Anti-Hypothermia Jacket For Pro Climbers

ECE 445 Final Paper

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Abstract

This report includes the introduction of our project, all block component's description, requirements, verifications, design details, design procedure, and the cost of whole project. Besides, the report also includes tables of measured data, partial code for software, circuit schematic, and pictures of actual product for corresponding blocks of the product.

1 Introduction

1.1 Objective and Background

Highland climbing is always dangerous because of extreme environments such as oxygen deficit and extreme low temperature. According to mountain-forecast [1], the average temperature from March 2 to March 14 is around -16 C at 6000m elevation in 2021 [Figure 1]. Many great explorers died because they are under Anoxia above 5000 m and then lose their body heat unconsciously under Coma and Hypothermia. In 1986, 13 climbers died over a two-week span in ARACHI, Pakistan. In 2008, 11 lives were lost [2].

To increase the safety of climbers, we decided to design a fully automatic system [Figure 2] to monitor hazardous body temperature loss and adjust the jacket temperature to keep human body temperature at a normal level. In the market, there is a similar product: Milwaukee's heated jacket. However, the jacket we designed is more versatile since our heated jacket can adjust the temperature automatically, has quicker heating speed and send out emergency signals when accidents occur.

More specifically, we aimed to design a jacket [Figure 3] integrated with TEC grids controlled by microprocessors and powered by detachable battery packages. The product has two modes: Auto and manual modes. When sudden body temperature loss is not detected but the user wants to increase his body temperature, users can simply press the manual mode button to turn on the heater. The heater's temperature will be monitored in order to prevent overheating. Another mode is auto mode. During this mode, the system will continuously monitor hazardous human body temperature drop and start to turn on the heater if climber's body temperature is below 33 degrees. The system will also give warning to user and surrounding climbers so that the user can return to base within the battery time by himself or with the help of other climbers.

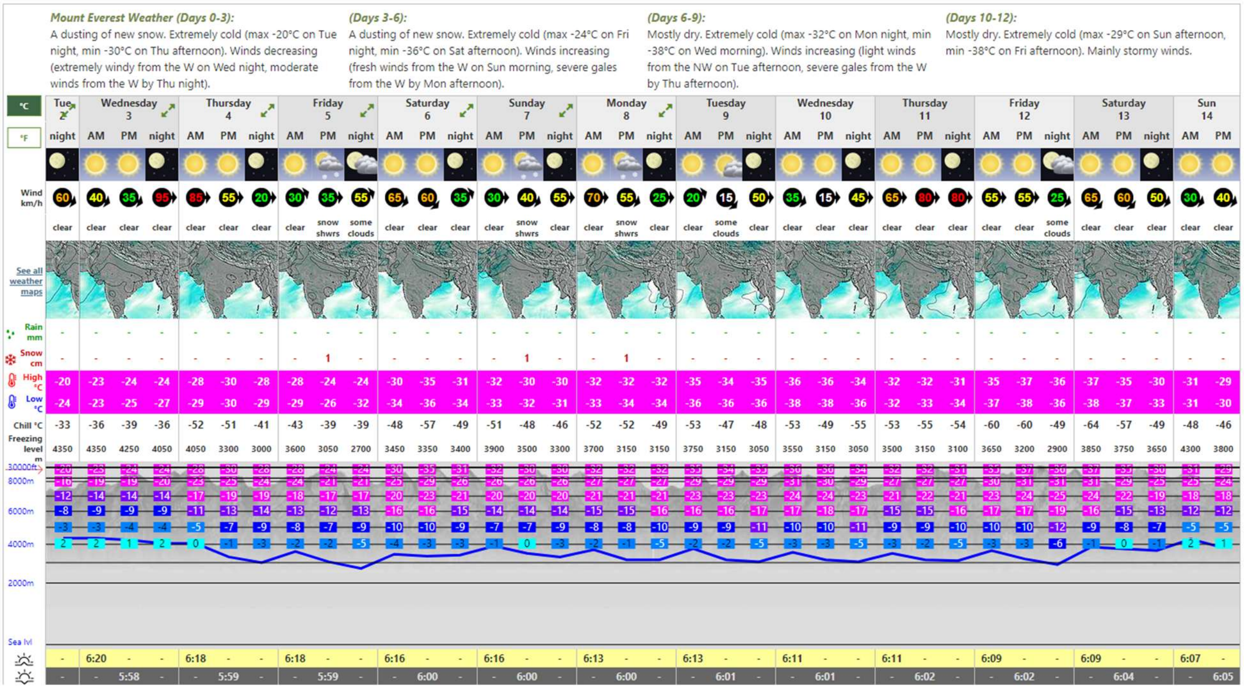

Figure 1. Temperature Diagram of Mountain Higher than 6000m

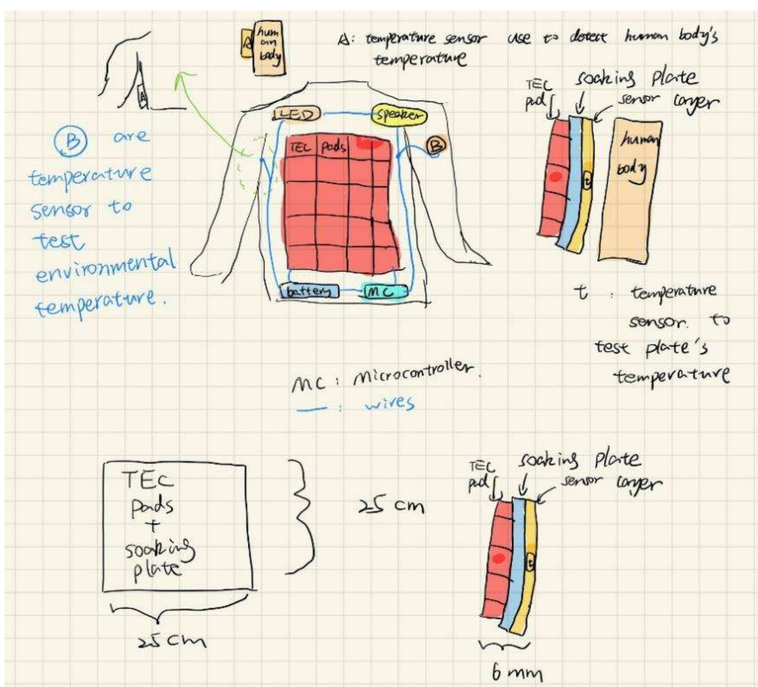

Figure 2. Physical Diagram of the whole system

Figure 3. Packaged System on Jacket

2 Design

2.1 Block Diagram

The whole package for the jacket requires three sections to work properly: the power supply module, the control unit, and the TEC heating module. The power supply module can handle the whole system's power consumption for at least 1 h at 12 V and 6.5 A peak. We use four parallel connected 12V-2Ah batteries as power source. The control unit is composed by a microcontroller called ESP32 to handle both digital I/O of temperature sensors and analog I/O of other peripherals. The TEC heating module contains both front and back breast TEC grids which can quickly compensate for body temp loss. Each grid has 9 TEC pads connected in 3x3 matrix [Figure 4].

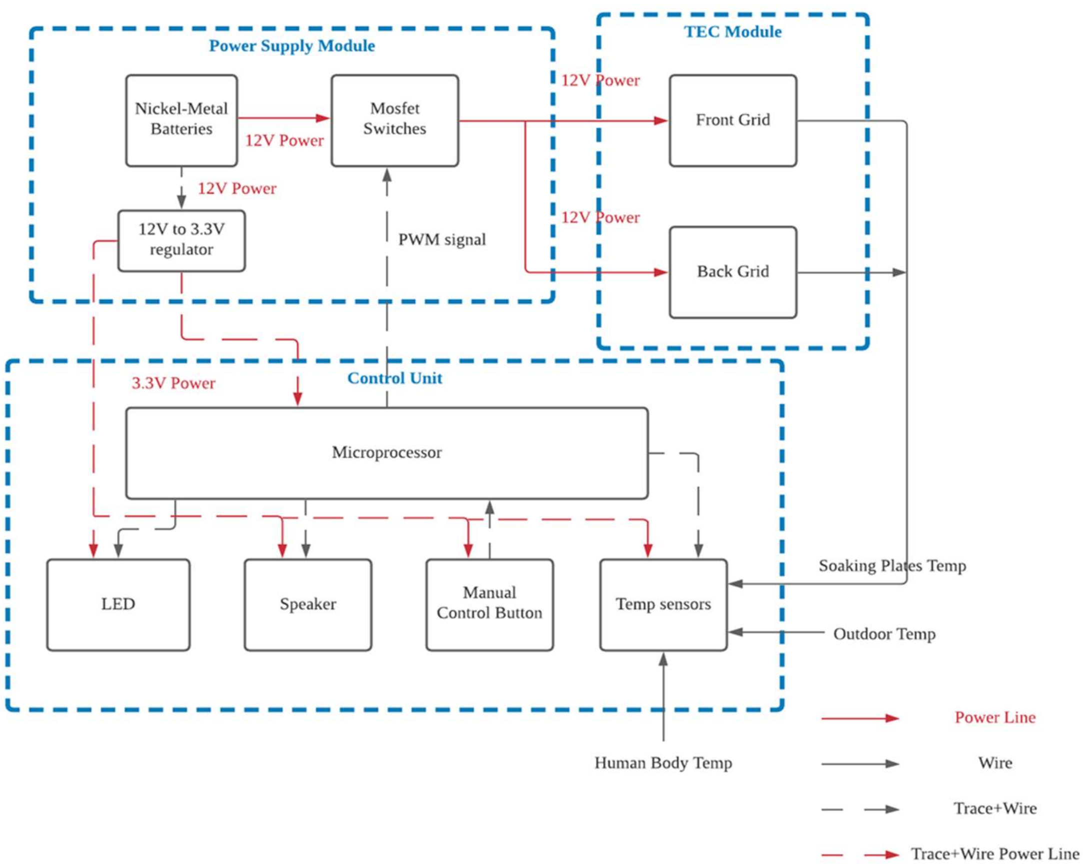

Figure 4. Block Diagram of System

2.2 TEC Module

TEC module contains TEC pads and Soaking plate. We use TEC pads to producing heat and use soaking plate to distribute heat evenly on the jacket.

2.2.1 TEC pads

Our project started from the TEC pads. TEC pads can transfer heat very fast so one side of the pad can heat up quickly(figure5). In our experiments, The grid could heat the soaking plate from 25°C to 40°C within 1.5 minutes. With this characteristic, we came up with an idea to design a jacket which can heat up automatically. Our goal is to heat up the core body area of the user and since the size of one TEC pad is 4cm wide and 4cm long, we distribute 9 TEC pads in 3 rows and 3 columns with 3 TEC pads in one row and 3 TEC pads in one column. Also, both front side and back side of the body are needed to be covered, so we assign each side one TEC grid containing 9 TEC pads.

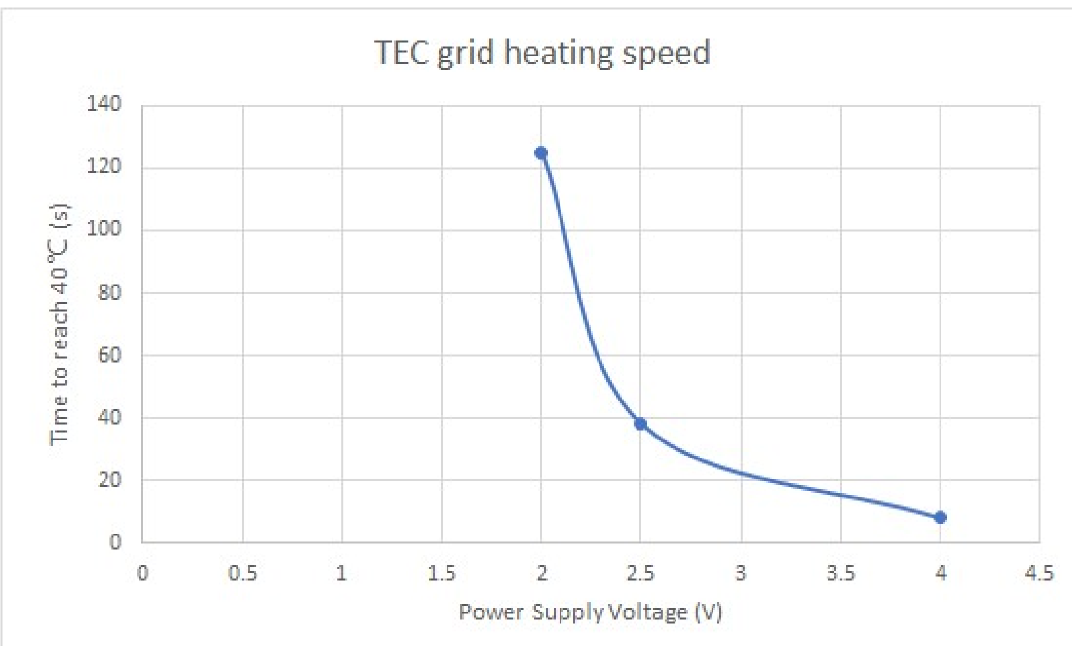

Figure 5. TEC Grid Heating Speed (Single TEC Pad)

2.2.2 Soaking plate

The reason to use soaking plate is to distribute heat evenly on the jacket.

Since each TEC is 4 cm wide and 4 cm long, we choose soaking plate with 20 cm wide and 20 cm long to satisfy our requirement. With this size, 9 TEC pads can fit properly.

2.3 Power Supply Module

A power supply is applied to keep the power consuming system working for at least one hour. Four Nickel Metal batteries will provide 12V voltage directly for the TEC module through a power amp module and will be stepped down to 3.3V to power the chipsets.

2.3.1 Nickel Metal Batteries

The Nickle Metal batteries must be able to keep all the TEC pads working at 35 degree (max temperature) for at least 1 hour under auto and manual mode. Besides, the battery also needs to provide 3.3V power for the control unit. Also, the battery requirement is based on the TEC pads' voltage and current. We did a test to find the best voltage value that the TEC pad can increase temperature fastest with smallest energy consumption (Table1).

Table 1. Heating Speed And Energy Consumed (3 TEC pads in series)

Start temperature	End temperature	Voltage	Current	Time	Energy
26.6°C	39.3°C	2V	0.400A	124.94s	99.952J
26.7°C	40°C	7.5V	0.530A	40.19s	159.755J
27.8°C	42°C	12V	1.046A	8.65s	108.575J

We can observe that 12V voltage can provide shortest time with small energy consumption.

So, we need a battery with 12 voltage output. Also, since 3 TEC pads are connected in series to make up a column and we have three columns connect in parallel. The battery must provide at least 3 A current. So, we choose to use the nickel metal battery can provide 12 V voltage output and at least 3A and at most 8A current output.

2.3.2 Mosfet

For the Mosfet, since it acts like a switch(Figure6), it's drain side is connected to battery and its source side is connected to TEC pads. So, we want a Mosfet can tolerate at least 3A drain-source current and we also want its Vds small enough to provide enough voltage to TEC module and reduce power waste.

So, we choose the FQP30N06L Mosfet, it can tolerate at most 32A current and when we connect it with 12 battery power and TEC module, we observe the Vds is 0.134V which is small enough to provide enough voltage to TEC module and reduce power waste (Figure7).

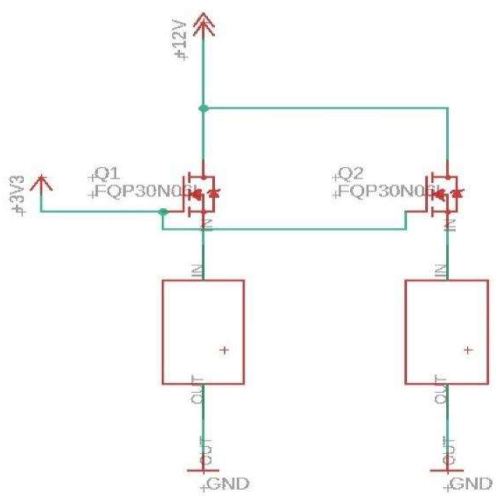

Figure 6. Mosfet and TEC Module Schematic

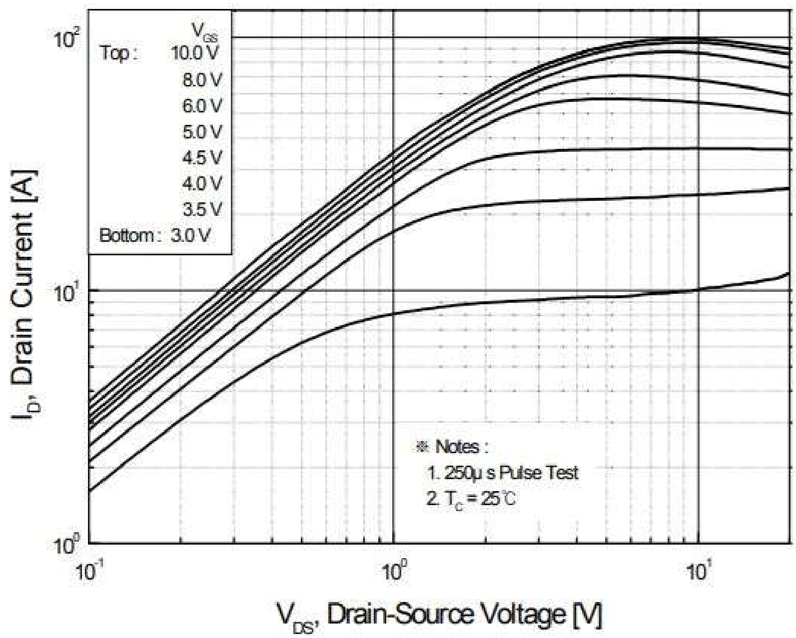

Figure 7. Id vs Vds Graph of Mosfet [3]

2.3.3 regulator

The regulator is used to power our microprocessor. According to the data sheet, the chip ESP32-S2-WROVER needs 3.3V input. So we need a 12V to 3.3V regulator.

We find the AZ1117IH-3.3TRG1 regulator. According to the data sheet, it can convert 12 V to 3.3 V when 1.5V <= Vin-Vout <= 10V.

2.4 Control Unit

Control unit includes ESP32, LED, Buzzer, Manual mode switch and Temperature sensors. We chose the ESP32 module instead of single chip because we want to prevent designing crystal circuit, SPI Flash, SPI PSRAM, and various kinds of matching networks by ourself. Besides, the module has plenty of GPIO pins that can be used for our peripherals. Moreover, the chip is SMT which means it's easier for us to surface mount it on out PCB. Also, the chip is compatible with Arduino IDE so that my teammates can use the packages provided by Arduino and chip manufacture. The LED and Buzzer can be directly driven by the ESP32 GPIO pins. Therefore, we don't need to step down the power from the battery to drive those components. Besides, the three temperature sensors are chosen to have three different addresses so that they can share then same SCL and SDA bus. This can significantly reduce redundant wires. Then, the manual mode switch is connected to the GPIO pin through a Pull up/ Pull down structure which is designed to pass almost no current to save power(Figure8).

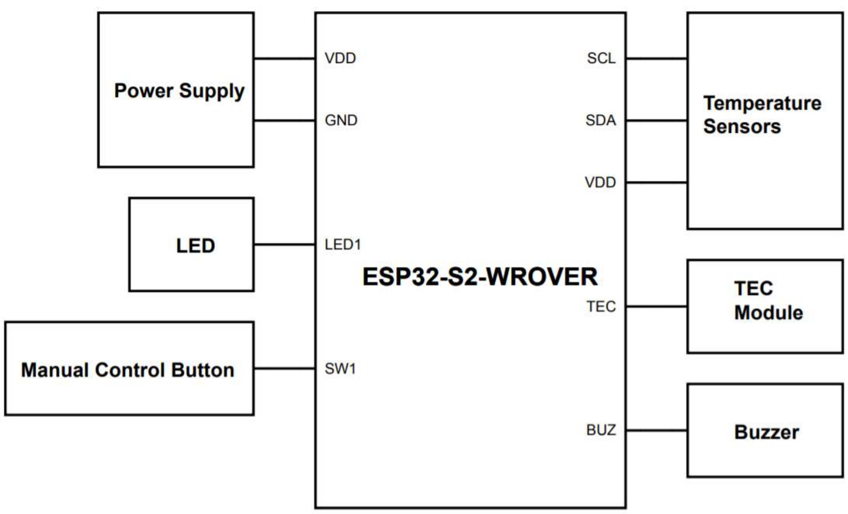

Figure 8. Microcontroller Schematic

2.4.1 ESP32 chip

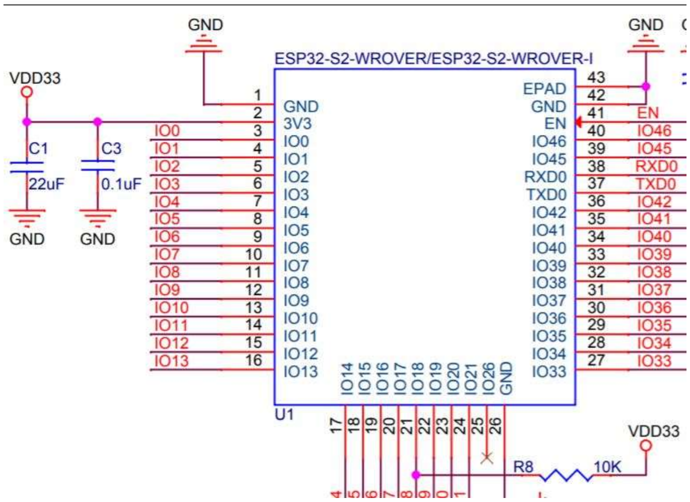

Figure 9. ESP32 Chip Schematic

For the ESP32 chip, it has 46 I/O pins(Figure 9). We have two capacitors to the power input of the chip to pass through noise and decouple the 3.3V power. Also, we have Pull Up and Pull Down switches for the EN and IO0 pins. Besides, IO18 is connected to 3.3V to prevent floating voltage. For the RX and TX pins, it is directly connected to external peripheral's RX and TX pins for data monitor. Also, we have SCL and SDA connected to three temperature sensors.

2.4.2 Switch

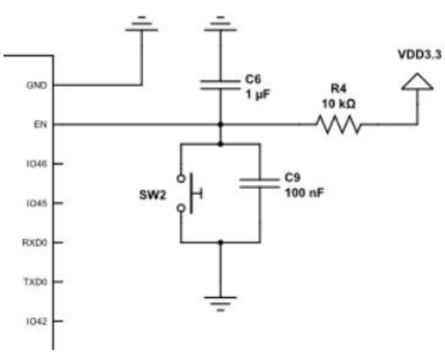

Figure 10. Switch Schematic

The Switch is used to start the manual mode of the system (Figure 10). During manual mode, the system will turn on the grids and monitor the grids' temperature to constantly keep grids' temperature at 33 degree. The switches have 1uF decoupling capacitor and 100nF bypass capacitor to ensure a stable digital signal for the EN pin. The Pull up/down structure uses 10k Ohm resistor to reduce power usage.

2.4.3 LED

Input: 3 ~ 3.8V

Output: green light with luminance 50000 mcd.

The LED has the input of 3.3V from ESP32 chip. Also, the LED light is used to warn climbers when the system detects any abnormal body temp drop and when body temperature is below 33 degree. So, we need the luminance of LED very large.

So, we choose the LED C503B-GAN-CB0F0791 which can take 3 ~ 3.8V input and output green light with luminance 50000 mcd.

2.4.4 Buzzer

Input: 3~15V

Output: 83dB @10V, 10cm away, max 5mA.

The speaker will make a series of loud sounds to give both climber and teammates low body temp warning. According to the search by google [4], "a typical fire alarm sounds off between the 65 decibel and 120 decibel range". With this information, we choose the TFM-73 buzzer which can produce 83dB at 10V and 10cm away. So it will sound very loud which can meet our requirement. Also, Buzzer takes 3.3V input from ESP32 chip and our TFM-73 buzzer can take 3 ~ 15V input which meets the requirement.

2.4.5 Temperature Sensors

Input: 3.3+/-0.03V; SCL

Output: SDA

The Sensors are located on the outer jacket, human body, and grids' soaking plates. They are used to give the microcontroller real time digital signals for evaluation. So, we need them to have good precision. In that case, we choose the Adafruit Industries LLC 1833 temperature sensor since it is a digital sensor with +/- 0.25°C variation. Also, it is powered by 3.3V from regulator and the Adafruit Industries LLC 1833 temperature sensor have input range of 3.3+/-0.03V which meets our requirement.

2.5 Schematics

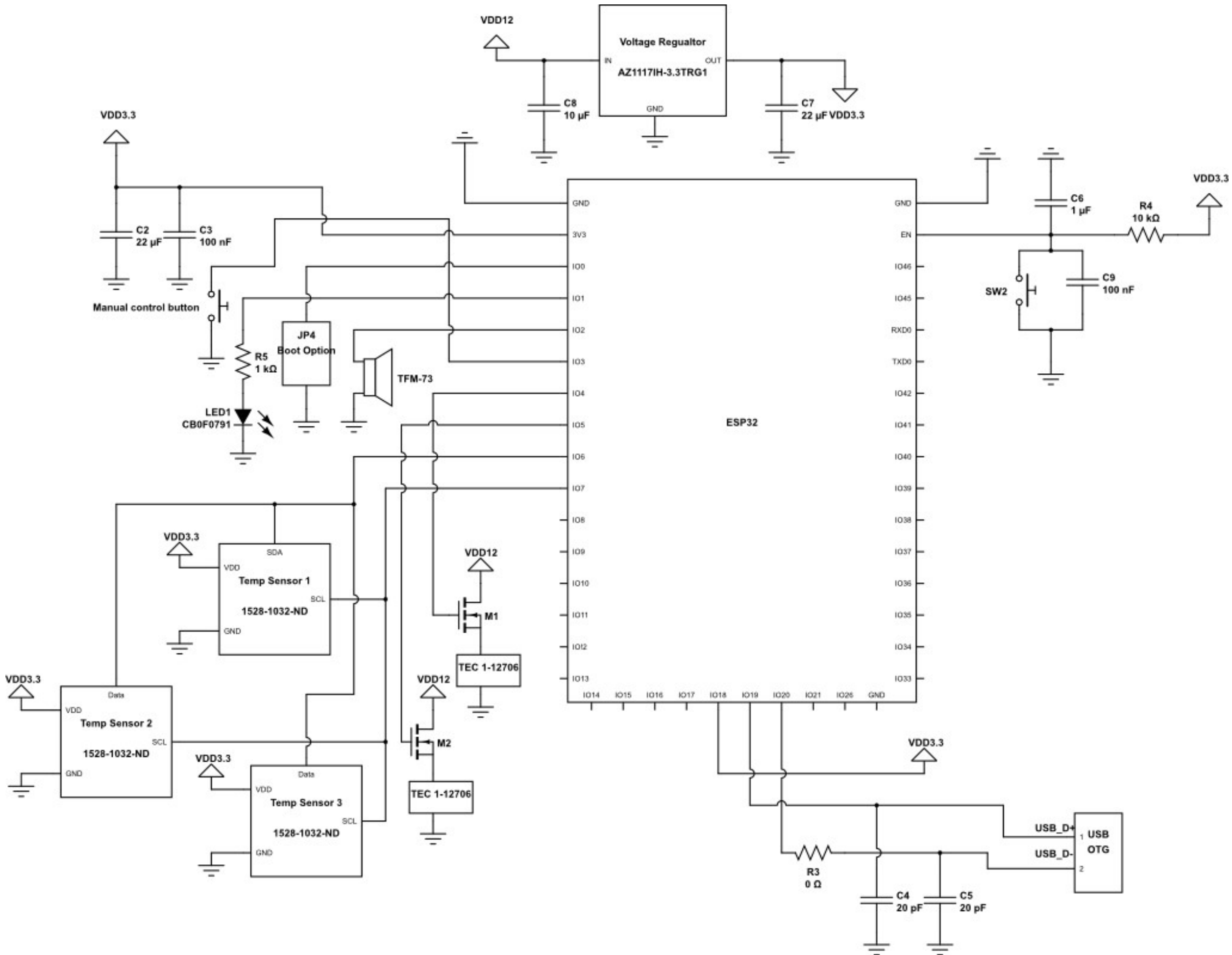

Figure 11. Overall Schematic

2.6 Algorithm

The software takes the input from temperature sensors and manual control bottom and control the turn on/off of the TEC pads. By using the software algorithm, the system can accurately control the TEC pads' temperature and dynamically save power usage. [Figure 12]

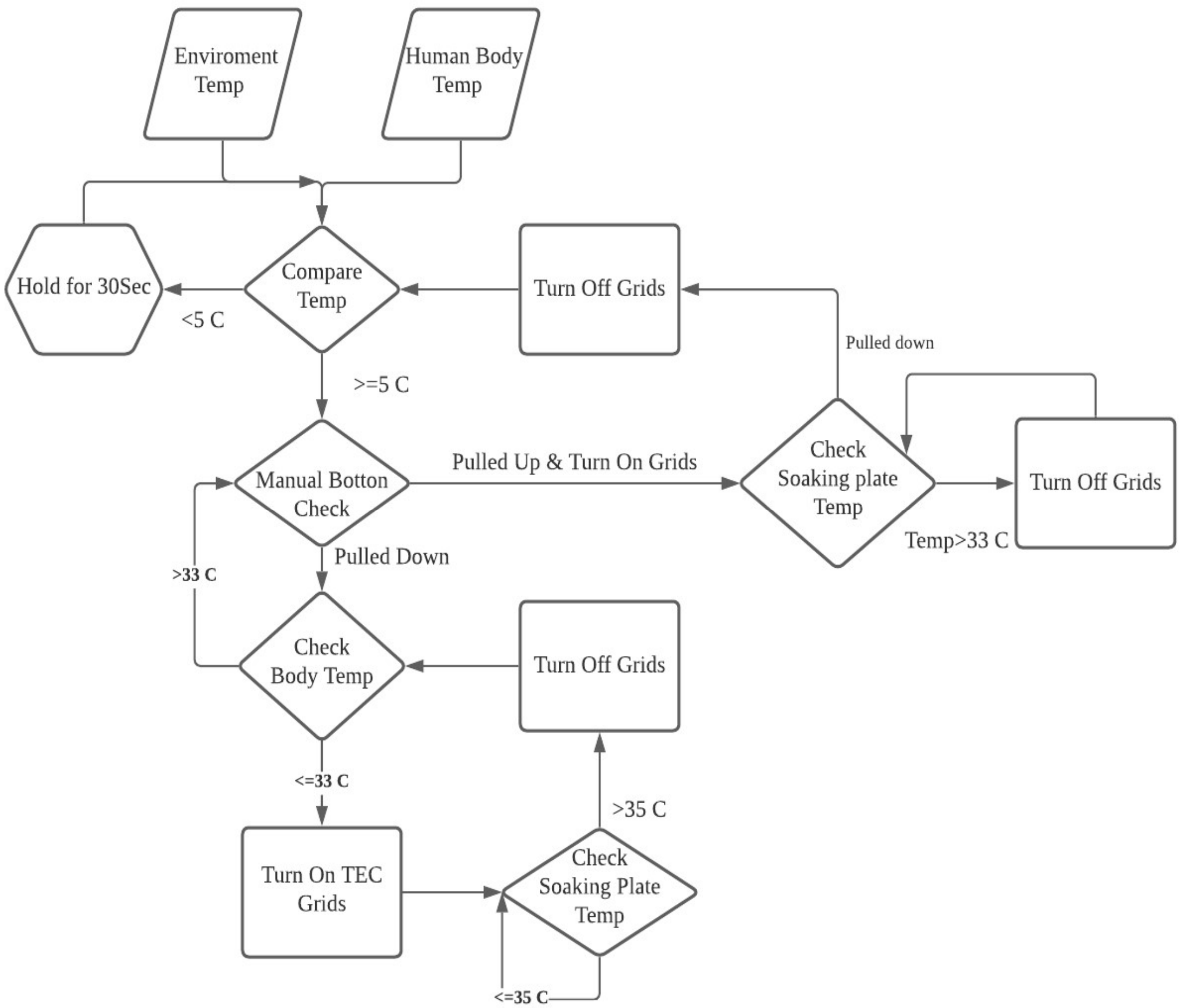

Figure 12. Microcontroller Algorithm

2.7 Tolerance Analysis

Mosfet tolerance:

We use Mosfet switches to control the pass through current of our pads. One of the most significant tolerances is the current variation caused by the TEC pads. We have tested the pads from 1V to 4V input voltage and calculated the variation of resistance at each voltage and found 17.5% to 30.2% current decrease when the pads heat up to 40 C and achieve steady state.

$$I\_max = I\_static * (1 + \text{Max Variation Factor}) \tag{1.1}$$

Therefore, the Mosfet should be able to tolerate higher than steady state current consumption at the beginning of heating. Because each grid will contain 9 pads which totally consumes 3.138A current, we need a Mosfet to have at least 4.14A (1.1) saturation current at Vgs=3.3V.

Power storage tolerance:

Our goal for the device is to make it last for at least 1 hour. According to our measurement, 18 TEC pads of the two grids will consume 4.6A to 6.5A under 12 V voltage. Therefore, we need a total amount of 6.5Ah batteries to supply our devices for 1 hour when the device is operating at max power continuously.

$$\text{Actual Energy Usage} = \text{Average TEC On time (s)} * \text{Average Current} * \text{Operating Voltage} \tag{1.2}$$

Therefore, the actual battery time should be longer. Because the TEC pads take 1.5 minutes to heat from 26 degree to 35 degrees when the grids turn on during cold condition. Then pads will be turn off and takes about 30 seconds to cool down to 33 degree. After that. The pads will be turned on and takes 10 seconds to reach 35 degree again. Therefore, according to equation (1.2) , We would expect four 2Ah batteries can support our device working for 1.0 ~ 4.0 hours.

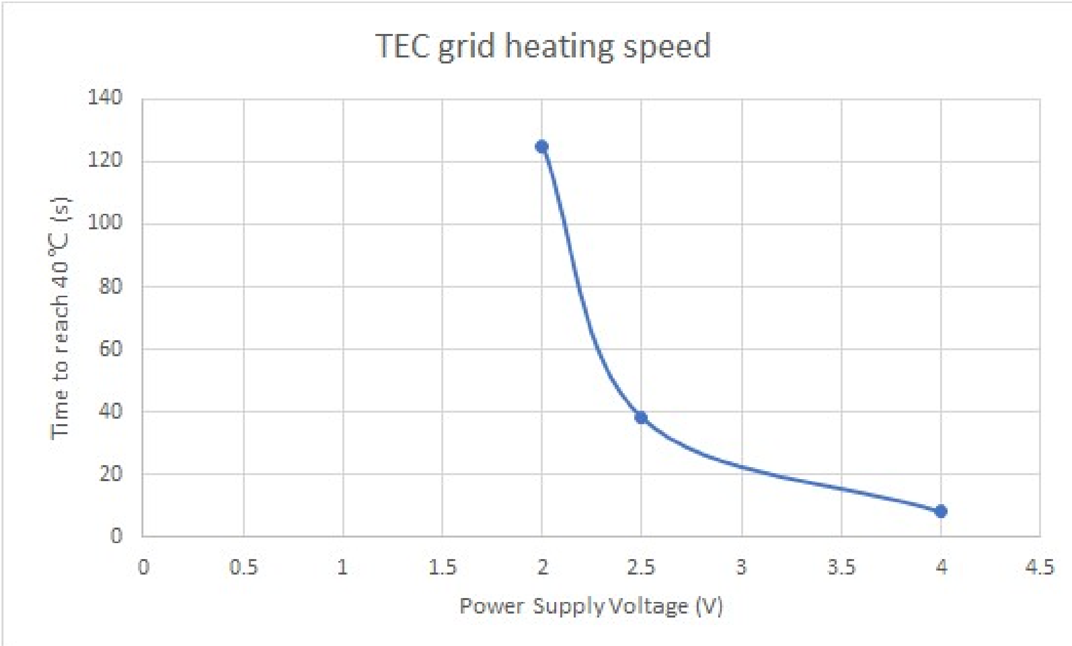

Figure 13. Measured Voltage vs. Time for TEC Pad To Reach 40°C (Experimental of single pad)

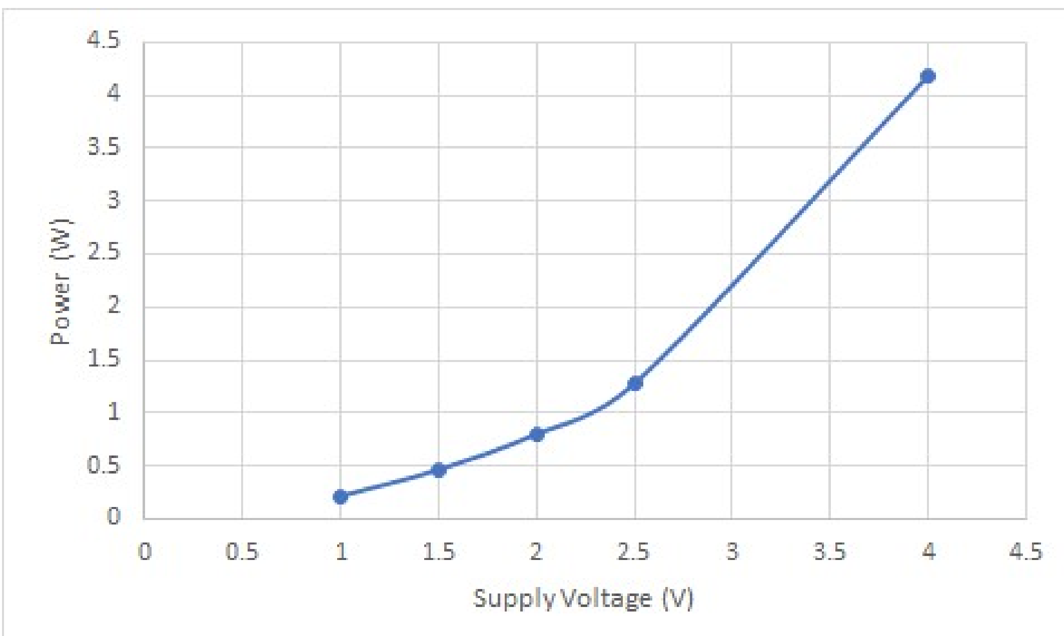

Figure 14. Power of TEC Pad vs. Supply Voltage (Experimental of single pad)

2.8 Power Consumption

Table 2. Battery Power Consumption

Battery	**Power**
Nickel Metal Battery	8Ah

Table 3. Power Consumption

Load	Voltage	Current	Power Consumption
Microcontroller	3.3V	22mA	72.6mW
Temperature Sensors	3.3V	0.2mA x 3	1.98mW
TEC module	12V	5A Average	60W(static)
Mosfet	Vds <=1V	<=3.5 A	<=7W
Regulator	12V	<=6mA	<=72mW
Buzzer	3.3V	25mA	82.5mA
LED	3.3V	30mA	99mA
Total			67.328W (Max)

3 Cost

$$2 \times \frac{\$35}{hr} \times \frac{10hr}{wk} \times \frac{16wks}{0.6} \times 2.5 = \$4666.67$$

Table 4. Cost

Part	Cost(prototype) USD	Cost (bulk) USD
12V 2Ah battery (Folk Battery)	50	50
Temp Sensor (MCP9808, Digi-key)	4.95	1.13
Mosfet (FQP30N06L Digi-key)	1.22	0.48
ESP32 Microprocessor (ESP32-S2-WROVER, Digi-key)	2.2	2.2
12V to 3.3V regulator (Az1117IH-3.3TRG1DICT-ND, Digi-key)	0.38	0.08
USB Female Plug (USB Micro-B Breakout Board PRODUCT ID: 1833)	1.5	1.2
LED(C503B-GAN-CB0F0791-ND)	0.24	0.1
Buzzer (2769-TFM-73-ND)	1.68	0.91
TEC pads (Aideepen 5pcs TEC1-12706, amazon)	68	68
Soaking Plates	30	30
Others (wires, PCB, Resistor, Cap, etc...)	10	10

4 Conclusion

In conclusion, our jacket works properly in both manual and auto mode. During auto mode, the system correctly monitor all body temperature change and control the turn on/off of the heating grids according to both human body temperature and grids' temperature. The heating grids satisfy both our time requirements and weight requirements. During manual mode, the switch can be switched easily and is attached on a wristband. The switch successfully control the turn on/off of grids. And the grids' temperature are correctly monitored to prevent overheat. However, our first version product is a prototype. As a first-aiding product for pro climbers, the products should be tested under real highland area to verify it's reliability. Besides, the product's wiring and design can be more compact if we can use flexible PCB to replace all cables in the future. Even though extreme reliability tests are needed for the product, the electrical functionality of the jacket is fully tested and works correctly and satisfy all high level requirements.

5 Safety and Ethics

There are potential safety hazards in our project. Lithium-ion batteries can be damaged or even explode due to physical impacts such as crushing and dropping and extreme cold temperatures [5]. If the TEC grid cells keep heating, it may cause burning of the circuit system and the jacket. To prevent those safety hazards, we will design a negative feedback loop to avoid excess heat. We would take all aspects of potential safety problems into consideration in our design and endeavor to the IEEE Code of Ethics, #9: "to avoid injuring others…" [6].

In our design of the anti-hypothermia jacket, we aimed to save climber's lives and protect their safety during climbing experiences. This purpose is coherent with the IEEE Code of Ethics, #1: "to hold paramount the safety…" [6].

In the process of designing and testing our project, we will consult teaching assistants and professors when we encounter troubles and we are open to criticism which would help to improve our project. Our attitudes align with the IEEE Code of Ethics, #5: "to seek, accept, and offer honest criticism…" [6].

References

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Appendix A Requirement and Verification Table

Table 1. Microcontroller Requirements and Verifications

Requirements	Verification	Verification Status (Y or N)
1. The Esp32 S2 chip should be programmable and can both receive and transmit analog or digital signals through GPIO ports utilized.	1A. Push the EN button and change IO0 to download booting mode. 1B. Write the program file into the Esp32 S2 chip. 1C. Change the IO0 back to SPI booting mode. 1D. Run the program and check that the microcontroller is receiving input signals from voltage regulator and temperature sensors and sending corresponding output signals to TEC grids, LED, and the buzzer.	Y
2. Auto mode: When the difference between the environment temperature and the human body temperature is higher than 5°C and the manual control button is off, the system would enter auto mode, heating up the soaking plate until its temperature reaches 35°C.	2A. Connect the battery to the system. 2B. Monitor the temperature sensors and the system using PuTTy. 2C. Increase the human body temperature to make it 5°C higher than the environment temperature and turn off the manual control button. 2D. Monitor whether the system enters auto mode and check whether the system exits auto mode when the soaking plate temperature reaches 35°C.	Y
3. Button mode: When the difference between the environment temperature and the human body temperature is larger than 5°C and the manual control button is on, the system would enter button mode, heating up the soaking plate until its temperature reaches 33°C.	3A. Connect the battery to the system. 3B. Monitor the temperature sensors and the system using PuTTy. 3C. Increase the human body temperature to make it 5°C higher than the environment temperature and turn on the manual control button. 3D. Monitor whether the system enters button mode and check whether the system exits auto mode when the soaking plate temperature reaches 33°C or the button is turned off.	Y

Table 2. Nickel Metal Batteries Requirements and Verifications

Requirements	Verification	Verification Status (Y or N)
1. Each 2Ah battery must be able to handle at least 1A and at most 1.5A current at 12V voltage.	1A. Connect the battery package to the drain side of MOSFET and connect source to the TEC pads in series circuit. 1B. Connect the VDD and ground pin of the microprocessor to the battery package. 1C. Turn on the whole circuit, when the TEC pads start heating, use a multimeter to measure the total current of the circuit and it should at least 4A and at most 6A.	Y

Table 3. Power Amplifier Module Requirements and Verifications

Requirement	Verification	Verification Status (Y or N)
1. The N channel MOSFET is able to work at vgs = 3.3V and pass at least 2A continuously and 3.5A shortly.	1A. Turn on the whole circuit, measure the output pin IO3 voltage is 3.3V within 5% variation. 1B. Measure the Current of the whole circuit and check if the current can reach at least 3A and can handle 6A shortly at the beginning of heating.	Y

Table 4. TEC Module Requirements and Verifications

Requirement	Verification	Verification Status (Y or N)
1. Each TEC grids should contain 9 TEC pads. can heat the soaking plate to 35°C in 3 min.	1A. Drive the whole circuit with our 12V battery package. 1B. Turn on the whole system. Count the time needed to heat the soaking pad to 35°C to ensure it within 3 minutes.	Y

Table 5. LED Requirements and Verifications

Requirement	Verification	Verification Status (Y or N)
1. The LED must be turn on when the human body temperature is below 32°C and can be visible by the wearer.	1. In auto mode, the GPIO 2 which controls the output to the LED should be turned on when human body temperature is below 32°C.	Y

Table 6. Buzzer Requirements and Verifications

Requirement	Verification	Verification Status (Y or N)
1. The sound made by the speaker must be 55-75 dB from 5m away.	1A. Put the speaker 5 meters away from the user. 1B. Use a cell phone with dB volume meter app to measure the loudness of the speaker when it is turned on. Ensure the loudness is in the range of 55-75 dB.	Y

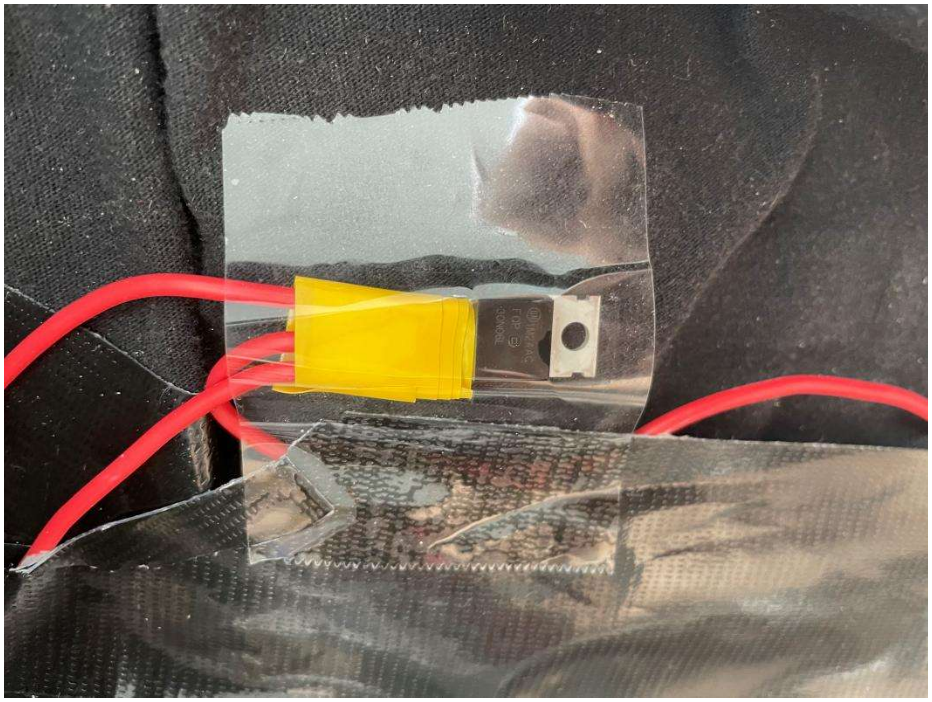
Table 7. Temperature Sensor Requirements and Verifications

Requirement	Verification	Verification Status (Y or N)
1. The accuracy of the human body temp sensor should be within +/-0.25 °C and can be power at 3.3V. The accuracy of external temperature and soaking plate temperature should be within +/-0.25 °C and can be powered by 3.3V.	1A. Connect the temp sensors' SCL and SDA pin to the I/O pins of the ESP32 S2 test board. And connect the VCC pin to 3.3V power source. 1B. Check the room temperature by an accurate handheld infrared temp monitor. 1C. Monitor the room temperature with the temperature sensor. 1D. Check whether the difference is within +/-0.25 °C.	Y

Table 8. Regulator Requirements and Verifications

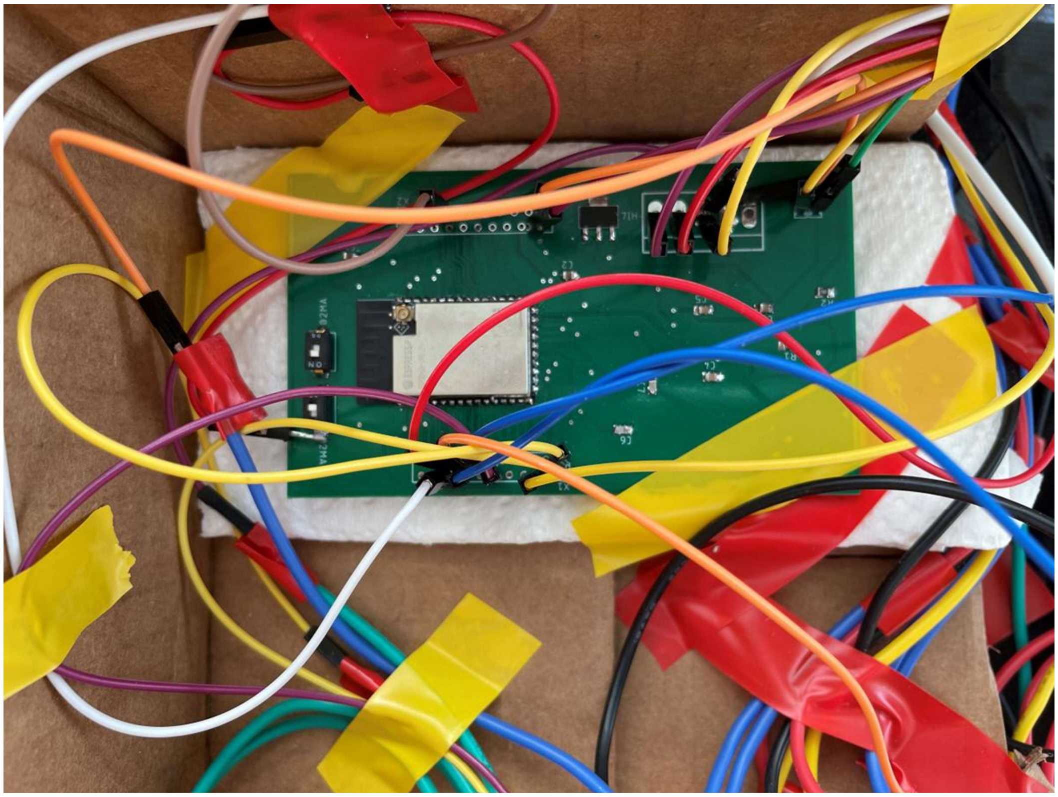
Requirement	Verification	Verification Status (Y or N)
1. Give a 12 +/-0.5 V input voltage to the regulator, it should output 3.3 +/- 0.03V.	1. Use a multimeter to measure the output voltage, ensuring it is in the range of 3.27V to 3.33V.	Y

[A1] Picture of Power Amplifier Module

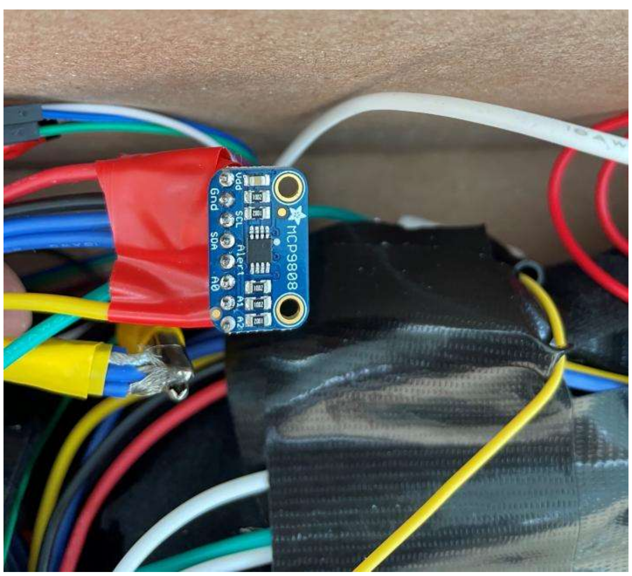


[A2] Picture of TEC Module

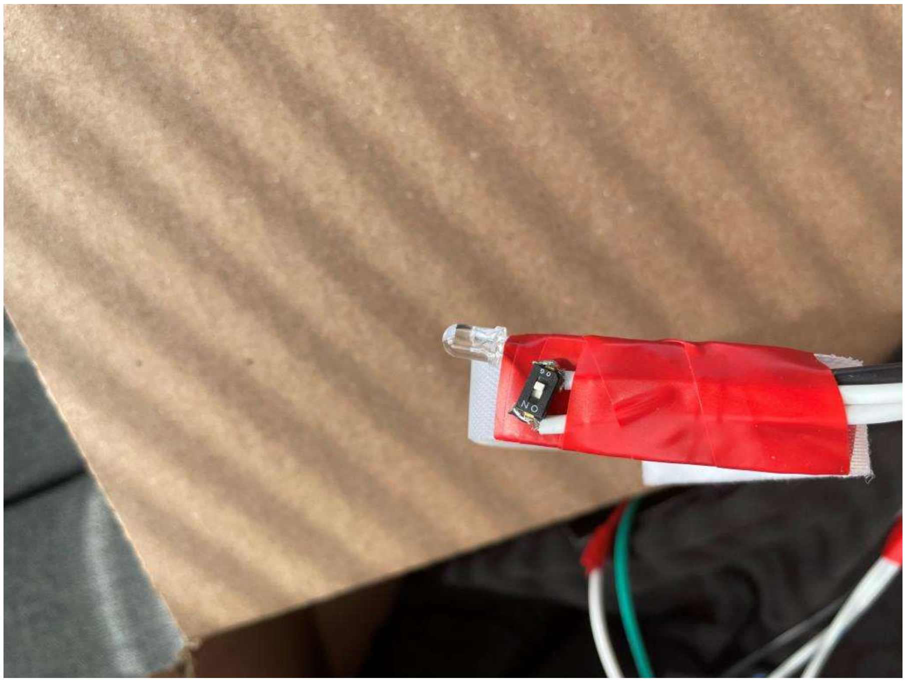
[A3] Picture of PCB Layout



[A4] Picture of Temperature Sensors

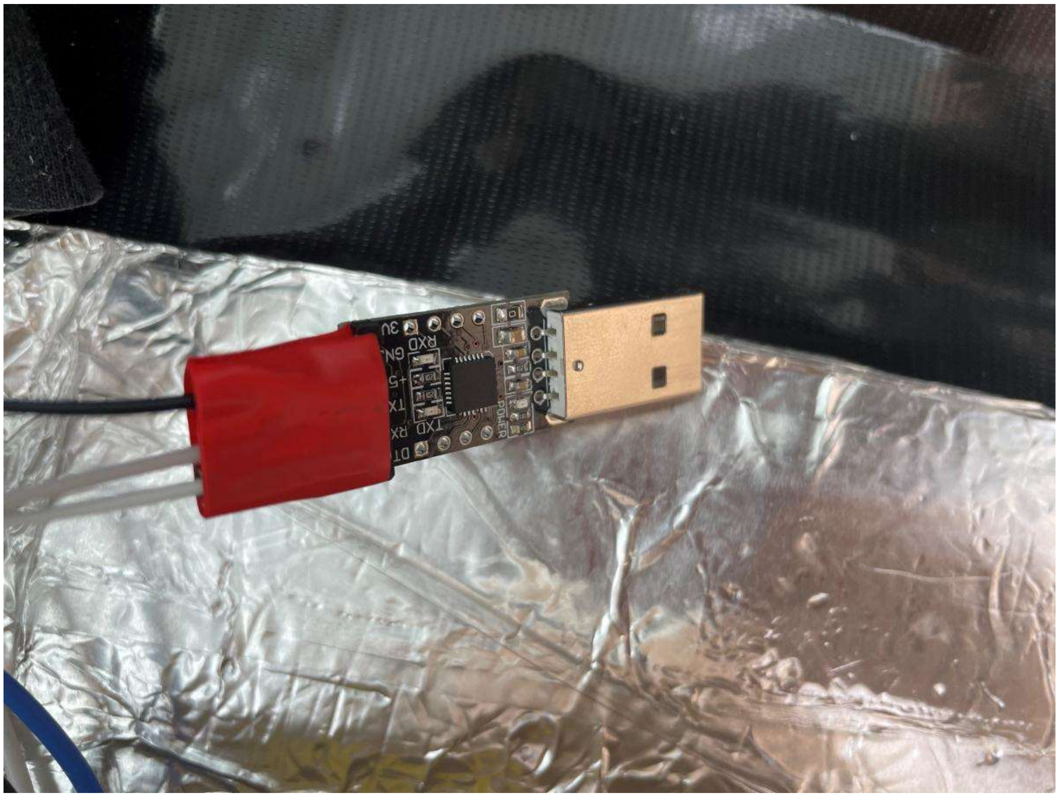


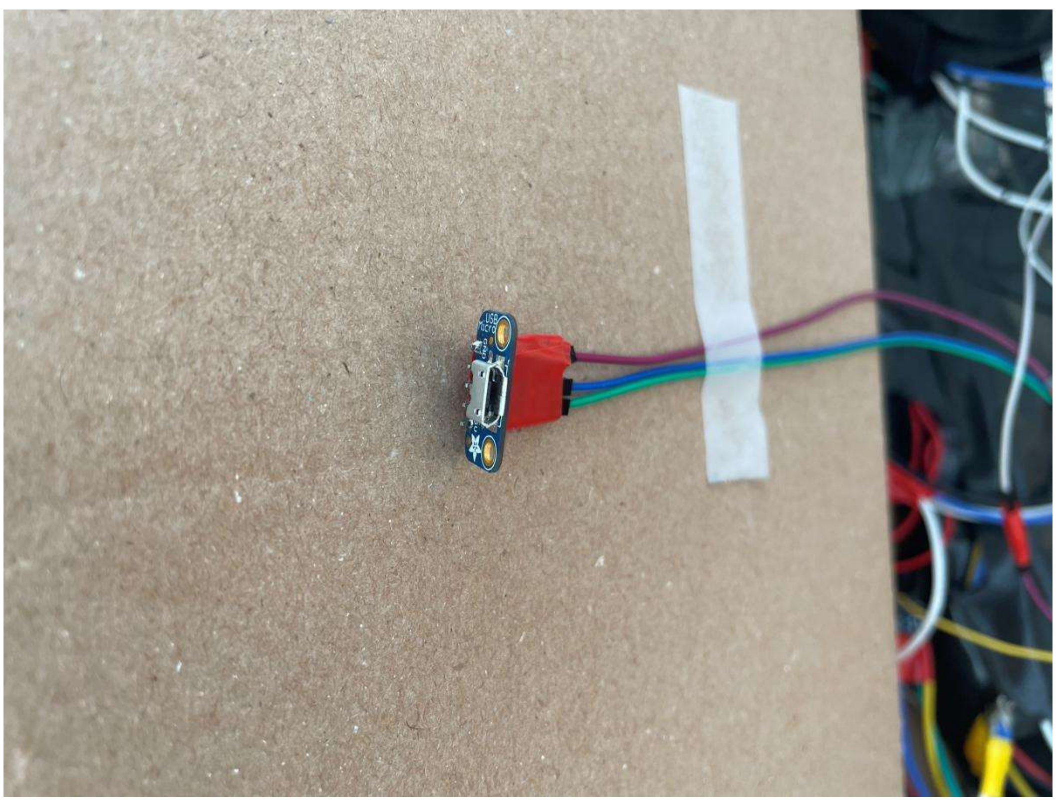
[A5] Picture of Manual Mode Switch and LED Wristband



[A6] Picture of Actual Buzzer on clothes

[A7] Picture of USB I/O and Serial Output Monitor





[A8] PCB Schematic