensor subsystem collaborate to ensure that the temperature remains within the set parameters. The heating system is designed to withstand temperatures of up to 100°C to enable the smart mug to provide optimal temperature control.

Reliable and consistent connectivity: The microcontroller with Wi-Fi transceiver must ensure reliable and uninterrupted connectivity to the Android application subsystem. The mug must be able to maintain a stable internet connection and communicate with the application consistently, without experiencing any dropped connections.

Robust and easy-to-maintain design: Mug should allow for easy cleaning and charging without causing any damage to the mug's electronic components.

Competitive pricing: The product must be affordably priced and cost at least 20% less than other comparable smart mugs in the market.

Safe and user-friendly design: The design of the mug must be safe and user-friendly, with features such as spill-proof lids, easy-to-use controls, and heat-resistant materials. The lighting system and Android application subsystem should provide clear and easy-to-understand feedback to the user about the temperature and status of the mug.

2. Design

2.1 Block Diagram

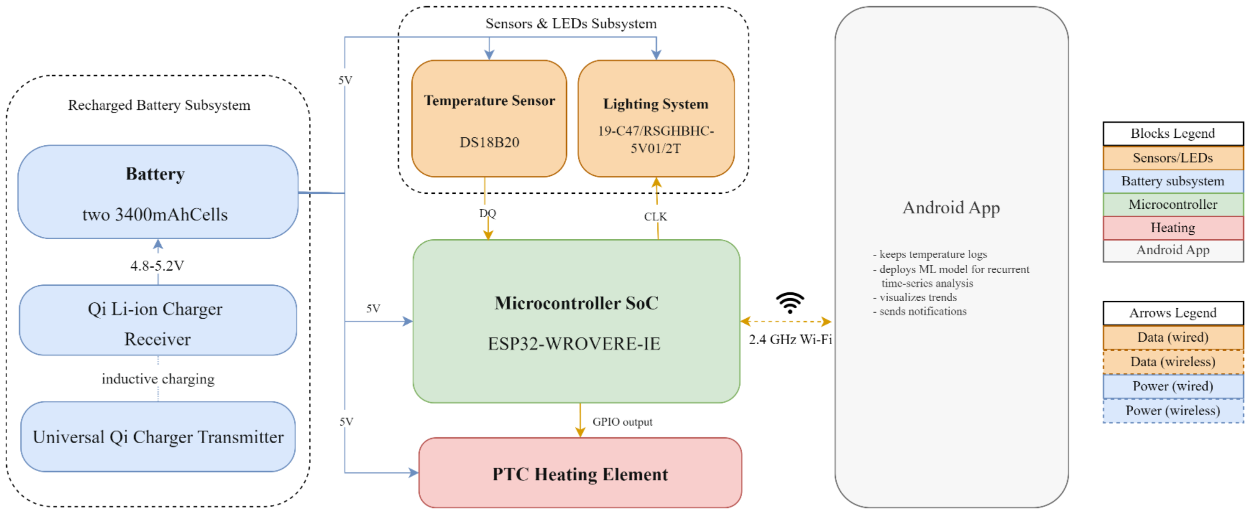

Figure 2: Block Diagram

The smart mug system's block diagram comprises several crucial subsystems that work together to deliver a complete solution for temperature monitoring and control. The ESP32 microcontroller serves as the control center of the system, responsible for processing inputs from the temperature sensor and LED modules, controlling the battery/heating system, and communicating with the Android app subsystem through WiFi. The temperature sensor and LED modules work in sync to monitor the liquid's temperature inside the mug and show the temperature range using different colors of LED lights. The battery/heating system consists of a Qi wireless charging transmitter and receiver module that wirelessly charge two Panasonic NCR18650B 3400mAh 4.9A battery cells, powering a heater plate that maintains the liquid's temperature inside the mug at a user-defined temperature. Finally, the Android app subsystem offers users an intuitive interface to wirelessly control the mug's temperature settings via Wifi, display real-time temperature data, and receive notifications when the beverage reaches the desired temperature. Overall, the system delivers a comprehensive, user-friendly, and portable solution for temperature monitoring and control in a mug format.

2.2 Sensors & LEDs

The sensor subsystem is in charge of collecting the liquid temperature in the mug and delivering it to the control module. The LED subsystem is simply a module that uses an RGB LED to indicate the status of the mug. In the shown circuits below, the data pin of the temperature sensor will be connected to a GPIO pin of the microcontroller ESP32 (ie, pin 4). The pin will read the temperature detected by the sensor and deliver the data to the control module.

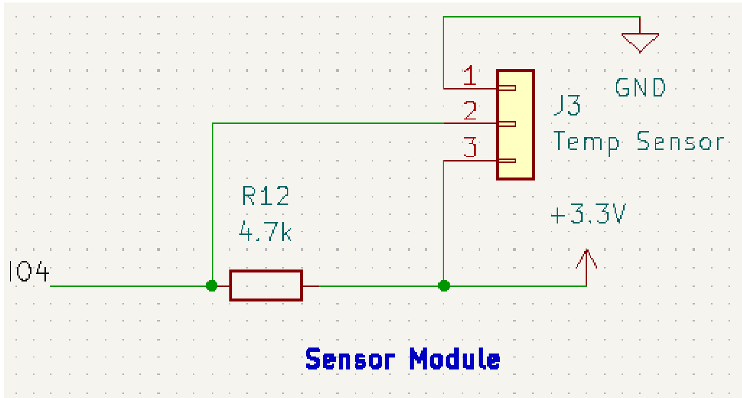

Figure 3: Sensor module schematics

For the LED module, three output pins are connected to the LED and deliver output data to the LED when called. When the LED is red, the whole system is shut down and no output/input is given/received. When the LED is blue, the system is turned on and the detected temperature is lower than the user input temperature, which indicates the operation of the heating module. When the LED is green, the system stays on and the liquid temperature has reached the desired temperature, which means that the heating module is turned off.

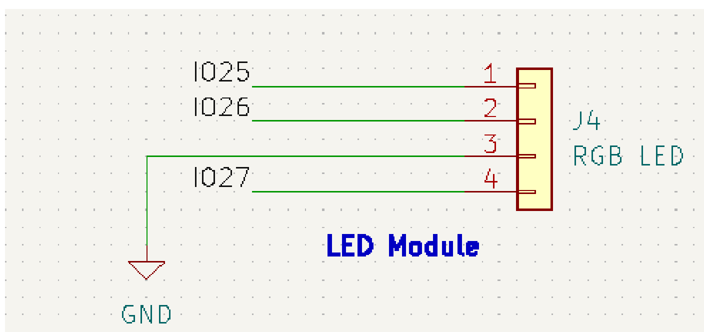

Figure 4: LED module schematics

2.3 Heating System

The heating subsystem is required to react to the given output from the control module by turning on the heating element which is powered by the battery system. Components used in this module contains: a DC-DC converter, an N-channel MOSFET, a PTC heating element, a voltage source and multiple resistors.

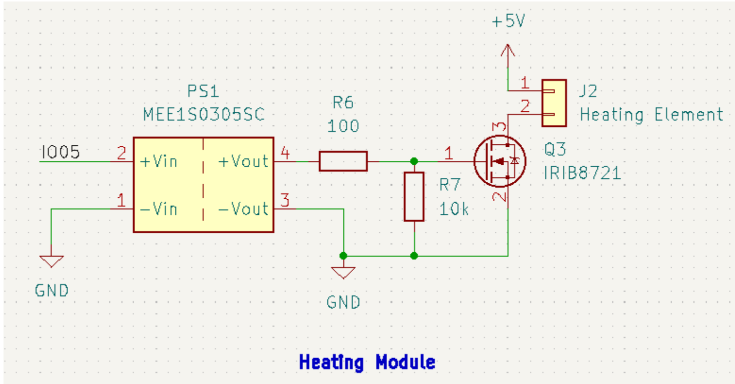

Figure 4: Schematics of the heating module

Since the output voltage of the control module is 3.3 volts, to obtain the optimal performance of the heating element, a DC-DC converter is used to convert 3.3 volts to 5 volts. The obtained output voltage from the control module will be delivered to the gate of the MOSFET. The source of the MOSFET is grounded so that voltage between source and gate is zeroed when given a HIGH output from the control module. The MOESET is acting as a switch which is controlled by the microcontroller and turns the heating element on/off.

The 5 volts voltage source in the given circuit comes from the battery module. The heating element is powered by the battery module but controlled by the control system. When the output from the controlled module is HIGH, the voltage at the drain of the MOSFET becomes zero which enables a 5 volts voltage drop across the heating element and the heating element is turned on. When the output becomes LOW, the voltage drop between the heating element disappears and the heater is turned off.

2.4 Battery System

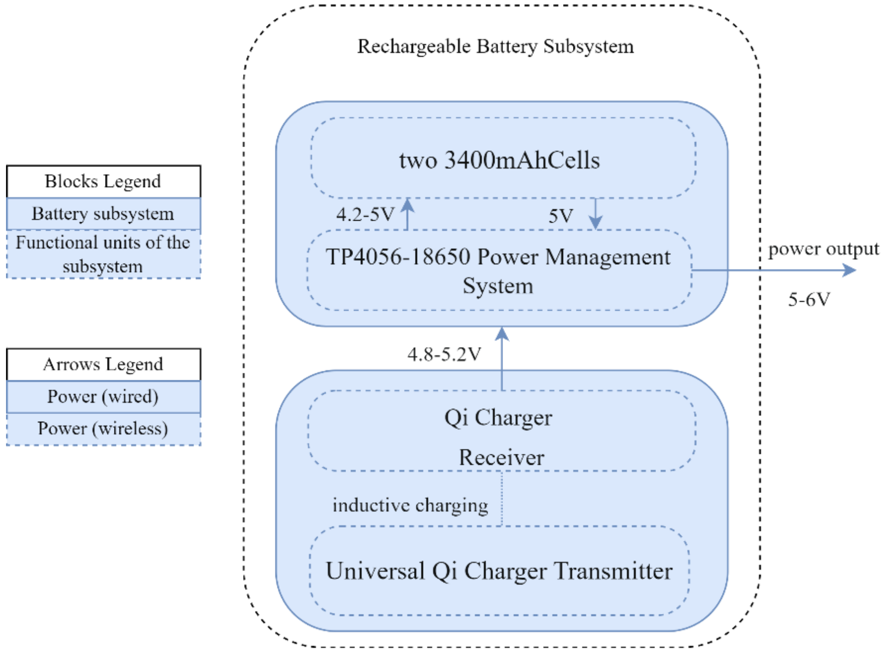

Figure 5: Modular block diagram of the rechargeable battery subsystem.

This subsystem consists of two Panasonic NCR18650B 3400mAh 4.9A battery cells to power the mug without the need for connecting cables to maintain its functionality. The batteries are connected to the following main functional units in the power subsystem:

2.4.1. Qi Charger Transmitter/Receiver

This subsystem utilizes an Adafruit universal Qi wireless charging transmitter and receiver modules to perform inductive charging of these tow battery cells. These modules can be configured to track battery level and output a discharge cut-off voltage of 5V. The two batteries are connected to the power management system. The user can simply place the base of the mug, which has the receiver, on the charging pad of the transmitter, or any Qi-compatible device, to initiate the charging process, without the need for plugging cables or connectors.

2.4.2. TP4056 Power Management

To ensure that the batteries are charged, protected, and used efficiently, we added the TP4056-18650 power management system. The TP4056-18650 includes various safety features critical to our design, such as short circuit protection, overcurrent protection, and thermal protection, which ensure that the batteries and the power management system remain safe during operation. Short circuit protection detects any sudden surge of current and shuts off the module to prevent damage to the battery and the system. Overcurrent protection detects an increase in the flow of current and reduces the output to prevent damage to the module and the connected components [1]. Thermal protection monitors the temperature of the module to prevent overheating. This is essential for lithium-ion batteries, which are prone to thermal runaway and can lead to fires or explosions.

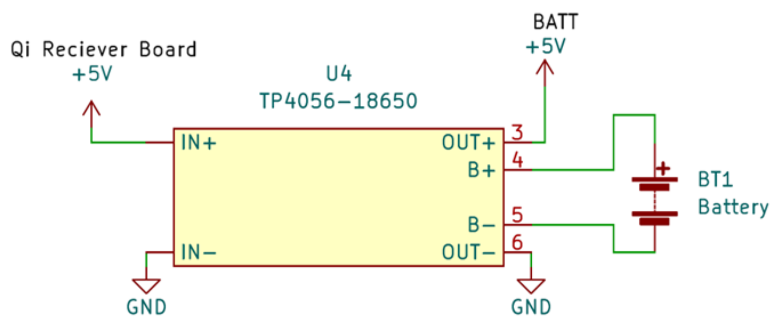

Figure 6: Circuit schematic diagram of the battery management system.

2.5 Control System

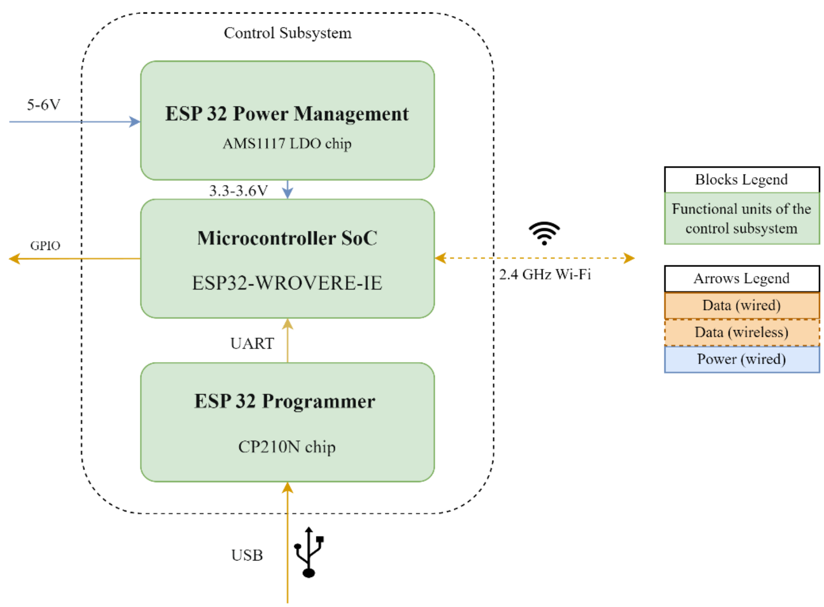

Figure 7: Modular block diagram of the control subsystem.

The current microcontroller design has the following three functional units:

2.5.1. ESP32 WROVER IE Module

The ESP32-WROVER-IE is a generic Wi-Fi + Bluetooth MCU module that comes with a transceiver PCB antenna. At the core of the module is the ESP32-D0WDR2-V3 chip with two CPU cores that can be individually controlled with adjustable clock frequency (from 80 MHz to 240 MHz). Using Wi-Fi allows a large physical range and direct connection to the Internet through a Wi-Fi router, enabling us to secure a connection to the server for temperature logging and app notification handling. The sleep current of the ESP32 chip is less than 5 µA, making it suitable for battery powered electronics applications like ours.

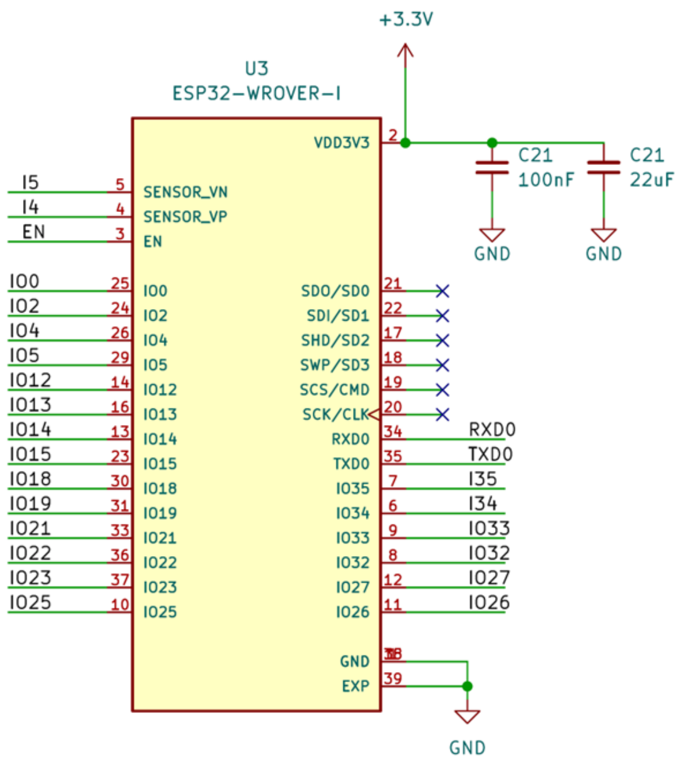

Figure 8: ESP32-WROVER-IE schematic diagram as connected in our device.

2.5.2. ESP32 Programmer

The second unit is the programmer (influenced by the Espressif ESP32 C6 DevKit4 [2]) which consists of a USB connector that drives a CP210N chip to perform USB-to-UART serial communication conversion. We added two RESET and BOOT switches. Our microcontroller operates on multiple modes: boot, reset, and debug based on the signals DTR and RTS. This mechanism automatically updates the state flags of the ESP32 WROVER IE Module during flashing of binaries and during normal operation.

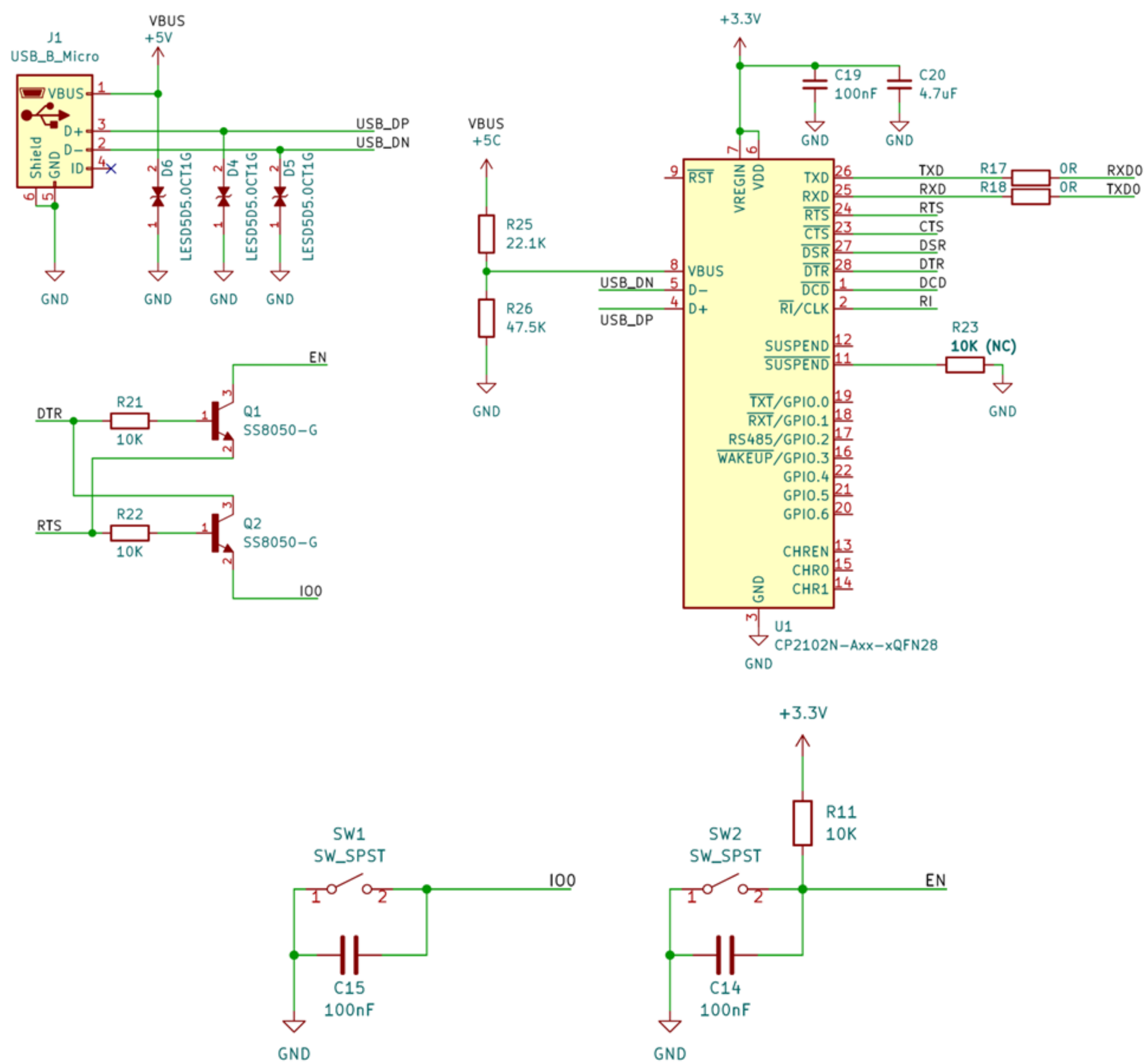

Figure 9: The ESP32 programmer circuit schematic diagram.

2.5.3. ESP32 Power Management

The microcontroller expects 3.3-3.6V. To this end, we installed the AMS1117 LDO chip to regulate voltage to the desired voltage range. We have also added connections to the

TP4056-18650 battery management module to select the power supply output in lieu of a single Schottky diode as in the original design. This addresses the contact bounce effects due to power spikes during external source power switching and reduces noise that causes battery exhaustion [3]. The device is supplied with 5V form the USB bus if the USB port is connected; otherwise, the batteries drive the circuit.

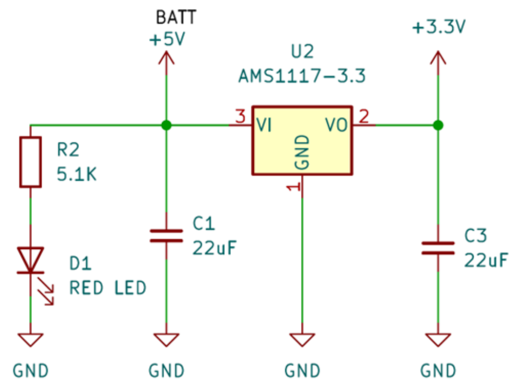

Figure 10: The ESP32 power management unit schematic diagram.

2.6 Android App

The Android app subsystem of the smart mug will serve as the central control point for the temperature control system. The app will be designed to be compatible with a wide range of Android devices as it runs on their phones' browsers. To ensure seamless communication between the app and the mug, Wi-Fi technology will be utilized. The app will be able to connect to the smart mug through a real-time database on Google Firebase , allowing users to control the mug's temperature settings and other features with ease. The app will also notify the user when the beverage has reached the desired temperature, ensuring that the user is always aware of the status of their drink. The app will also incorporate the ability to turn off the smart mug, allowing users to conserve battery life when the mug is not in use. This feature will ensure that the mug does not remain active unnecessarily, leading to wasteful use of energy.

3. Design Verification

3.1 Sensors & LEDs

We tested the sensor system by comparing different room temperatures to the detected temperatures. We got an average of 5% difference between the room temperature and the detected temperature. Although the expected difference is set to be 2%, we defined the obtained temperature as acceptable since the room temperatures were read from the monitor without precise value.

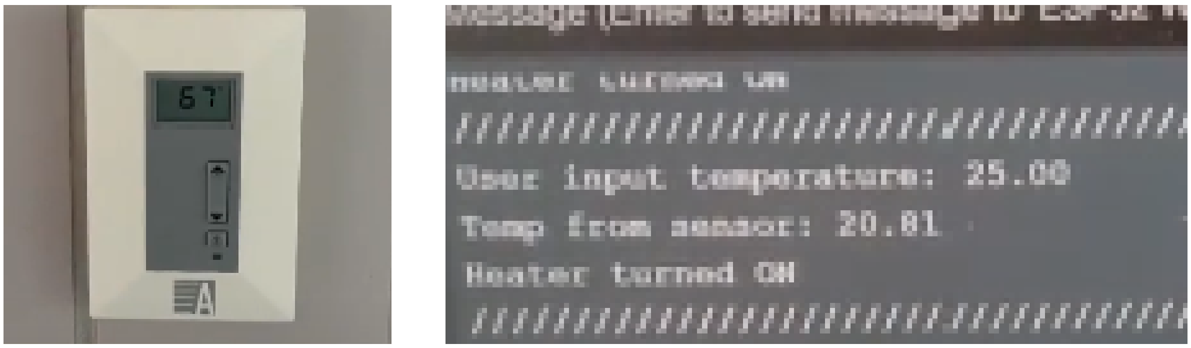

Figure 11: example of a successful testing of temperature snesing

The LED subsystem is verified with a voltmeter to detect the voltage drop between the heating element when the LED is in each color.

3.2 Heating System

The heating subsystem is controlled by the control module and is powered by a 5 volts battery/voltage source. To verify the functionality of the heating element and the subsystem, a voltage multimeter is connected to track the voltage drop through the heating element. When the output from the ESP32 (GPIO 5) is HIGH, the voltage is around 5 volts; when the output is LOW, the voltage drop should reach 0.

Figure 12: voltage drop between the heating element when GPIO 5 is LOW

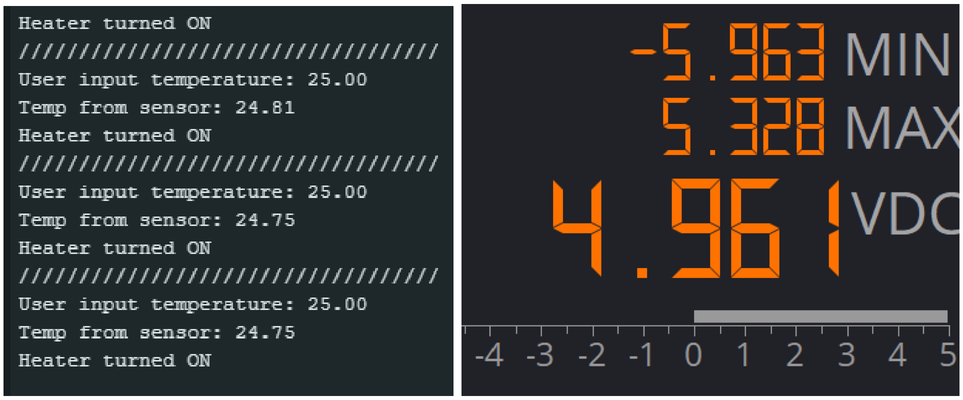

Figure 13: voltage drop between the heating element when GPIO 5 is HIGH

With this testing data, we can confirm that the heating module was successfully operated by the control module. The other expectation for the heating module is to ensure the liquid could reach around 100 degrees in Celsius. Unfortunately, due to the unsuitable selection of our heating element and the battery, we are unable to achieve this expectation. The heating element is unable to reach its optimal performance in our circuit. This can be solved in the future by switching to a different heating element and battery.

3.3 Battery System

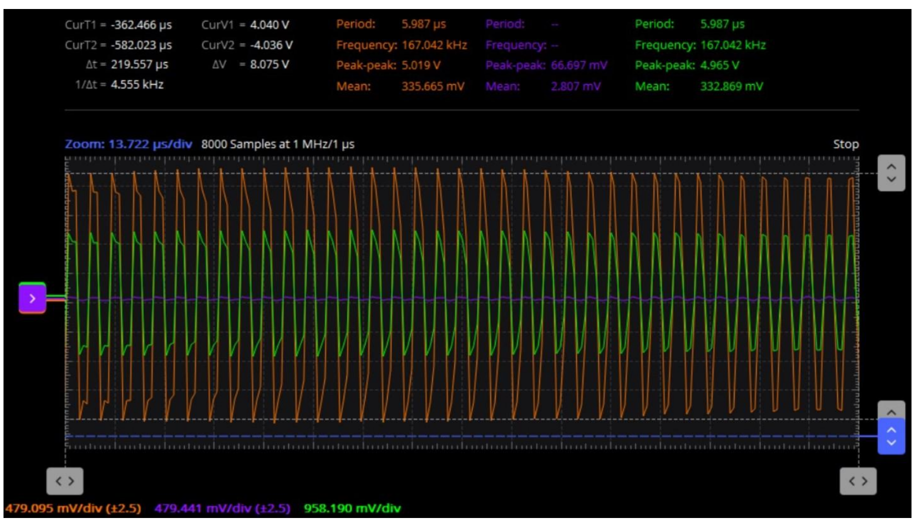

Figure 14: Voltage trace of the Qi transmitter terminals

The Qi charger transmitter shall be able to handle a 5V input voltage and output that much through the coil so as to wirelessly charge the batteries. Figure 13 shows the voltage trace when connecting an oscilloscope to the two terminals of the coil in the transmitter.

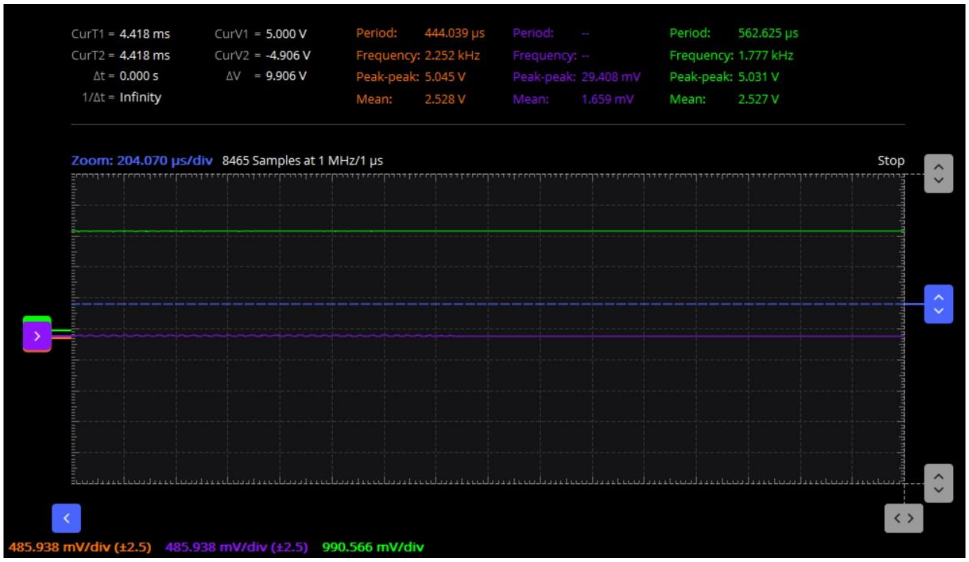

Figure 15: Voltage trace of the power management system

The power management system should output 5-6V to the battery cells during the charging cycle. Figure 14 shows that a continuous DC output is being supplied to the batteries with the specified specifications as in the requirements.

3.4 Control System & Android App

In a similar manner to verifying the requirements of the heating system, the serial monitor form the Arduino IDE was used in addition to the interface of the real-time database to check the status of the device and the ability to log values as successfully demonstrated. For future work, we are planning on implementing a notification hanler in the application which was the only requirement that was not met.

4. Costs

4.1 Parts

Table 1. Parts Costs

Description	Manufacturer	Quantity	Retail Cost	Link
Wireless power Li-ion charger Receiver compliant with Qi (WPC) with RT1650 Chip	Adafruit	1	$14.95	Link
Universal Qi Wireless Charging Transmitter	Adafruit	1	$26.95	Link

TP4056 Type-C USB 5V 1A Battery Charger Module Charging Board with Dual Protection Functions	Adafruit	1	$8.99	Link
PTC HEATING ELEMENT - 5V 100C	DFRobot	2	$5.00	Link
Panasonic NCR18650B 3400mAh 4.9A Battery	Panasonic	2	$8.99	Link
Battery Holder (Open) 18650 2 Cell SMD (SMT) Tab	Eoutstanding	1	$8.99	Link
ESP32-WROVER-IE-N8R8	HiLetgo	1	$3.60	Link
USB - micro B USB 2.0 Receptacle Connector 5 Position Surface Mount, Right Angle; Through Hole	Molex	1	$1.01	Link
5.6V 18.6V 5V Bi-Directional SOD-523 ESD Protection Devices ROHS	LRC	3	$0.02	Link
25V 300mW 120@100mA,1V 1.5A NPN SOT-23 Bipolar Transistors - BJT ROHS	Jiangsu Changjing Electronics Technology Co., Ltd.	2	$ 0.0197	Link
LDO Voltage Regulators 800mA & 1A LDO	Texas Instruments	1	$3.07	Link
USB Interface IC USBXpress - USB to UART Bridge QFN20	Silicon Labs	1	$4.66	Link
Tactile Switches 6.0X8.35MM R/A 160G	E-Switch	2	$0.44	Link
Programmable Resolution 1-Wire Digital Thermometer	Analog Devices Inc./Maxim Integrated	1	$7.78	Link
Addressable Lighting - 1 LED Serial Red, Green, Blue (RGB) 1.80mm L x 1.80mm W	Everlight Electronics Co Ltd	1	$0.92	Link
Red LED		4	$1.12	Link
5.6V 18.6V 5V Bi-Directional SOD-523 ESD Protection Devices ROHS	LRC	3	$0.79	Link
Total	N/A	N/A	$97.30	

4.2 Labor

Our group consists of two electrical engineers and one computer engineer. Average pay for electrical engineers with a bachelor's degree is $80,296 and $105,352 for computer engineers according to the Grainger College of Engineering.

Tasks	**Hours Estimated**		
	Hani	Siqi	Srishti
Circuit Design	30	5	5
Board Layout and Components Check	15	15	5
Software Development	10	10	30
Soldering	0	20	5
Prototype and Debug	60	60	60
Documentation and Logistic	25	25	25
Total Hours	**135**	**135**	**130**
Labor Cost	**$4,851.90**	**$4,851.90**	**$5,033.60**

5. Conclusion

5.1 Accomplishments

Although we were unable to heat the liquids in the mug as quickly as we intended due to the responsiveness of some elements in our design, we have accomplished all the core requirements to make our device fully operational. Our device is capable of utilizing a microcontroller (ESP32) that connects to Wi-Fi to detect and regulate the temperature of the mug, primarily to maintain the temperature of the liquid rather than heating it up.

5.2 Uncertainties

Our major hurdle was underestimating how much time it would take us to actualize the circuit from its schematic diagrams. Due to physical constraints with some of the components, hand soldering was a challenging task. As the deadlines approached, we were forced to demo on a breadboard instead of the yet to be completed PCB. A second defining failure was the "first" choice of MOSFET in the heating subsystem which proved to be ineffective in meeting the requirements and specifications of our design. In addition to that, upon further analysis, we discovered that the recharging time of the battery may be a significant problem that could impact user acceptance.

5.3 Ethical considerations

IEEE Code of Ethics section 7.8, subsection I.5 [6] highlights the importance of considering the long-term impact of engineering work and striving to create sustainable designs that can meet the needs of both present and future generations. For a project involving a battery-powered device and a heating element like ours, this involves a range of considerations related to sustainability, energy efficiency, and environmental impact. Our choice of components has been the manifestation of this core consideration. As in subsection II.9, we have a responsibility to not harm others during the course of creating and testing our project. The major concern related to this end is ensuring that our heating element does not cause any bodily injury to any of those surrounding us in the lab area. This subsection also emphasizes the importance of designing systems and equipment that can operate safely and effectively within a larger context, taking into account other systems and equipment that may interact with or depend on the design.

5.4 Future work

One possible direction would be to improve the efficiency of the battery subsystem, perhaps by incorporating a more sophisticated power management system to reduce charging times and extend battery life. Another potential area for improvement would be the heating subsystem, a more responsive heating element is required for our design to be fully functional. Furthermore, the circuit design could be optimized to reduce the overall size and weight of the device, making it more practical and user-friendly. In addition, the user interface and software could be enhanced to provide more advanced functionality, such as incorporating machine learning for analyzing the user's drinking habits. Lastly, further testing and validation of the device could be carried out, including user testing and certification for compliance with relevant safety and quality standards, before releasing the smart mug to the market.

References

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[6]] "IEEE Code of Ethics." IEEE, 2022, Available at: https://www.ieee.org/about/corporate/governance/p7-8.html.

Appendix A Requirement and Verification Table

Table 2: LEDs & Sensors System Requirements and Verifications

Requirements	Verification	Verification status (Y or N)
Temperature sensor must accurately measure the temperature within ±1°C range	Measure the temperature of a known heat source at different temperatures and compare the readings with a calibrated thermometer	Y
LED lights must change color according to the temperature range of the input liquid. LEDs change to red if the temperature detected is more than 5% above the desired temperature. LED becomes blue if the temperature detected is over 5% below the desired temperature. The mug will only be able to heat to 80°C.	Observe the color change of the LED lights when the temperature of the input liquid changes and verify that the LED lights change to the correct color.	Y
The microcontroller must be able to receive the temperature data from the sensor and translate it into the corresponding color of the LED lights accurately and in real-time	Simulate different temperature inputs by hard coding it to the microcontroller and verify that the LED lights change to the correct color in real-time.	Y
The temperature sensor and LED module must be able to withstand an operating temperature up to 80°C	Test the temperature sensor and LED module in an environment with temperature levels up to up to 80°C and verify that they can operate properly under these conditions.	N

Table 3: Control System Requirements and Verifications

Requirements	Verification	Verification status (Y or N)
The control system must be insensitive to the environment changes like temperature. It shall not be affected by small changes in the certain parameters of the system.	Operate the heating system and verify the stable running of the system by using an oscilloscope connecting to the output I/O port.	Y
The microcontroller must be able to receive data and operation commands from the android application via Wifi tranciever.	Simulate an operation by implementing the microcontroller and connect it to a LED. Verify the functional status by controlling the on and off of the LED on the apps.	Y

Table 4: Power/Heating System Requirements and Verifications

Requirements	Verification	Verification status (Y or N)
The Qi charger transmitter shall be able to handle a 5V input voltage and a 2A input current from a USB port.	Connect the Qi charger transmitter controller board with a USB port and check the IV characteristics of the two terminals of the coil using an oscilloscope.	Y
The Qi charger receiver shall be able to output 5 V to charge the two battery cells	Check the voltage trace of the power management output	Y
The two battery cells shall output 5 V to the heater element	Upon successful configuration of the batteries, test that the discharge cut-off voltage is reasonably close to 5V	Y
The heater film shall keep the temperature of the cup at a maximum of 100°C	Use a calibrated thermometer to test the maximum temperature maintained by the heater film	Y

Table 5: Android App System Requirements and Verifications

Requirements	Verification	Verification status (Y or N)
The Android application shall be able to receive and display data from the microcontroller in real-time	Connect the microcontroller to the Android device via Wifi and send data. Verify that the data is received and displayed correctly and with minimal delay.	Y
The app shall be able to notify the user when the beverage has reached the desired temperature	The app will display a message and/or send a push notification to the user when the temperature of the beverage in the mug reaches the desired temperature	N
The app shall be able to turn off the smart mug	The app will send a signal to the smart mug to turn off when the user taps the "turn off" button in the app	Y

Appendix B PCB Prototype

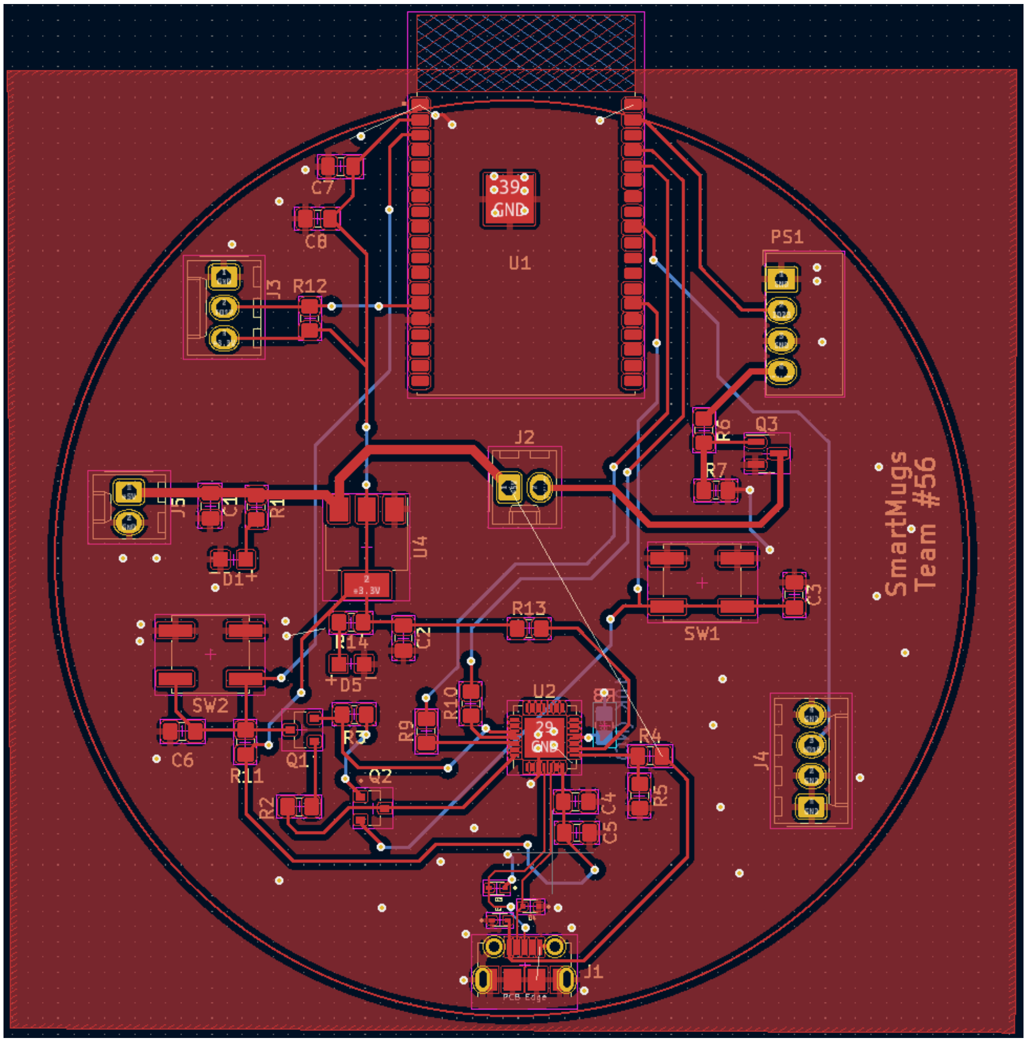

Figure 16: The smart mug PCB prototype.

Appendix C Final Product

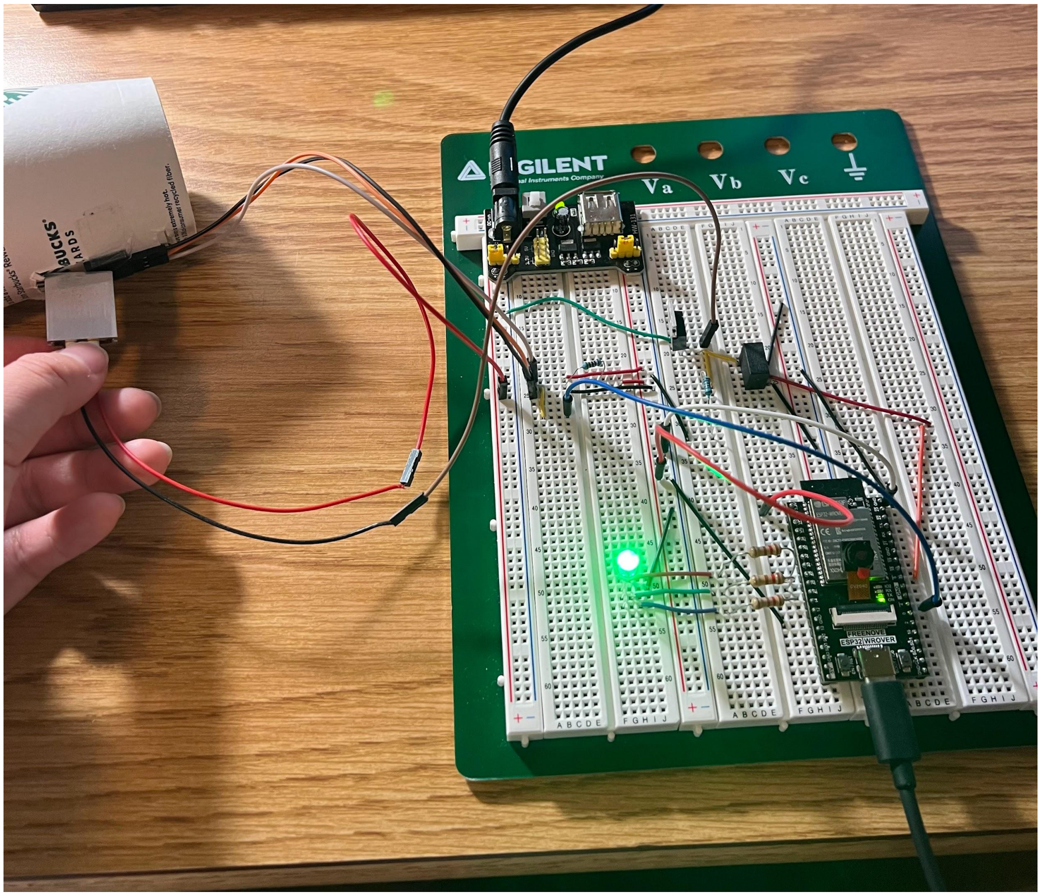

Figure 17: The breadboard circuit when the temperature reached the desired temperature.