Anti-Hypothermia Jacket For Pro Climbers

ECE 445 Design Document

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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 [2], 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 [1].

To increase the safety of climbers, we decided to design a fully automatic system 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 and send out emergency signals when accidents occur.

More specifically, we aimed to design a jacket integrated with TEC grids controlled by microprocessors and powered by detachable battery packages. The package has two modes. When sudden body temperature loss is not detected but the user wants to increase his body temperature, users can simply press the manual button to heat for around 15 minutes monitored by a microcontroller to prevent overheating. Another mode is first-aiding mode. During this mode, the system will detect sudden human body temperature drop and start to heat the inner temperature of jacket constant at about 37 ℃ and give warning to climbers so that they can return to base within the battery limit or ask their teammates for help. For design overview, we will arrange two TEC grids (about 20 pads) in an efficient way to cover both fore-breast and back-breast, use a microprocessor to control it and power it by detachable battery packages [Figure 2].

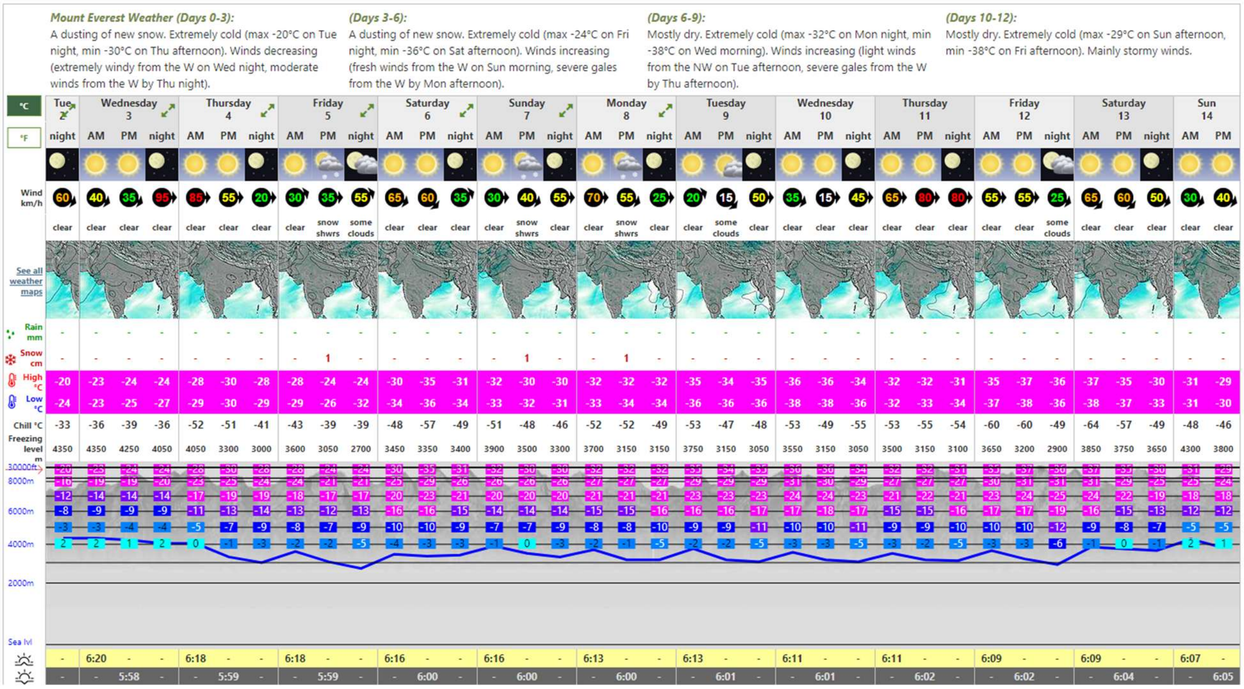

Figure1. Temperature Diagram [2]

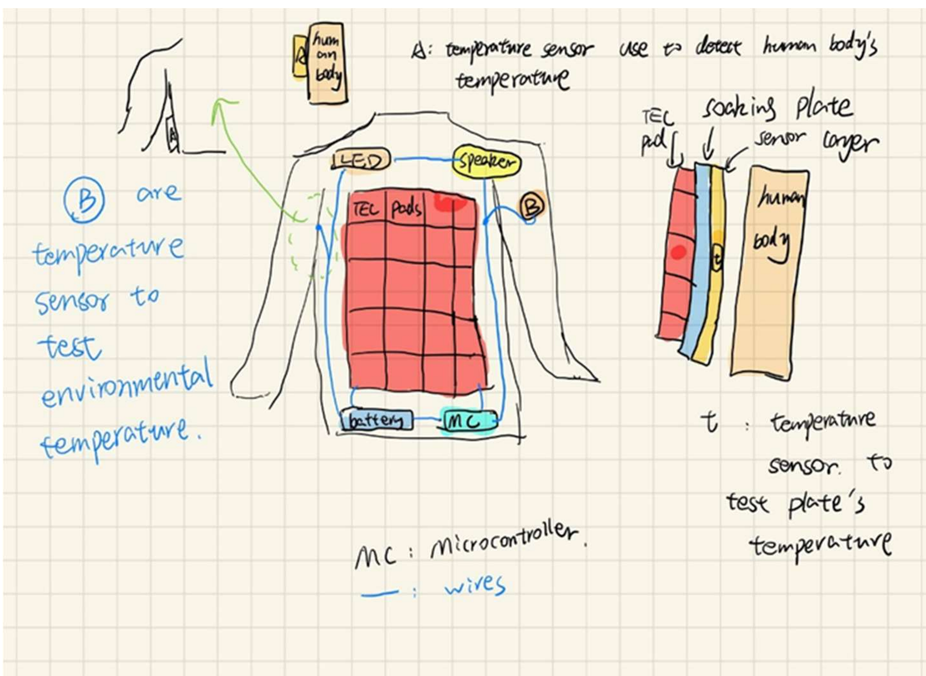

Figure2. Physical Diagram

1.2 High-Level Requirements

- The jacket with the whole system is designed compactly, incorporating the power supply, control unit, and TEC module systems with total weight lighter than 2 kg.
- The whole system should work at low temperature environment around -20℃ and is able to heat the human body to a designated temperature in 30 seconds after demands are made by body temperature or manual control.
- The whole system should be fully functional for 1 hour without running out of power.

2 Design

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 18 A peak. The control unit is composed by a microcontroller to handle both analog input from sensors and digital PWM signal output. The TEC heating module contains both front and back breast TEC grids which can quickly compensate for body temp loss [Figure 3].

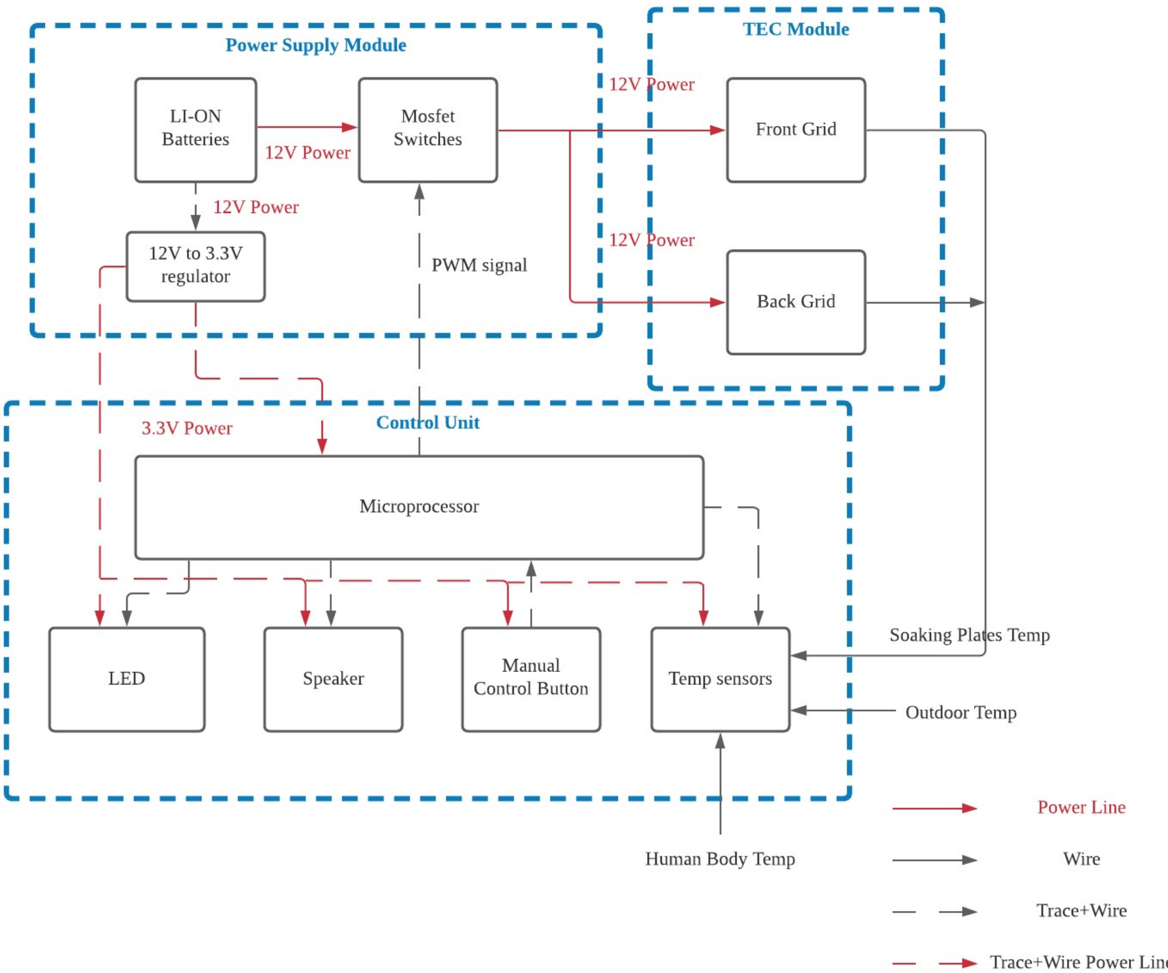

Figure 3. Block Diagram

2.1 Power Supply Module

A power supply is applied to keep the power consuming system working for at least one hour. The Li-ON batteries will provide 12V voltage directly for the control unit and will also provide large current for the TEC module through a power amp module.

2.1.1 Li-ON Batteries

The Li-ON batteries must be able to keep all the TEC pads working at a certain temperature for at least 15 min under manual model and at least 1H under first aiding mode. Besides, the battery also needs to provide 12V power for the control unit.

Table1. Li-ON Batteries RV

Requirement	Verification
1. The batteries must be able to handle at least 4A and at most 10A current at 12V voltage. The operation period is dynamically controlled by a 5V PWM signal.	1. a. Connect the battery package to TEC pads circuit. b. Connect the I/O pin and Use the multimeter to verify the PWM signal is 5V. c. Use the multimeter to measure the current and voltage of the battery package, ensuring the current I in the range of 4~10 A, the voltage stays with 5% of 12 V.

2.1.2 Power Amplifier Module

The Power Amp Module takes 5V PWM inputs from Control Unit and then acts as switches to deliver at least 9A and at most 18A for TEC Module and is worked under 12V.

Table2. Power Amplifier Module RV

Requirement	Verification
1. The N channel Mosfet is able to work at vgs = 3.3V, vds <= 1V, and pass at least 3A continuously and 5A shortly.	1. Preparing a 3x3 TEC grid and connect input of the grid to 12V power supply and connect the output to the drain of Mosfet. Then connecting the source of Mosfet to ground and gate to 3.3 V. 2. Measure the Current of the whole circuit and check if the current can reach at least 3A.

2.2 Control Unit

The Control Unit is powered by a 12V power supply and can handle analog inputs from temperature sensors and dynamically output PWM signal to the power amp module to control TEC grids. The micro-controller provides a user interface with LED, Speaker, buttons. The LED and Speaker are for first-aiding purpose and the manual control button is for operation mode change.

2.2.1 Microcontroller

We choose the chip ESP32-S2-WROVER to be our microcontroller. It deals with analog signals from temperature sensors/ buttons, conducts logic evaluation based on the quantized signal and outputs the PWM control signal to the TEC module.

Table3. Microcontroller RV

Requirements	Verification
1. The Esp32 chip should be programmable and can both receive and transmit analog or digital signals through GPIO ports utilized.	1. a. Push the EN button and change IO0 to download booting mode. b. Write the program file into the Esp32 chip. c. Change the IO0 back to SPI booting mode. d. 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.

2.2.2 LED

The LED light is used to warn climbers when the system detects any abnormal body temp drop.

Table4. LED RV

Requirement	Verification
1. Requirement1: The LED light must be 450 lumens from 5m away during foggy day. 2. Requirement2: The LED must use less than 20mA current.	1. a. Use 1-part glycerin and 3 parts distilled water to make 0.5-liter fog juice. b. Use a large soda can with fog juice we made to build a homemade fog machine. c. Pour fog juice into machine and wait until fog fill the whole room which is 5-meter long. d. Use a light meter to measure the luminance and ensure it within 5% of 450 lumens. 2. Use a multimeter to measure the current going through the LED when it’s on, ensuring it is less than 20 mA.

2.2.3 Speaker

The speaker will make a series of loud sounds to give both climber and teammates low body temp warning.

Table5. Speaker RV

Requirement	Verification
1. Requirement1: The sound made by the speaker must be 65~120 dB from 5m away during a windy day. 2. Requirement2: The Speaker must use less than 20mA current.	1. a. Put the speaker 5 meters away from you and turn on an electrical fan near the speaker. b. 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 65~120dB. 2. Use a multimeter to measure the current going through the speaker when it's on, ensuring it's less than 20mA.

2.2.4 Manual Control Button

The button is used to start the manual mode of the system. During manual mode, the system will work for 15min/cycle to help users remove sudden weather change.

Table6. Manual Control Button RV

Requirement	Verification
1. The button should be capable of being pushed in a temperature range of -30℃ to 50℃.	1. Place the button in a refrigerator with temperature below -20℃ to make sure the button works as it does in the standard room temperature. 2. Use a TEC grid to heat the button up to 50℃, ensuring the button is push able.

2.2.5 Temperature Sensors

The Sensors are located on the outer jacket, human body, and grids' soaking plates. They are used to give the microcontroller a real time analog signal for evaluation.

Table7. Temperature RV

Requirement	Verification
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.	1. Connect the temp sensors to one of the I/O pins of ESP32 test board. 2. Attach the sensor on a TEC pad. 3. Set the pad to 40 C checked by accurate handhold infrared temp monitor. 4. Read the sensor value and convert the digital data into degrees. 5. Compare the difference and check if the temp difference is within +/-0.25C for human body temperature and +/- 1 C for external and soaking plate temp sensor.

2.3 TEC Module

The TEC module contains 20 TEC pads and two soaking plates. The pads are designed for attachment on soaking plates to evenly distribute heat.

Table8. TEC Module RV

Requirement	Verification
The TEC grids should contain 9 TEC pads. Each grid can be drive at 3-4V and can heat the soaking plate to 40 degrees in 1 min.	1. Place the pads in 3x3 structure and glue them on a solid base and put a soaking plate on those pads. 2. Drive the whole circuit with a 12V and 8A power supply. 3. Count the time needed to heat the soaking pad to 40 degrees.

2.5 Schematics

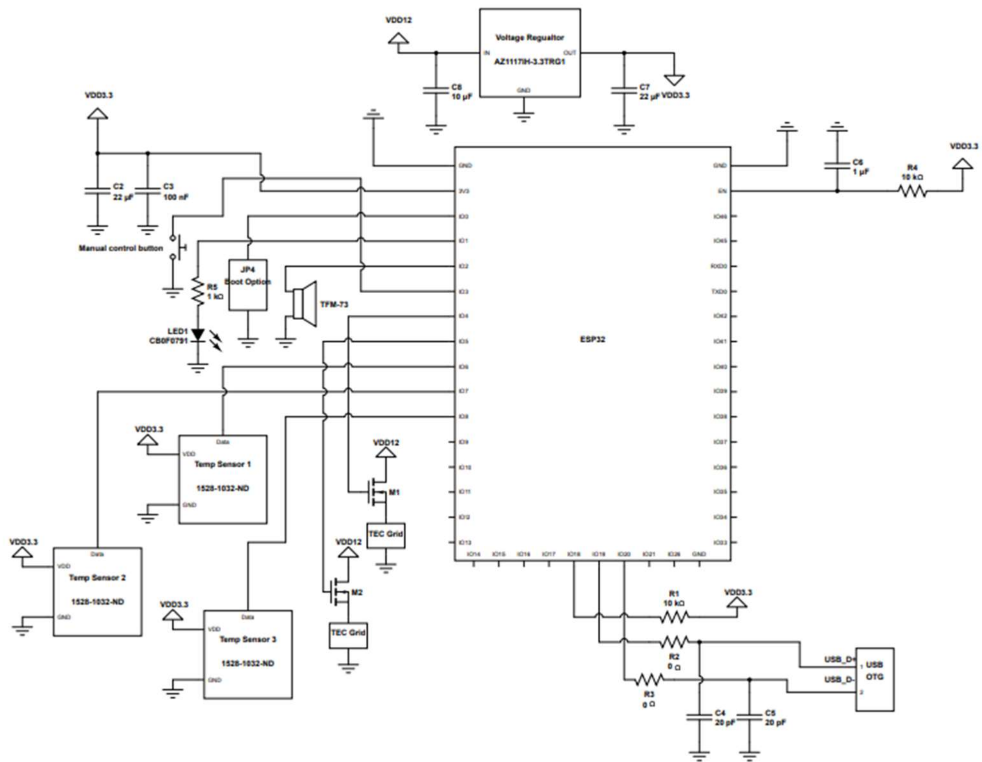

Figure 4. Overall Schematic

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 5]

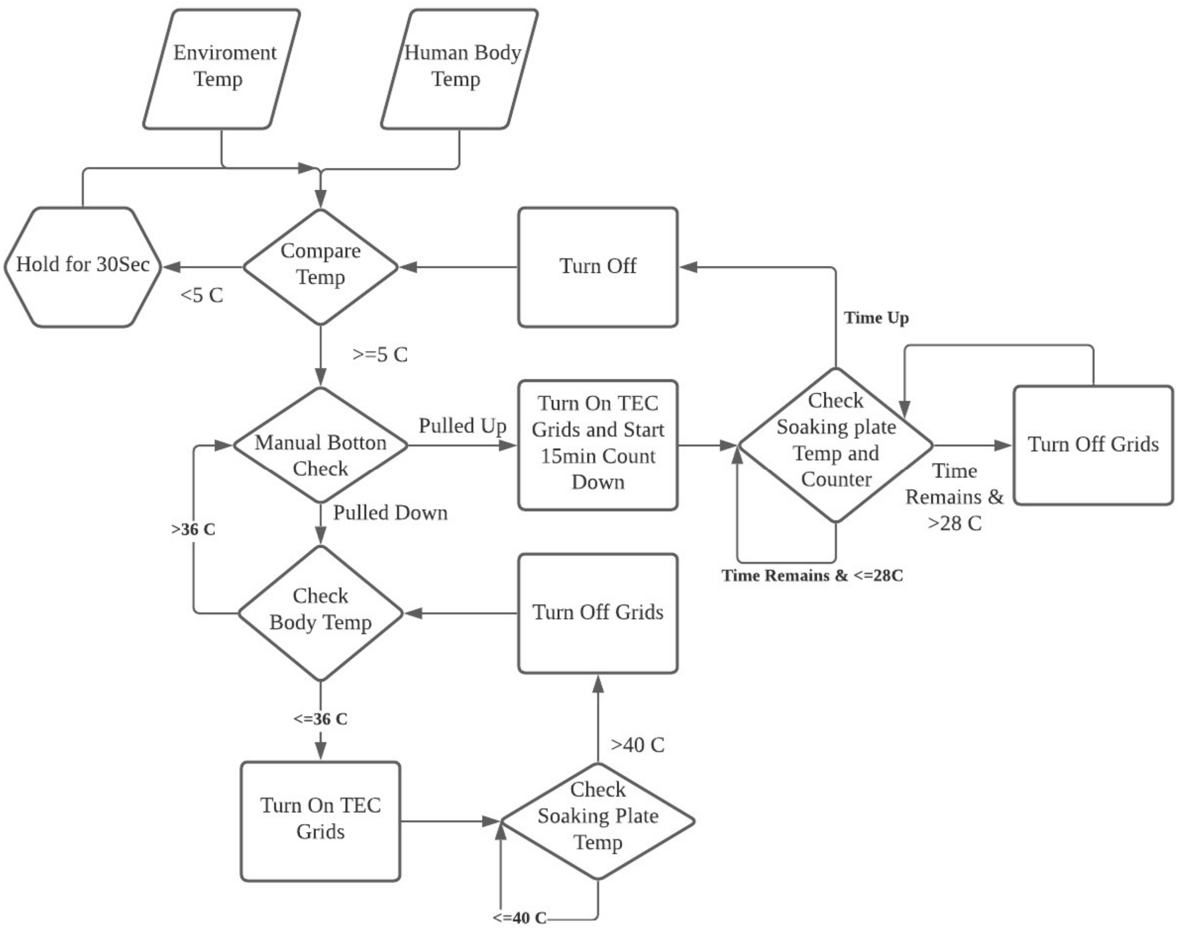

Figure 5. Microcontroller Algorithm

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. 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 saturation current at Vgs=5V.

Temperature sensor tolerance [Figure6, Figure7]:

In the microcontroller's algorithm, the temperature sensors in different places are aimed to detect changes in temperature and give feedback to the microcontroller in terms of voltage. The resistance of a temperature sensor will be changed due to the variance in temperature and we utilize a voltage divider and monitor the voltage across the temperature sensor to reflect changes in temperature. Ideally, we can monitor the exact temperature at a temperature sensor if its resistance strictly depends on the environment temperature. Errors may occur due to internal resistance of power supply, accuracy of the resistance of the temperature sensor at a given temperature, and internal resistance of the microcontroller's internal logic components. We would expect the temperature monitored by the microcontroller to be within 0.5 ℃ away from the desired temperature (+/- 0.5 ℃).

Power storage tolerance:

our goal for the device is to make it last for at least 1 hour. Due to our measurement, 3 TEC pads connected in series will consume around 12.6 W under 12 V voltage. Also, it takes around 8.5 seconds to increase the temperature of TEC pads from 26.8 Celsius degree to 45.0 Celsius degree. We have 18 pads in total, so the total power for TEC pads is 75.6W. So, at least, we need one 100 Wh batteries to supply our devices and ideally it can support 1.3 hours. However, the actual battery power storage may change with the temperature changes. We would expect three batteries can support our device working for 1.0 ~ 1.3 hours

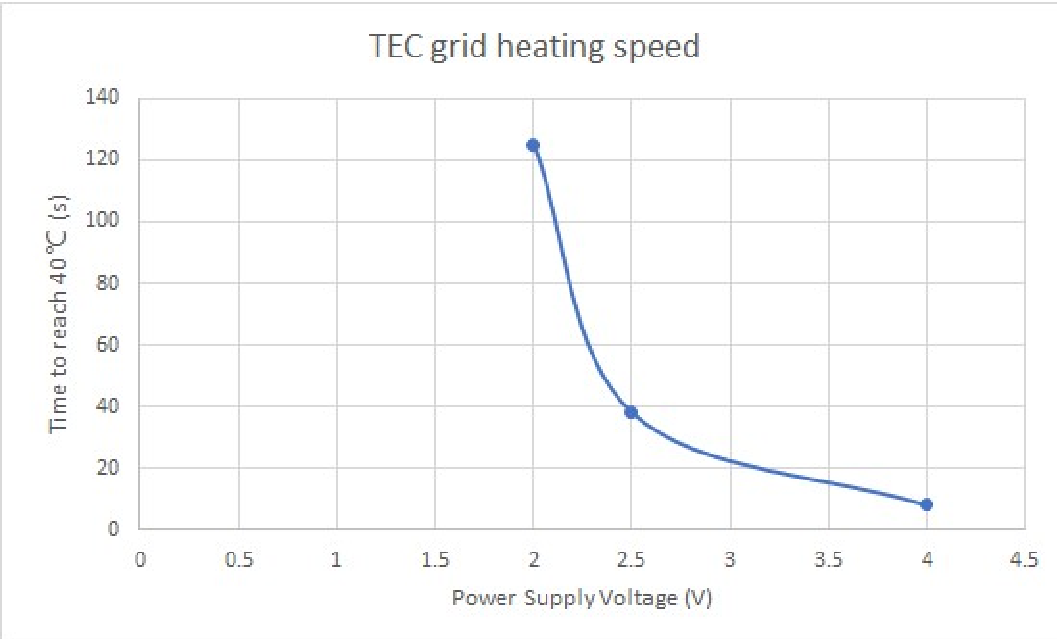

Figure 6. Power Supply Voltage vs. Time for TEC Grid to reach 40°C(experimental)

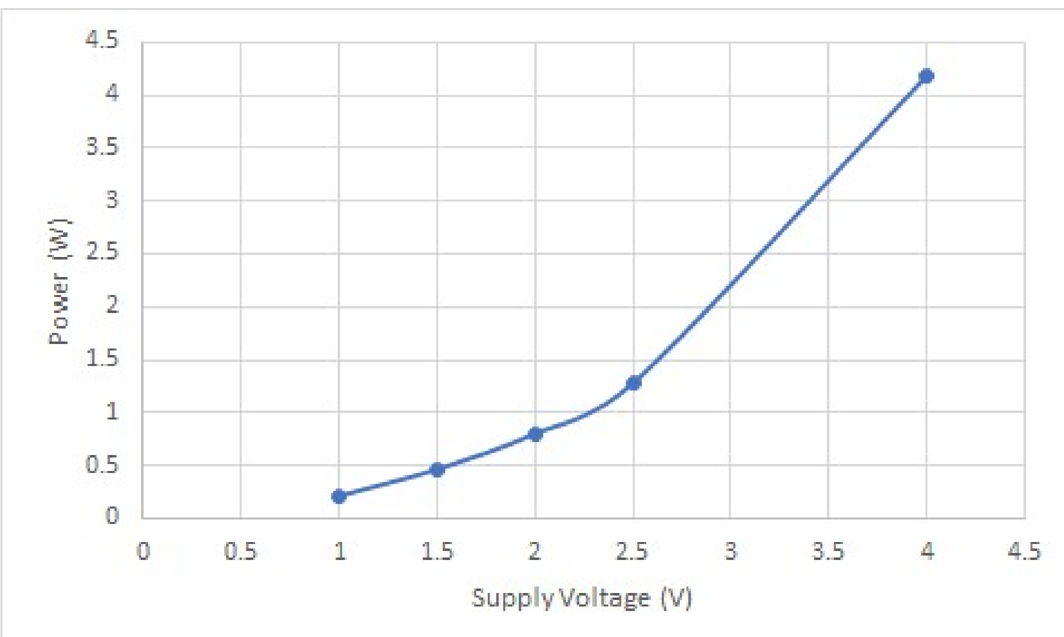

Figure 7. Power of TEC Grid vs. Supply Voltage(experimental)

3 Cost

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

Table9. Cost

Part	Cost(prototype) USD	Cost (bulk) USD
12V 4000mAh battery (Folk Battery)	12.5	12.5
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 Schedule

Table9. Schedule

Week	Yifan Pan	Chengyu Fan	Yifu Guo
2/8/2021	Consider specific parts needed in the project	Analyze project feasibility and come up with abstract design logic	Analyze project feasibility and prepare backup project
2/15/2021	Do research on partial elements revolved in the project and analyze requirements	Work on project approve and provide data for power consumption	Analyze system logic and do paper editing
2/21/2021	Do test on the TEC pads and temperature variation	Do test on the TEC pads and temperature variation	Do test on the TEC pads and temperature variation
3/1/2021	Work on design document and complete circuit diagram for microcontroller	Work on design document check and choose LDR, chip, Mosfet for schematic	Choose LED and Speakers and edit Design document
3/8/2021	Perform tests on MOSFET and temperature sensors to check MOSFET operation range and errors of temperature sensors. Build version1 PCB	Perform tests on MOSFET and temperature sensors to check MOSFET operation range and errors of temperature sensors. Build version1 PCB	Perform tests on MOSFET and temperature sensors to check MOSFET operation range and errors of temperature sensors. Build version1 PCB
3/15/2021	Work on PCB layout for microcontroller	Build the whole 3x3 TEC grid and test the performance of Mosfet switches.	Design version 2 pcb and submit pcb order
3/22/2021	Program the microcontroller for fundamental functions	Test the program with development board and test I/O of sensors, LED, buzzers	Test the program with development board and debug the errors

3/29/2021	Debug the microcontroller program and collaborate test with temperature sensors, MOSFET.	Solder the entire PCB board and test hardware connectivity of IC components	Solder the entire PCB board and test hardware connectivity of IC components
4/5/2021	Run the entire system and test all the functions of the system	Run the entire system and test all the functions of the system	Run the entire system and test all the functions of the system
4/12/2021	Install the whole package on the jacket and test performance	Install the whole package on the jacket and test performance	Install the whole package on the jacket and test performance
4/19/2021	Encapsulation all the components and come up with prototype model	Encapsulation all the components and come up with prototype model	Encapsulation all the components and come up with prototype model
4/26/2021	Perform tests on various environments.	Perform tests on various environments.	Perform tests on various environments.
5/3/2021	Begin on final report	Prepare final presentation	Begin on final report

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 [3]. 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…” [4].

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…” [4].

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…” [4].

References

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