Team 12 Project Document

Optical Feedback Wearable

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5.1. Universal Constraints

5.1.1. The system may not include a breadboard.

5.1.2. The final system must contain a student designed PCB.

5.1.3. All connections to PCBs must use connectors.

5.1.4. All power supplies in the system must be at least 65% efficient.

5.1.5. The system may be no more than 50% built from purchased 'modules.'

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1. Overview

1.1: Executive Summary

The objective of this project is to develop a self-sufficient, long-lasting wearable device that can provide feedback to the user and assist with interacting with their environment. The target audience of our project is students. The project is intended to be used in a casual on-campus environment to interactively enhance comfort and safety.

The project must include the use of sensors. Sensor proposals include temperature sensors and light sensors. The temperature sensors will support the use of heating elements to warm the user when walking between classes, and the light sensors support the use of automatic safety lights for crossing roads at night.

The form factor for this project is a back belt in a cheap, comfortable material. This selection suits the casual environment of a university, and it will be relatively easy to locate space throughout the loose-fitting back belt to place batteries, sensors, and peripheral devices.

To address the limitations imposed by the need for the project to be wearable, this project anticipates the use of flat-body lithium ion batteries, flexible conductive strips or auxiliary cables, and small, well-contained printed circuit boards for major circuit designs. Two batteries are anticipated for use in order to provide adequate power to heating elements while still ensuring that after extensive use some power remains to sustain safety light features. Power supplies will be encased in plastic pockets to prevent water damage and shorting of the device, while auxiliary cables provide some water resistance at peripheral contact locations.

1.2: Team Contacts and Protocols

Contact Information:

Table I: Contact information

Name	Email	Role
Hassan Alakbari	alakbarh@oregonstate.edu	Sensor Integration
Junda Qiu	qiuju@oregonstate.edu	Visual Feedback

Team Protocols:

Table II: Team protocols

Topic	Protocol	Standard
Openness and Accountability	We anticipate challenges that may exceed our capabilities and time. We will notify the team as soon as possible when we need extra support, but not penalize or shame any member who cannot fulfill the obligations they set out to do. Treating one another with kindness and forgiveness supersedes any deadlines or project goals.	Full and timely communication is required regarding any failures to complete work to the standards set out by assignment descriptions.

Team Meetings and Collaboration	The team will meet all together at least once per week, but in respect for people's time and physical proximity to the university many communications can and should be pushed to an online setting.	Attendance each week at team meetings is mandatory, and participation in online communications must be regular.
Goal Setting and Task Oversight	Assignments will be broken into individual parts with tasks assigned to individuals to own the completion and timeline. These tasks are not necessarily completed by the person overseeing their completion.	It is the responsibility of the task owner to ensure the task is completed in accordance with recommendations and rubric standards.
Documentation Maintenance and Access	Documentation will be developed within the team Google Drive to promote collaboration and accessibility to vital project information.	Information must be accessible to appropriate stakeholders in a timely and complete manner.
Deliverables and Contact Management	Any changes to the intended design will be immediately communicated to the project partner through email with an invitation to meet and go over such changes in detail.	The project will maintain standards set out by the project partner and not be altered without open and clear communication.

1.3: Gap Analysis

The Optical Feedback Wearable is requested by the project partner to serve as an exploration into the potential applications and implementations of wearable technology. The intended outcome is a proof of concept or a prototype demonstrating integration of sensors and feedback into an energy efficient, comfortable device that serves students. The onus was on the team completing the project to select both the target audience as well as the intended use of the wearable.

Students were selected as an excellent option due to the proximity of the team's personal experience for testing and design, as well as the feasibility of designing a prototype that upholds a degree of rigor appropriate for their needs. An example of a project similar to the team's would be a heating sweater which is being popularized these days, this would help the team get more ideas and insight on the project.

Students possess an openness to technological innovation, experimentation, and participation in open source projects. Personal experience of the team members suggests that students are open to implementing new technology to enhance their capabilities. The environment prompts solutions focused on comfort and safety, as campuses range in temperature and light availability throughout the nation. Some concepts on the design originated from discussion with peers about what they would like to see in a wearable device.

1.4: Proposed Timeline

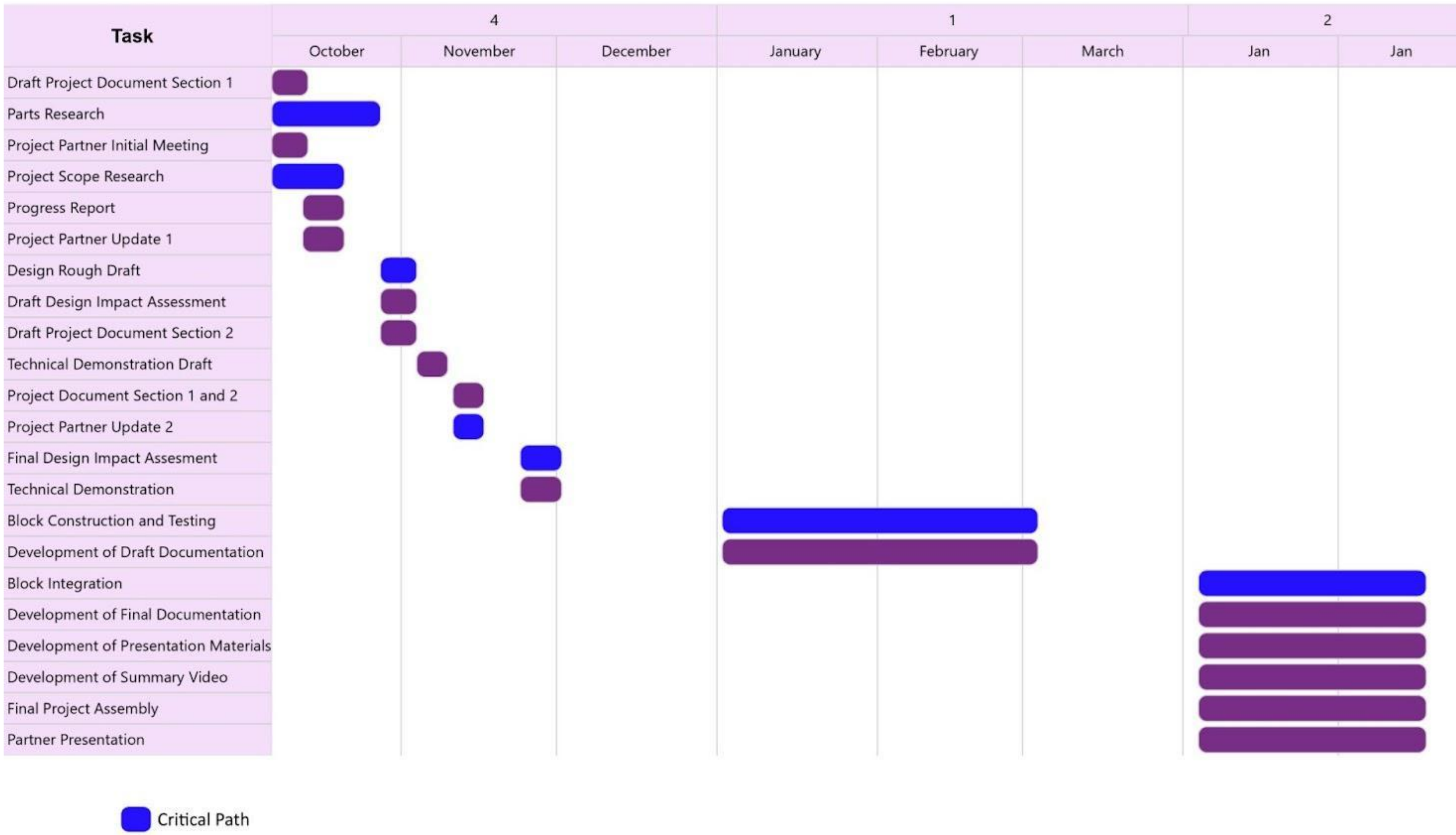


Fig. 1. Proposed timeline

1.5: Reference Links and File Links

Section 1.5.1: Reference Links

Section 1.5.2: File Links

Project Proposal:

"EECS Project Portal," Single Project. [Online]. Available: https://eecs.oregonstate.edu/capstone/submission/pages/viewSingleProject.php?id=m45JxJrSFM6s5rwm. [Accessed: 18-Nov-2022].

1.6: Revision table:

10/14/2022	Mae: Contributed content to initial draft of section 1. Mae: Revised section 1 to meet formatting specifications and content requirements.
11/4/2022	Mae: Adjustments to formatting including tables. Adjustments to gap analysis and executive summary reflecting updated target audience.
11/18/2022	Hassan: Changed the format to IEEE for the file link section. Added a figure number to the proposed timeline table, and table numbers in IEEE format. Edited the revision table. Added an example to a project in the Gap analysis section.
11/18/2022	Mae: Technical detail added to executive summary. Added deliverables team protocol.

2. Impacts and Risks

2.1: Design Impact Statement

2.1.1 Introduction

This assessment reflects efforts to investigate the potential ethical impacts of the design the team is hoping to fulfill. These efforts are intended to guide the team toward solutions that are conscious of the engineer’s role in maintaining ethical standards in design. The wearable back belt prompts concerns for the safety of the wearer as well as the well being of the team designing it. The wearable is intended to be a convenient and comfortable back belt that is designed with the intention of making a student’s life easier by providing safety lights, reading lights, and a heating element for warmth. The team is conscious of the social responsibility to make the design accessible for the majority of the student cohort it’s designed for. Environmental concerns regarding the disposal of the device and ethical considerations for the economic impact it may have with reference to its position in the textile industry are also addressed.

2.1.2 Public Health, Safety, and Welfare Impacts

The primary safety concern for the device is its potential to overheat and cause burns to the user, either from the power source or the heating element. In the case of the power source, one major concern is the lithium ion batteries. The cause of lithium battery fires may come about in multiple ways. The first is a manufacturing defect, where metal impurities seep into the battery during the manufacturing process, or the compartment of the battery is too thin. The second is a design defect, a defect caused by a compromise in the design process for other properties or components. The third is improper use from the battery being too close to the source of goods or deliberate piercing of the battery, etc. Fourth is a mismatch between the battery and charger. Lastly, the components used in production may be inferior [1].

The team should apply principles for handling flammable materials by maintaining easy cutoff of the current supply, using dry powder fire extinguishers to put out potential fires, and avoid the use of Class D fire extinguishers. The team can also use aqueous vermiculite dispersion (AVD) to extinguish potential fires [1]. In preventing fires during use, any intended release of the product design or product itself must contain appropriate warnings surrounding the use of lithium ion batteries.

We must not only consider the safety of the potential users of the device, but also the safety of the contributing team members responsible for fulfilling the design. University students are disproportionately and increasingly impacted by depression, anxiety, and suicidal thoughts in addition to being at an age when mental illnesses are more likely to onset [2]. Studies have shown that mindfulness techniques such as decentering and self-compassion may mediate the psychological challenges faced by this cohort [3]. Mutual compassion and support through more challenging moments in the year should be a key focus in teammate interactions.

If successful, the light strips on the wearable should contribute to the safety of students while on campus. The Insurance Institute for Highway Safety outlines that pedestrian fatalities, which have been increasing since 2009 particularly in younger populations, occur most in urban areas where many college campuses exist and may be mitigated by increased illumination [4]. The team has personally experienced the struggle of crossing busy roads near campus, and can clearly see a potential benefit in adding to the visibility of students on campus.

2.1.3 Cultural and Social Impacts

Our team has decided that our project (which is a wearable) needs to be conscious of the divide of affluence between students and challenge ourselves not to contribute to it. Soaring student loan debts are becoming a problem [5], and higher education is becoming more and more unattainable by people of lower socioeconomic status. The design should contribute to making the student's experience better by being cheap and reproducible. Students who were not fortunate in their lives because of being poor have their performance slowed down due to them feeling a lack of belonging, so making a cheap product levels that field, and might even make them feel that they belong more at the university with their other peers.

It is imperative that our product be affordable and also available to all students. Our product is a wearable sweater that should be worn by any student, and it should make their experience in college more bearable. It should be able to comfort students to help their experience while attending college and that is why it should be available to all students no matter their socioeconomic status. People with high SES (socioeconomic status) tend to get higher grades and are less likely to drop out due to many reasons [6], and one of them is academic preparation. The studies above show that making all students feel that they fit in improves their academic performance and helps cushion the affluence between students in universities, and that is why it is imperative that our product is available and affordable to all students. Overall, it would satisfy us if our project makes academic preparation easier in any way to all students, and to contribute to social justice with our project for a better college experience to all.

2.1.4 Environmental Impacts

Most e-waste will be disposed of with ordinary garbage with the momentary negligence of ordinary people, which in turn releases toxic chemical elements. First of all, they can have an impact on the soil. Toxins released into the soil from e-waste can exist for thousands of years and can contaminate plants and also enter the food chain of humans and animals. Second, elements such as mercury and lead in e-waste can flow into groundwater, streams, ponds, lakes and other water sources, potentially disrupting the food chain and increasing the health risks to people. Third, the emissions from burning electronics are harmful. Gasses from burning objects such as plastic, glass, and metal are harmful and can lead to ozone depletion and an increase in greenhouse gasses, leading to global warming and climate change. Finally, dumping electronic waste into the ocean is also undesirable. Because e-waste is not biodegradable, it damages the ecosystem and disturbs biodiversity [7].

There are multiple considerations for e-waste disposal regarding our project. First of all, we need to find an e-waste disposal site and we should search by region. Some e-waste sites are far away from our location. We are not allowed by law to transport more than 125 pounds of hazardous waste, and a waste disposal company would be a good option. We need the e-waste disposal company to separate the hazardous waste from the non-hazardous waste. Drop-off facilities may not accept all of your e-waste, and the type of e-waste accepted will vary from facility to facility. We have to remove the data from the equipment for safe disposal [8]. The team can reduce the use of hazardous materials through the use of lead-free solder, attempts to reuse discarded batteries in future projects, and modularity in the design allowing for compartmentalized disposal of individual parts.

2.1.5 Economic Factors

The use of textiles in the design invokes a concern over the economic exploitation involved in the production of back belts like the one we plan to use in our design. Production of apparel is dominated by sweatshops in low-wage countries where workers may experience long hours, unsafe conditions, wages insufficient relative to the cost of living, harassment, abuse, invasive surveillance, and few labor rights [9]. The team should therefore consider the interoperability of the design with second-hand clothing or the creation of sewing patterns so that such labor may be done by hand. Second hand clothing is increasingly regarded as a viable solution due to the lower cost and environmental impact of already worn goods [10]. Careful sourcing of materials and consideration for the conditions of those providing labor to generate the back belt form factor is vital to avoid contributing to economically exploitative systems. This indicates that research must be done on the manufacture of any newly purchased fabric, and that purchasing already made back belts is not worth consideration. If this product were in consideration for mass production, more careful analysis would need to be taken on potential manufacturing sources.

2.1.6 Conclusion

To make a truly accessible wearable for students, the design should center around the capacity of students to manufacture, maintain, and use the device. Key aspects of achieving this include reproducibility to ensure equitable access, modularity to reduce waste and disposal impacts, and safety features which protect the user. The aim to improve the well-being of students through use of the wearable must come at minimal expense to the ethical concerns of stakeholders from the team through the manufacturers of the parts used in the device.

2.1.7 References

[1] “Battery safety : Top 5 reasons why lithium-ion batteries catch fire,” *ION Energy*, 2-May-2022. [Online]. Available: https://www.ionenergy.co/resources/blogs/battery-safety/. [Accessed: 04-Nov-2022].

[2] M. McLafferty et al, "Mental health, behavioural problems and treatment seeking among students commencing university in Northern Ireland." *PLoS ONE*, vol. 12, no. 12, pp. e0188785, December, 2017. *Gale Academic OneFile.* Accessed: November, 4, 2022. [Online]. Available: link.gale.com/apps/doc/A518695724/AONE?u=s8405248&sid=bookmark-AONE&xid=b5d200d8

[3] D. Martínez-Rubio, J. Navarrete, J. Montero-Marin, “Feasibility, Effectiveness, and Mechanisms of a Brief Mindfulness- and Compassion-Based Program to Reduce Stress in University Students: A Pilot Randomized Controlled Trial.” Int J Environ Res Public Health. 19(1):154. doi: 10.3390/ijerph19010154. PMID: 35010414; PMCID: PMC8750204. December 2021. Accessed: November, 4, 2022. [Online]. Available: https://pubmed-ncbi-nlm-nih-gov.oregonstate.idm.oclc.org/35010414/

[4] “Fatality facts 2020: Pedestrians,” *IIHS*. [Online]. Available: https://www.iihs.org/topics/fatality-statistics/detail/pedestrians. [Accessed: 02-Dec-2022].

[5] “How norms of affluence on college campuses affect inequality,” *How Norms of Affluence on College Campuses Affect Inequality* | *RSF*. [Online]. Available: https://www.russellsage.org/news/how-norms-affluence-college-campuses-affect-inequality. [Accessed: 04-Nov-2022].

[6] “Ho:E cues at˜universities increase the˜social Class Achievement Gap.” [Online]. Available: https://huolab.psych.ucla.edu/wp-content/uploads/sites/5/2021/08/Ni-Goodale-Huo-SOE-2019.pdf. [Accessed: 05-Nov-2022].

[7] Earth911, “E-waste: What happens when we fail to Recycle Electronics,” *Earth911*, 16-Jul-2021. [Online]. Available: https://earth911.com/eco-tech/e-waste-why-you-should-recycle-electronics/. [Accessed: 04-Nov-2022].

[8] “Electronic waste disposal issues and how to fix them,” *IDR Hazardous Waste Disposal Blog*. [Online]. Available: https://blog.idrenvironmental.com/electronic-waste-disposal-issues-and-how-to-fix-them. [Accessed: 04-Nov-2022].

[9] R. Ross, “Slaves to Fashion: Poverty and Abuse in the New Sweatshops.” University of Michigan Press. 2004. *ProQuest Ebook Central.* Accessed: November, 4, 2022. [Online]. Available: http://ebookcentral.proquest.com/lib/osu/detail.action?docID=3414744

[10] Y. Xu, Y. Chen, R. Burman, H. Zhao, “Second-hand clothing consumption: a cross-cultural comparison between American and Chinese young consumers.” International Journal of Consumer Studies. ISSN 1470-6423. doi: 10.1111/ijcs.12139. Pp. 670-677. 2014. Accessed: November, 4, 2022. [Online]. Available: https://web-p-ebscohost-com.oregonstate.idm.oclc.org/ehost/pdfviewer/pdfviewer?vid=0&sid=c4059cc9-eceb-480d-b056-5b9f9111c75d%40redis

2.1.8 Revision table:

12/2/2022	Hassan: Removed extra space from reference list. Made grammatical corrections for the environmental impact section. Improved the cultural section (dug deeper and mentioned studies). Added more context for the project in the introduction in compliance with feedback from the instructor and peer reviews.
12/2/2022	Mae: Added research to the section on safety lights. Added suggested details to the Economic Impact section. Added more detail on the intended use of the wearable. Implemented potential solutions to the issues presented regarding electronics waste. Updated table of contents pages.

2.2: Risks

ID	Description	Category	Probability	Impact	Indicator	Action Plan
R1	Can't get replacement parts	Technical	Med	High	Low stock	Get duplicates, check stock
R2	Hot parts cause injury	Safety	Med	Med	Temp. sensors	Measure and test
R3	Project work unsatisfactory to project partner	Organiz.	Low	Med	Updates aren't approved	Regular updates, clear communication
R4	Going over budget	Organiz.	High	Med	High expenses	Adjust scope or buy own parts
R5	Team member mental health crisis	Organiz.	High	Med	Absence, distress	Adjust scope and redistribute
R6	Lipo batteries catch fire	Safety	Low	High	Excessive heat	Fire extinguisher
R7	Blocks fail to integrate fully	Technical	Med	High	Interfaces adherence	Block redo or adjustments
R8	Blocks are incomplete	Technical	Low	High	Progress reports	Assist team members

2.3: References and File Links

Section 2.3.1: Reference Links

Section 2.3.2: File Links

2.4: Revision Table

11/4/2022	Mae: Added risk table, section 2 headers
11/18/2022	Mae: Added R7 & R8.

3. Top-Level Architecture

3.1: Black Box Diagram

The black box diagram gives a more simplistic view on the block and shows the interfaces that connect to it. For example a block can have two interfaces or more, some of the interfaces being inputs and some being outputs. The following figure shows an example of a black box diagram for one of the blocks:

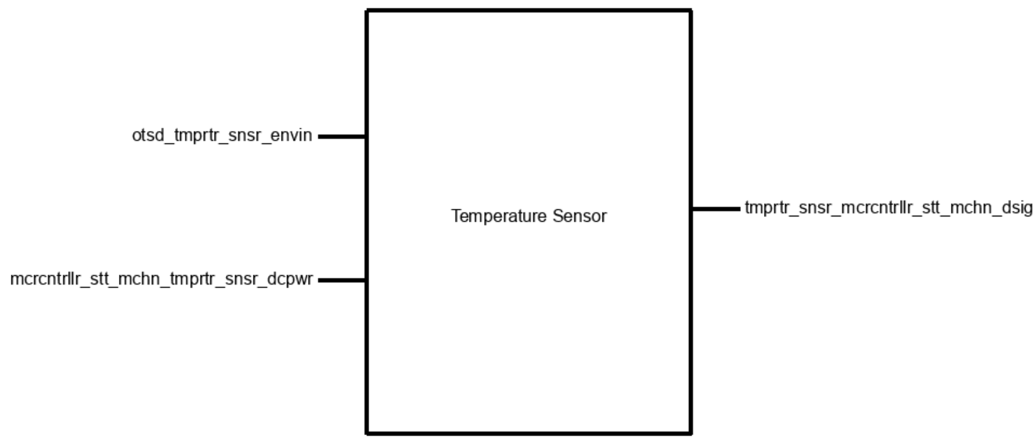


Fig. 1. Temperature sensor black box diagram

3.2: Top-Level Diagram

The top level diagram shows the complete system as a set of blocks that connect to each other with a series of inputs and outputs. The following figure is the top level diagram.

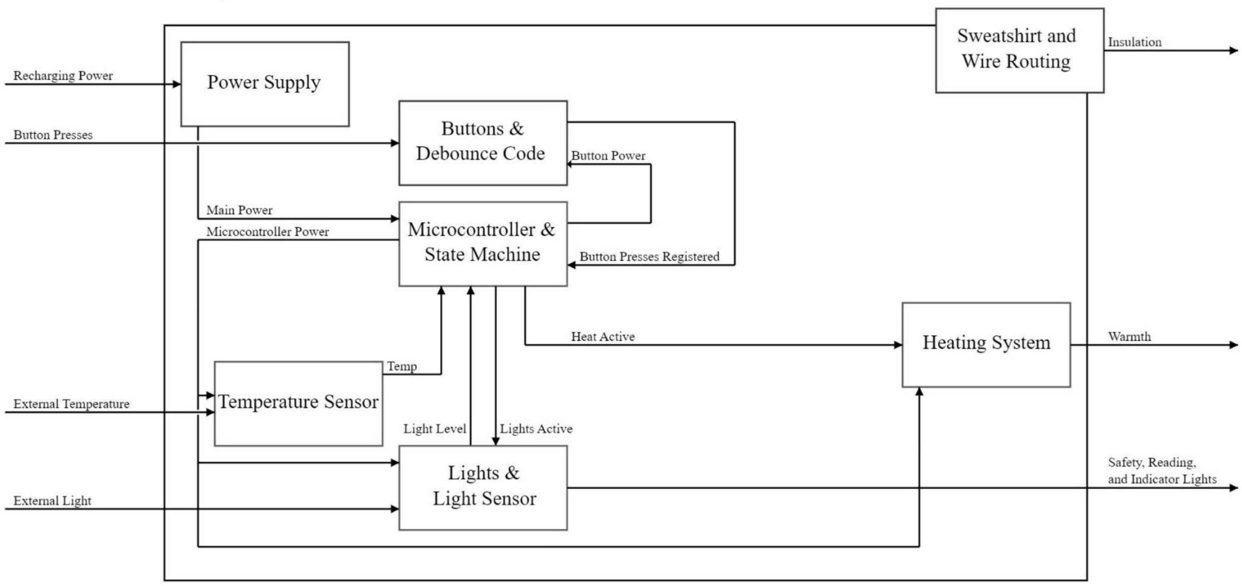


Fig. 2. Top level diagram

3.3: Block Descriptions:

Block descriptions is a section that is necessary to make the user understand the fundamental subsystems that make up our main system. The following table shows the descriptions of each block that makes up the system.

Table I
Block Description

Name	Description
Power Supply Champion: Hassan Alakbari	The power supply of the system is a power bank that is able to supply 5V to the system constantly and is able to make the system run without power issues.
Buttons & Debounce Code Champion: Junda Qiu	Separate buttons must exist to control the lights and heating element, altering the mode between passive, on, or off. The passive mode automatically changes the state of the lights and heating element based on sensor readings. The button debouncing code is responsible for detecting button presses from the buttons. It must mediate false presses of the button and distinguish them from intentional operation of the buttons, reporting this to the microcontroller to operate the state machine and applying intentional control to the lights and heating element.
Wire Routing Champion: Hassan Alakbari	The backbelt is the enclosure of the device, and must contain a set of wires which connect all other blocks to one another. The wires must be able to disconnect from devices which are sensitive to moisture and temperature for washing of the device, and must either be removable or resistant to washing themselves.
Microcontroller & State Machine Champion: Junda Qiu	The microcontroller contains the button debouncing code, the state machine code, and the heating element feedback loop. It must support the operation of all code block simultaneously. It must receive sensor information from the external temperature sensor, the heating element internal temperature sensor, the buttons, and the light sensor. It must provide activation signals to the heating element feedback loop and the various lights. The state machine mediates the state of the lights and heating element. It must track changes in the button presses that alternate the state between passively responding based on external temperature and light sensing, all outputs being turned off, and any outputs being manually turned on.
Lights & Light Sensor Champion: Junda Qiu	The light sensor detects the ambient light around the wearer of the back belt. This input is used in the passive light sensing mode to automatically activate the safety lights in low light conditions. The lights consist of three varieties. The first is a set of safety lights to notify surrounding individuals of the presence of the wearer and may be operated manually, or activated automatically in the passive sensing mode. The safety lights will be located along the upper part of the sleeves to ensure a high degree of visibility from multiple angles. The second is a set of reading lights on the front of the device which allow reading in low light conditions, controllable by button presses. The final lights are indicator lights which allow the user to determine the current state of the device, distinguishing whether the heating element and safety or reading lights are in an activated state.

Heating System Champion: Hassan Alakbari	The heating element provides warmth to the user when either activated manually or a low temperature is detected in passive sensing mode. It must operate within safe temperature ranges and successfully contribute to the warmth of the wearer. The heating feedback loop code is responsible for mediating the temperature of the heating element when active. It must turn the heating element on when the temperature must be increased to provide warmth, and turn off the heating element when the max operating temperature is detected. It must respond to the state machine when it indicates the heating element should be in an active state.
Temperature Sensor Champion: Hassan Alakbari	The temperature sensor is an outside facing sensor that measures the air's ambient temperature. This temperature sensor is essential for reporting the air temperature in order to regulate the heating element's operation. The integration of the temperature sensor block is crucial as a number of other blocks in the system are dependent on it.

3.4: Interface definitions:

A vital part of the blocks in the block descriptions is the interfaces, which were analyzed and chosen specifically to match the system's needs. The table below shows The interfaces and their properties:

Table II

Interfaces

Name	Properties
otsd_pwr_spply_dcpwr	Inominal: 510uA Ipeak: 1500uA Vmax: 6V Vmin: 3.75
otsd_bttns_dbnc_cd_usrin	Timing: 9 out of 10 users report a tactile sensation when pushing the button. Type: The button is embedded in the back belt fabric. Usability: The button exists on the collar for easy access.

otsd_lghts_lght_snsr_envin	Light: max 15000 lux Light: minimum 1 Lux Light: threshold of environment light input = 3000+- 10% Lux (if larger, turn off, other wise turn on)
otsd_tmprtr_snsr_envin	Other: Accuracy: + - 0.5C within the actual temperature. Other: Sensing period: 4 seconds, meaning the sensor will sense temperatures every 4 seconds. Temperature (Absolute): The sensor will get temperatures with 0.1C increments.
pwr_spply_mcrcntrllr_stt_mchn_dcpwr	Inominal: 0.04A Ipeak: 0.06A Vmax: 5.5V Vmin: 4.5V
pwr_spply_lghts_lght_snsr_dcpwr	Inominal: 120mA Ipeak: 140mA Vmax: 5.5V Vmin: 4.5V
bttns_dbnc_cd_mcrcntrllr_stt_mchn_data	Messages: check_button1(): returns the state of button 1 Messages: check_button0(): returns the state of button 0 Protocol: Code is written in C
swtshrt_nd_wr_rtng_otsd_envout	
mcrcntrllr_stt_mchn_lghts_lght_snsr_dsig	Other: Logic level: Active high Other: threshold V of A0 = 150*5V/1024 = 0.75V +- 10% Vnominal: 4.7V
mcrcntrllr_stt_mchn_htng_systm_dsig	Logic-Level: Active high Vmax: 5V Vmin: 3.7V
lghts_lght_snsr_otsd_envout	Light: luminous intensity peak = 24000 lux(when I peak = Inominal * 1.5 = 0.009) Light: Luminous Intensity nominal = 19000 lux (when I nominal = 0.006) Other: survey: 9 out 10 people saythe intensity of light is bright enough to indicate the system is turn on.

htng_systm_otsd_envout	Other: When the heating element is operating an LED light will also be turned to indicate that the element is operational. Other: 9/10 people will touch the heating pad after the first 3 minutes of operation and feel no discomfort or harm from the element. Temperature (Absolute): After 3 minutes of operations the temperature of the heating pad will not exceed 39 degrees Celsius.
tmprtr_snsr_mcrcntrllr_stt_mchn_dsig	Other: Baud rate: 9600 Other: Microcontroller supplies 5V nominal to power sensor Other: Data type: Serial.

3.5: References and file links:

[1] "ECE Capstone," EECS Senior Design/Capstone. [Online]. Available: https://eecs.engineering.oregonstate.edu/capstone/. [Accessed: 13-Mar-2023].

3.5.2: File Links

3.6: Revision Table

5/14/2023	Hassan: Revised the block description table.

4. Block Validations

4.1: Temperature Sensor Block

4.1.1: Description

The temperature sensor is an outside facing sensor that measures the air's ambient temperature. This temperature sensor is essential for reporting the air temperature in order to regulate the heating element's operation. The integration of the temperature sensor block is crucial as a number of other blocks in the system are dependent on it, these consist of a heating element block and some part of the microcontroller.

The temperature sensor block will be the one that is put through its paces for validation. The temperature readings that the sensor captures will be put to good use by another component of our project, making it a crucial building block. To be more specific, the operation of the heating components will be dependent on the temperatures that are recorded by the temperature sensor and inputted into the microcontroller.

4.1.2: Design

The temperature sensor used in the project will be the DHT22 sensor. The sensor is fairly accurate as it measures temperatures ranging from -40 to 80 degrees celsius with +-0.5 degrees accuracy [1], and this range is within the scope of our project. In fact, the range of the temperatures for the DHT22 and the accuracy are specifically needed for our system. The temperature sensor is going to be connected to an arduino uno (the microcontroller used in our project) and tested thoroughly in the verification process later mentioned. Below is the interface diagram for the block:

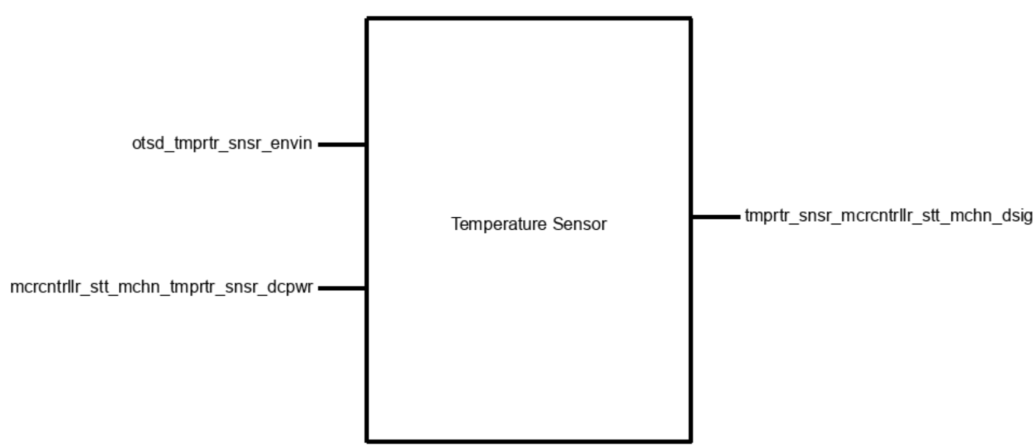


Fig.1. Temperature sensor block

The three interfaces are touched on in the interfaces section in this document where it goes into details about each interface and its properties. The DHT22 sensor has three pins that are to be connected to the microcontroller chosen by the team which is the Arduino Uno microcontroller. The three pins are the VCC, Data, and ground pins. The VCC pin is where the temperature sensor receives its power from the microcontroller where it operates between 3.3 and 5 volts. The data pin is where the temperature sensor sends the data to the microcontroller in use, and the data type of the DHT22 is serial data. Finally the ground pin is the pin used to ground the DHT22 and this completes its circuit.

The microcontroller, which in this case is an Arduino Uno R3, as well as the sensor itself make up the entirety of the circuit. The following schematic illustrates the connections that should be made in order for the DHT22 temperature sensor to communicate with the Arduino UNO R3 microcontroller:

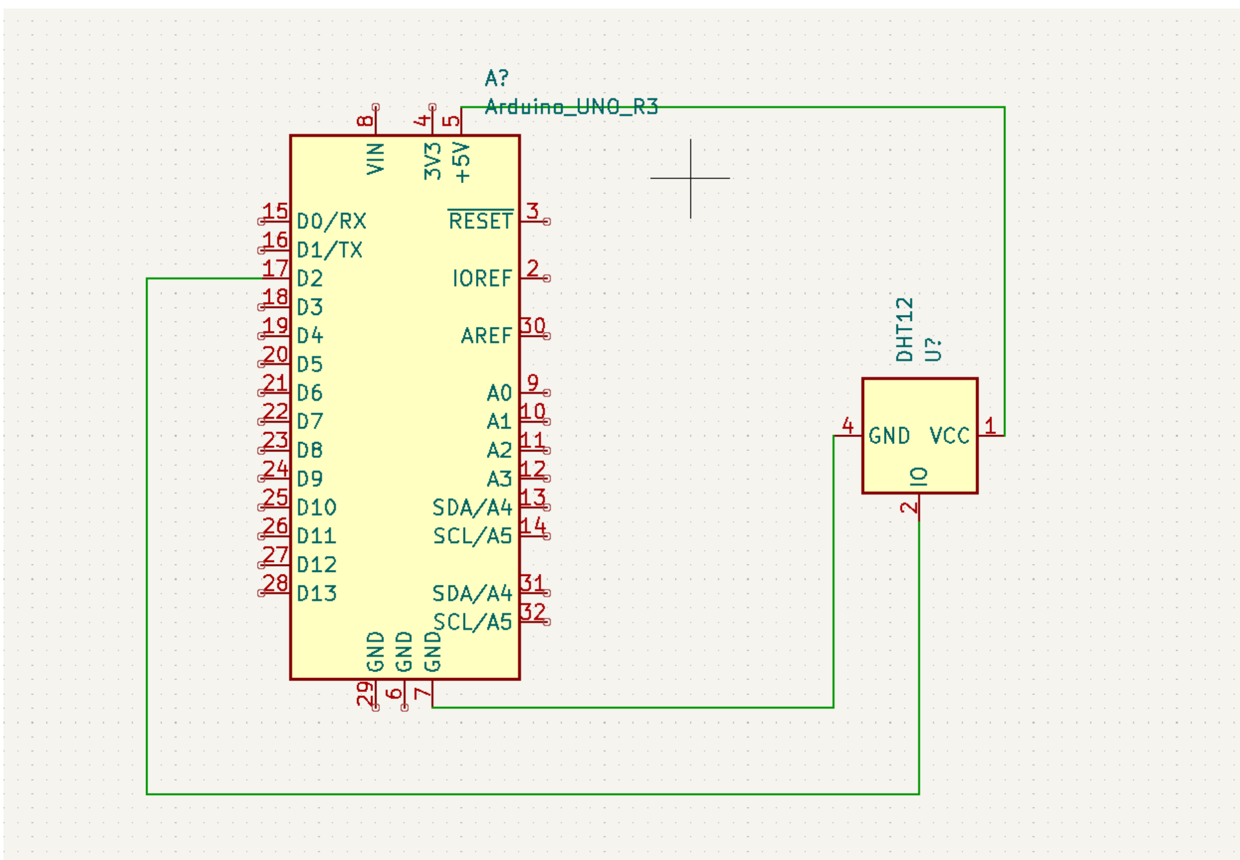


Fig.2. Temperature sensor circuit

4.1.3: General Validation

The DHT22 is a widely known sensor that is used by engineers around the world. It was chosen by the team due to a number of reasons. Firstly, it is compatible with all other blocks in the project. For example, the DHT22 will perfectly connect to the microcontroller of the team without any issues that concern power or compatibility. This means that the temperature sensor can be easily integrated in the project without hurdles. The sensor is also small in size which allows it to be easier to integrate, the dimensions of the DHT22 are as follows: 15mm x 25mm x 7.5mm.

The DHT22 temperature sensor is a cost effective sensor, and the reason is that the temperature sensor itself is relatively low cost and fairly accurate. The sensor’s accuracy is +- 0.5C which means that the temperature sensor will measure the environment’s temperature while being in the range of 0.5C above or below the actual temperature. The DHT22 has a sensing period of 2 seconds which more than fits the design of our system since our system will require new temperature reading of a period of 10 seconds or less, and having that fast sensing period from the temperature sensor will make things a lot easier.

Using any thermistor instead of a DHT22 as a temperature sensor is the alternative solution that can be implemented. Thermistors are similarly cost effective; however, it will be more challenging to integrate them due to the fact that thermistors need to convert resistances to temperatures, which would require the usage of an external circuit to accomplish. Despite this, thermistors are still cost effective. The temperature range for the DHT22 is -40C to 80C, which is greater than any thermistor's range. Thermistors have a temperature range that is more restricted, despite the fact that they are fairly precise like the DHT22.

4.1.4: Interface Validation

There are three interfaces for the temperature sensor block. The first would be the ‘Mcrcntrllr_stt_mchn_tmprtr_snsr_dcpwr: input’ interface, which shows how power is supplied by the microcontroller to the DHT22 sensor. There are four properties for that interface, which are the Inominal, Ipeak, Vmin, and Vmax all of which will be tested in the verification method later.

The second interface will be ‘Tmprtr_snsr_mcrcntrllr_stt_mchn_dsig: output’ which is an output interface that describes the output signal from the temperature sensor to the microcontroller used. The three properties for this specific interface are resolution, baud rate, and data. The interface tables below go into detail regarding each property for every single interface.

The third and final interface is ‘Otsd_tmprtr_snsr_envin: input’ which is an input interface regarding the temperature sensor and what it gathers from the surrounding environment, and there are three properties which are the temperature range, sense period and accuracy of the temperature gathered from the environment. Below are the tables that go into specifics regarding each interface and its properties.

Interface Property	**Why is this interface property this value?**	**Why do you know that your design details <u>for this block</u> above meet or exceed each property?**

Mcrcntrllr_stt_mchn_tmprtr_snsr_dcpwr: input

Inominal: 0.3mA	The nominal current is chosen based on the current draw of the temperature sensor which the system’s power supply will be able to handle.	For the DHT22: The current draw of the DHT22 is 0.3mA according to its datasheet.
Ipeak: 2.5mA	This value was chosen because it is the max current draw that the temperature sensor operates on, and it will be handled by the system’s power supply.	For the DHT22: While requesting data, the max current usage is 2.5mA (during conversion)
Vmax: 5V	This value was chosen because the sensor needs 5 volts as a maximum voltage that can be supplied by our microcontroller.	For the DHT22: The voltages it operates on are as follow: Minimum voltage: 3.3V Maximum Voltage is 5V according to the datasheet.
Vmin: 3.3V	This was chosen because the microcontroller can supply our minimum voltage of 3.3V.	For the DHT22: The voltages it operates on are as follow: Minimum voltage: 3.3V Maximum Voltage is 5V according to the datasheet.

[2] DHT22 Datasheet, Accessed 1/19/2023

Tmprtr_snsr_mcrcntrllr_stt_mchn_dsig: output

Resolution: 0.1C	This value was chosen because the temperature sensor will measure values in increments of 0.1C minimum, and these are the increments that will be suitable for our system.	For the DHT22: The resolution of the temperature is 0.1C.
Baud rate: 9600	This value was chosen because it is the most suitable baud rate which balances the speed and accuracy of communication between the microcontroller and the temperature sensor which is needed for our system.	For the DHT22: Set Baud rate to 9600.
Data: serial	This is chosen because we need the temperature sensor to send data bit by bit, using a single bus communication protocol, and monitor our temperature values using a serial monitor.	For the DHT22: The sensor sends the data in serial format.

[3] City OS, Accessed 1/19/2023

Otsd_tmprtr_snsr_envin: input

Range: -40 to 80 degrees C	The value is chosen to show the temperatures the temperature sensor will be able to measure in our system.	For the DHT22: The range of temperature sensing is -40C to 80 degrees C.
Accuracy: +-0.5C	The value is chosen because we need the accuracy when measuring the actual temperature of the surrounding area to be within 0.5C above or below the actual temperature.	For the DHT22: Temperature reading +-0.5C accuracy.
Sense period: 4 Seconds	This value was chosen in order to make the sensing period 4 seconds for every reading. The response time is 2 seconds and the sampling period time is 2 seconds which both add up to 4 seconds. 4 seconds is the amount of sensing time the system needs.	For the DHT22: No more than 0.5 Hz sampling rate (once every 2 seconds)

[4] City OS, Accessed 1/19/2023

4.1.5: Verification Plan

Environment and signal testing:

Step 1 - The DHT22 has three pins. Firstly VCC which will be connected to the 5V pin in the arduino. GND which will connect the GND pin to the arduino. Finally, the data pin which will connect to digital pin 2 in the arduino

Step 2 - The user will connect the arduino to the personal computer.

Step 3 - The user will run test code in the arduino IDE while setting the baud rate to 9600 to print the data given from the DHT22 on the screen, and use the serial monitor tool to observe the temperatures. The temperatures recorded will be displayed in 0.1C increments to prove the resolution of the temperature sensor. Meaning the resolution, baud rate, and data type properties will all be proved in this step.

Step 4 - The user will operate another accurate temperature sensor and use the values to compare to the DHT22 making sure that the DHT22's temperatures are within +-0.5C of the other temperature sensor to prove its accuracy.

Step 5 - The temperatures displayed on the serial monitor will be displayed every 4 seconds to prove the sensing period property. The temperatures will be within the -40 to 80 degrees C range to prove the temperature range property. Finally

Power testing:

Step 1: measure the operating current while the DHT22 is connected to the arduino which will supply it with 3.3 volts. Having a voltage of 3.3V is essential as it is the bare minimum that can be supplied by the microcontroller.

Step 2: A digital multimeter will be connected in series with the temperature sensor to read the current. The current should read similar to the Inominal and not exceed the Ipeak according to the first two properties in the 'Mcrcntrllr_stt_mchn_tmprtr_snsr_dcpwr: input' interface.

Step 3: The operating voltages should be between 3.3V minimum and 5V maximum to satisfy the other properties in the 'Mcrcntrllr_stt_mchn_tmprtr_snsr_dcpwr: input' interface. Which means that the process has to be repeated only this time with 5 volts instead of 3.3.

[The test code used to verify the block.]
[5] OpenAI test code, Accessed 1/20/2023

4.1.6: References and File Links

4.1.6.1: References (IEEE)

[1] electronicsfan123, “Interfacing dht22/dht11 with Arduino Uno,” *Hackster.io*, 08-Nov-2021. [Online]. Available: https://www.hackster.io/electronicsfan123/interfacing-dht22-dht11-with-arduino-uno-931539. [Accessed: 19-Jan-2023].

[2] “Electronic Components Distributor - Mouser Electronics.” [Online]. Available: https://www.mouser.com/datasheet/2/737/dht-932870.pdf. [Accessed: 20-Jan-2023].

[3] “5. DHT22 - digital temperature and humidity sensor,” *CityOS Air*. [Online]. Available: https://cityos-air.readme.io/docs/4-dht22-digital-temperature-humidity-sensor. [Accessed: 20-Jan-2023].

[4] “5. DHT22 - digital temperature and humidity sensor,” *CityOS Air*. [Online]. Available: https://cityos-air.readme.io/docs/4-dht22-digital-temperature-humidity-sensor. [Accessed: 20-Jan-2023].

[5] “Chat.openai.com.” [Online]. Available: https://chat.openai.com/. [Accessed: 21-Jan-2023].

4.1.6.2: File Links

https://drive.google.com/file/d/1xx02eavV9X_sr8s6r-Fic0tflWEj8MEA/view?usp=share_link

4.1.7: Revision Table

01/20/2023	Revised the interfaces
02/09/2023	Finalized the interface tables. Edited the verification plan. Added Schematic for the design section. Added details to the description and all sections of the document.

4.1.8: Revision statement

Based on the Feedback given by the instructor, the interface section and the verification plan section were both heavily improved on, as I have gained more insight into what the interface properties are supposed to be. Section 2 was also improved on by adding a schematic of the block to the section which was not in the original draft. The overall description of the block has some more detail regarding the true purpose of the block. Overall, the feedback given by the instructors was essential for the final revision.

4.2: Heating System Block

4.2.1: Description

The heating element block is responsible for turning the heating pad on and off depending on the environmental temperature. For example, if it is cold outside then the heating element would turn on and when it is hot outside the heating pad would turn on. This process is done by utilizing the temperature sensor and the heating pad.

4.2.2: Design

The heating pad used in the project is the sparkfun 5x15 heating pad. The pad draws a max current of 600mA and can get exponentially hot.

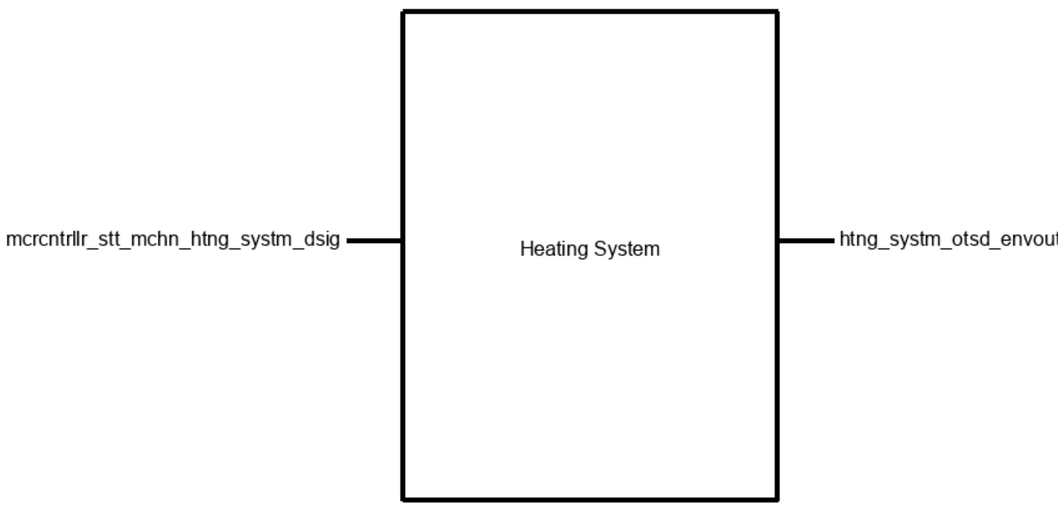


Fig.1. Heating element block

There are two interfaces that connect to the heating system block itself. The mcrcntrllr_stt_mchn_htng_systm_dsig interface which is an input interface that connects from the microcontroller to the heating system providing a signal that allows the heating pad to turn on through the use of a mosfet, a pull down resistor, and a diode. The htng_systm_otsd_envout interface is an interface that describes the output changes that occur to the environment. The heating pad is paired with a mosfet to control its operation with an arduino, and the circuit is similar to the figure below:

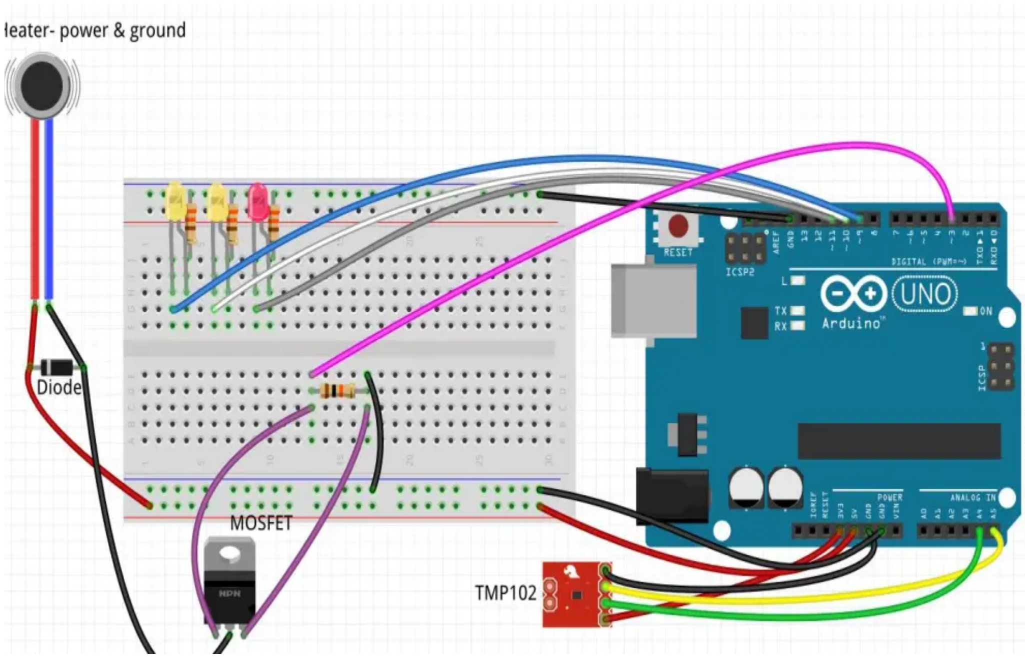


Fig.2. Heating element circuit

4.2.3 General Validation

When selecting a heating pad for a particular application, there are a number of aspects to think about, including the size and shape of the pad, the temperature range it can reach, the minimum and maximum temperatures it can reach, the amount of power it needs, and the cost.

When compared to other heating pads, the SparkFun 5x15 heating pad's size and shape are two advantages that may sway your decision. The 5x15 size is relatively compact, which makes it suitable for a wide range of applications; in addition, the rectangular shape makes it easy to integrate into a variety of different systems. In addition, the SparkFun heating pad comes with a power cable and connector that are already attached, making it simple to connect the pad to an external power supply.

The temperature range offered by the SparkFun heating pad is yet another argument in favor of purchasing it. The pad can withstand operating temperatures of up to 70 degrees Celsius, making it suitable for a wide variety of applications. In addition to this, the pad features an integrated thermistor that allows the user to keep track of the temperature of the pad itself and adjust the level of heating output accordingly.

The SparkFun heating pad has reasonable power requirements, with a maximum current draw of 500mA at 5V. This rating is based on the pad operating at 5 volts. This translates to the fact that the pad can receive power from a wide variety of sources, such as batteries and USB power supplies.

A nichrome wire can be used as a heating element as an alternative to a SparkFun heating pad, which is another alternative. Nichrome wire is a high-resistance wire that is easily formed into a variety of shapes and sizes, making it a flexible choice for use in a variety of heating applications. The use of nichrome wire, on the other hand, necessitates more complicated wiring and control circuitry. Additionally, the wire may call for an increased amount of power in order to achieve the same level of heating output as a heating pad. In addition, nichrome wire might not be as easily accessible or as economically viable as a heating pad.

In general, the SparkFun 5x15 heating pad is a flexible and cost-effective heating solution that is appropriate for a wide variety of applications due to its adaptability and versatility. Because of its compact size, wide operating temperature range, and low power requirements, it is an appealing option for a wide variety of projects.

4.2.4 Interface Validation

There are two interfaces for the heating system block. The first is the mcrcntrllr_stt_mchn_htng_systm_dsig which is an input interface that describes the signal between the microcontroller and the heating system itself. The second interface is the htng_systm_otsd_envout interface which is an output interface that describes the environmental output of the heating system. Below is a table for the interface and properties of the heating system block:

Table I
Interfaces

Interface	**Properties**
mcrcntrllr_stt_mchn_htng_systm_dsig	Logic-Level: Active high Vmax: 5V Vmin: 3.7V
htng_systm_otsd_envout	Other: 9/10 people will touch the heating pad after the first 3 minutes of operation and feel no discomfort or harm from the element. Other: When the heating element is operating an LED light will also be turned to indicate that the element is operational. Temperature (Absolute): After 3 minutes of operations the temperature of the heating pad will not exceed 39 degrees Celsius.

4.2.5 Verification Plan

The plan to verify the system is simple, which requires connecting up the heating pad to a separate power source and one of the mosfet pins to an arduino digital pin.

The system will be able to turn on and off depending on the arduino's signals.

4.2.6 References and File Links

4.2.6.1 References (IEEE)

[1] M. #886674, M. #912835, M. #486530, M. #514085, M. #682749, M. #360054, M. #1817389, M. #400731, M. #510056, and M. #759817, "Heating pad - 5x15cm," COM. [Online]. Available: https://www.sparkfun.com/products/11289. [Accessed: 13-Mar-2023].

4.2.6.2 File Links

4.2.7 Revision Table

03/13/2023	Revised the interfaces

4.3: Lights and Light Sensor Block

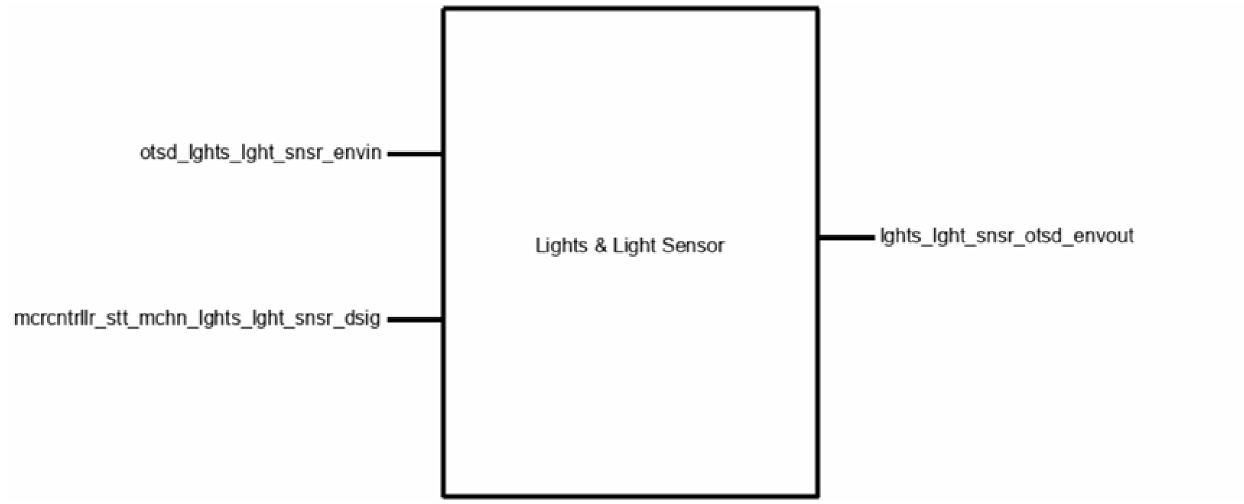
4.3.1. Description

The light sensor detects the ambient light around the wearer of the back belt. This input is used in the passive light sensing mode to automatically activate the safety lights in low light conditions. Microcontroller controls three groups of lights. The first is a set of safety lights to notify surrounding individuals of the presence of the wearer and may be operated manually, or activate automatically in the passive sensing mode. The safety lights will be located along the upper part of the sleeves to ensure a high degree of visibility from multiple angles. The second is a set of reading lights on the front of the device which allow reading in low light conditions, controllable by button presses. The final lights are indicator lights which allow the user to determine the current state of the device, distinguishing whether the heating element and safety or reading lights are in an activated state. `

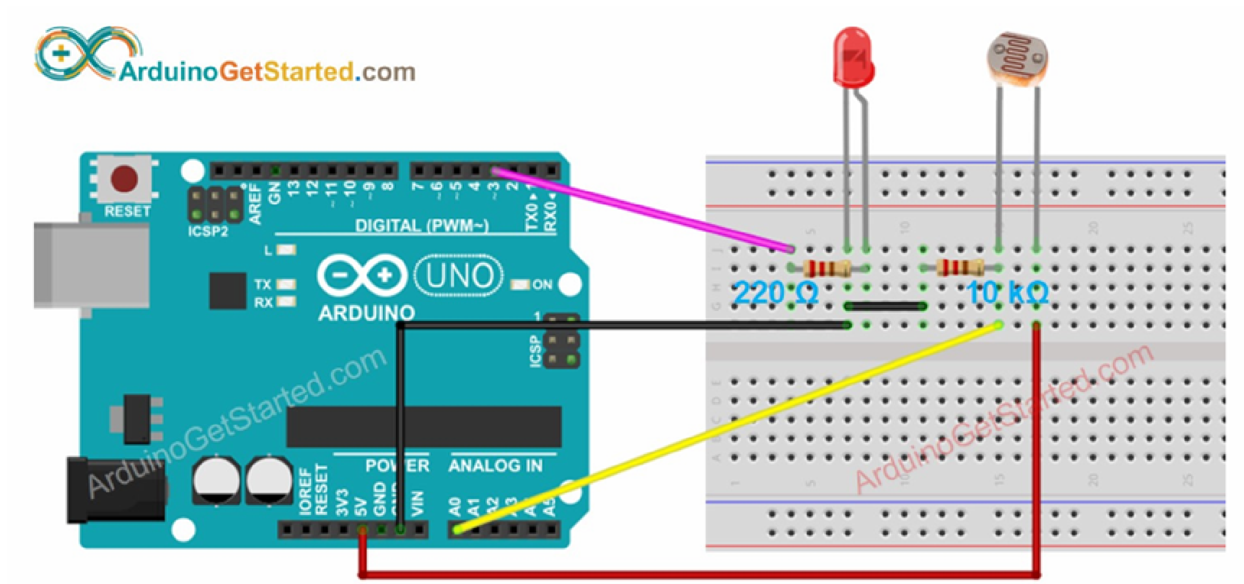
Among the three groups of light, the focus of this block is the safety light group. Our system requires us to use the button as input to determine the three gears of the led switch through the microcontroller control. The first gear is that we can turn off the LED manually, the second gear is to turn on the LED permanently, and the third gear is to analyze when to switch the LED through the light sensor. When the light sensor judges that the external light condition is insufficient, it will turn on the LED, and when the external light condition is higher than the threshold we set, it will turn off the LED. What the light sensor receives is the natural light of the environment or the artificial light source used for testing. Its output is the light emitted by the LED. This block is composed of various voltage divider resistors, LEDs and light sensors. We will mount the LED on the upper arm of the back belt.

4.3.2. Design

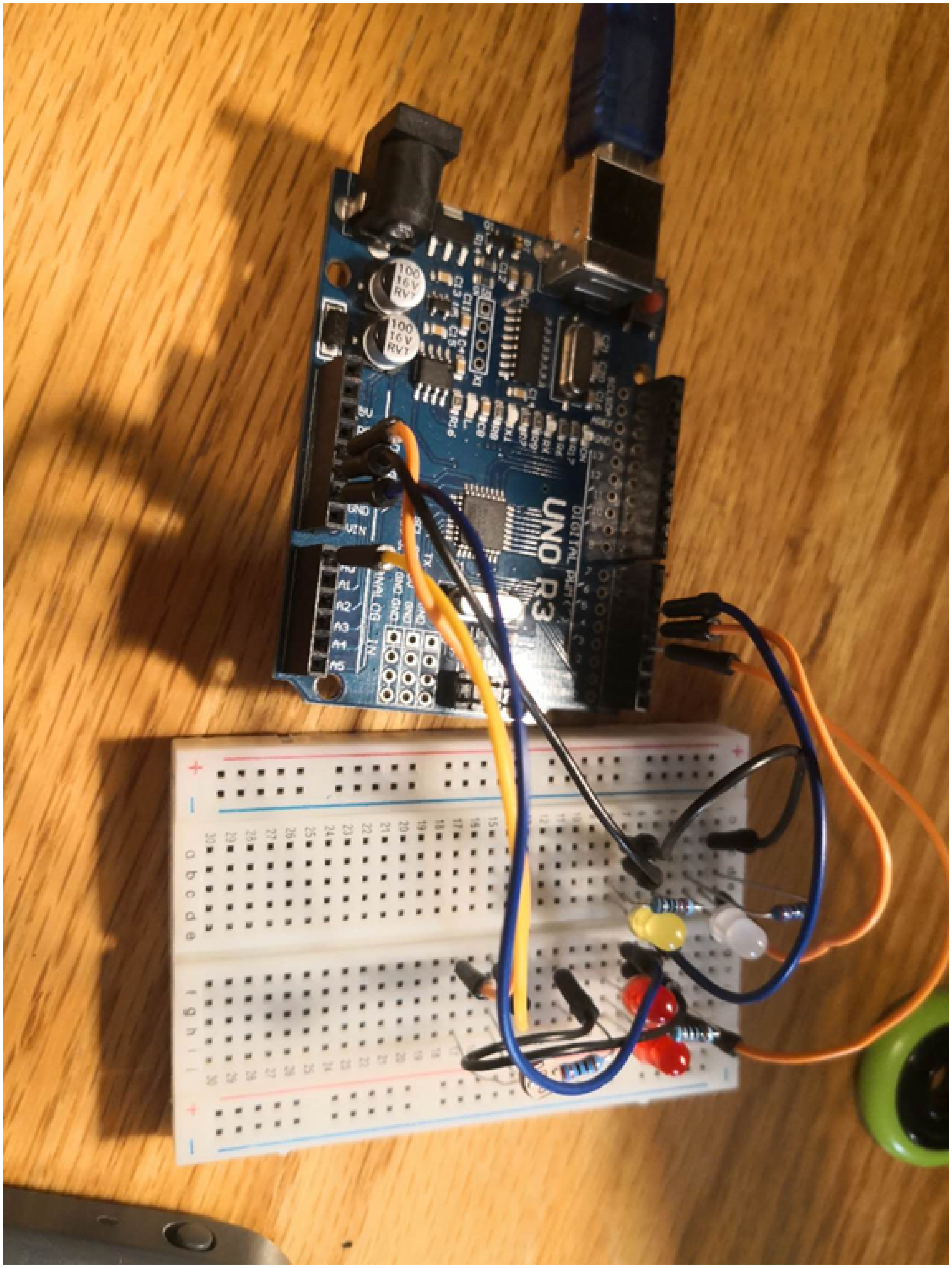
Block diagram



Wiring diagram



Actual diagram



Pseudocode:

```
Void loop()

{

analogValue = analogRead(LIGHT_SENSOR_PIN); // read the input on analog pin


  if(analogValue < ANALOG_THRESHOLD)

    digitalWrite(LED_PIN, HIGH); // turn on LED

  else

            digitalWrite(LED_PIN, LOW);  // turn off LED

}
```

The light sensor will change its resistance according to the intensity of light it detects, we will read its resistance or its voltage. After getting its voltage, compare it with the threshold we set, if the threshold is exceeded, the LED is turned off, and if the threshold is not reached, the LED is turned on. In addition to these logics, what we need to pay attention to is that we need to assign and set the input and output interfaces of Arduino as input ports or output ports.

4.3.3. General Validation

We need three different lights to implement this system. These are a safety light to alert those around you of your position, a reading light to enable the wearer to read, and a heating status light. The safety light has three modes: manual on, manual off and automatic. The automatic mode allows the light sensor to detect the intensity of the ambient light, and if it is lower than a value we set, the light will come on. So we need to import the sensor input into the microcontroller. We need to control the light mode of the safety light by pressing a button, one press is manual on, another is manual off, another is auto adjust, another is back to manual on and so on. So we need the microcontroller to read the number of buttons pressed to activate the appropriate mode. For the light & light sensor system, we need to get the control signal from the microcontroller to select the mode. In the case of the reading light, it is only controlled by the button, which is pressed once to turn it on and again to turn it off. So we just need to read the number of times the reading light button has been pressed from the microcontroller. For the heating indicator, when the user presses the button to turn on the heating or the temperature sensor selects to turn on the heating, it gives a signal to the microcontroller to turn on the heating and the microcontroller also gives a signal to the LED to turn on the heating indicator to tell the user that the heating is on and the same when it is off.

Light sensors are divided into four categories: ambient light sensor, infrared light sensor, sunlight sensor, and ultraviolet light sensor. I use the cheapest sunlight sensor here. Because our purpose is to judge whether the light of the external environment is high enough, rather than ultraviolet and infrared rays, so I use the sunlight sensor here. Because our requirements for accuracy are not so high, we only need to know whether the sunlight is bright enough. So what I choose here is a relatively cheap sunlight sensor.

Second, I chose the cheapest led lights here, because I only want to use them to indicate whether the heating system or the LED light system is on.

4.3.4. Interface Validation

otsd_lghts_lght_snsr_envin : Input

Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
Light: environment light input（wave length = 390~770nm）	We need to control the led by measuring the ambient brightness	Because I know that my light sensor will give me an expression of the ambient light intensity in voltage. By reading this voltage and comparing it to our desired limit, we can control the LED.
threshold of environment light input = 11.5 Lux (if larger, turn on, other wise turn off)	According to the table I found on its data sheet, I found that about 11.5LUX is the most in line with my idea during the test.	Because when I set it to 11.5lux it can be brighter when I want it brighter and darker when I want it to be darker.
frequency == 4～ 8×10^(14)Hz	The frequency of natural light is in this frequency range.	because input is natural light

---

mcrcntrllr_stt_mchn_lghts_lght_snsr_dsig : Input

Vmax: 5V(High)	The output of the arduino is 5V After the microcontroller judges, output the corresponding voltage to the LED, whether to turn on or turn off the light	The output of the arduino is 5V
type: analog	Because the voltage type is analog	Because the voltage type is analog

Logic-Level: 0V(Low)	After the microcontroller judges, output the corresponding voltage to the LED, whether to turn on or turn off the light	In the microcontroller, the voltage received from the sensor is compared with the limit value we set, and the current gear is judged, and the voltage is output by the microcontroller to turn on the LED.

lghts_lght_snsr_otsd_envout : Output

Light: Luminous Intensity = 180lux	This value depends on the light intensity of the LEDs we want to use in the end.	If the light intensity in the environment falls below a

		threshold, our clothing will turn on the LED.

freq = 400~484 THz	frequency of red light	frequency of red light
color == red	because my output is red	because my output is red

4.3.5. Verification Plan

Reading light: 1. Change the corresponding value of my setting in arduino to simulate that I received the control signal for the circuit gear from the button of my team member.. 2. Then it will be evaluated in the microcontroller and output the corresponding voltage, if it is on, then Vdd, if it is off, 0. 3. Assemble it with the necessary electronic components, such as resistors, to form the necessary circuit to allow it to operate in a normal working environment.

1. When I set the gear to 1, the light should be off. Test 10 times to see if the light is on, so as to judge whether the block is working normally. 2. When I set the gear to 2, the light should be off. Test 10 times to see if the light is on, so as to judge whether the block is working normally. 90% of the results should be correct.

Heating light: 1. Change the corresponding value of my setting in arduino to simulate that I received the control signal for the circuit gear from the button of my team member and the status of heating system. 2. Then it will be evaluated in the microcontroller and output the corresponding voltage, if it is on, then Vdd is output, if it is off, 0 is output. 3. Form it into a necessary circuit with the necessary electronic components such as resistors to allow it to operate in a normal working environment.

1. When I set the gear to 1, the light should be off. Test 10 times to see if the light is on, so as to judge whether the block is working normally. 2. When I set the gear to 2, the light should be off. Test 10 times to see if the light is on, so as to judge whether the block is working normally. 90% of the results should be correct.

Safety light: 1. Change the corresponding value of my setting in arduino to simulate that I received the control signal for the circuit gear from the button of my team member. 2. Read the output voltage of the light sensor. 3. Make a determination in the microcontroller, if it is on, then output Vdd, if it is off, output 0. 4. Form it into a necessary circuit with the necessary electronic components, such as resistors, to enable it to operate in a normal operating environment.

1. When I set the gear to 1, the light should be off. Test 10 times to see if the light is on, so as to judge whether the block is working normally. 2. When I set the gear to 2, the light should be off. Test 10 times to see if the light is on, so as to judge whether the block is working normally. 3. Set the gear to 3, and shine a flashlight on the sensor to see if the LED does not light up. Cover the sensor with your hand to see if it glows. Test ten times to judge whether the block is working properly. 90% of the results should be correct.

4.3.6. References and File Links

"Arduino - light sensor triggers led: Arduino Tutorial," *Arduino Getting Started*. [Online]. Available: https://arduinogetstarted.com/tutorials/arduino-light-sensor-triggers-led. [Accessed: 11-Feb-2023].

4.3.7. Revision Table

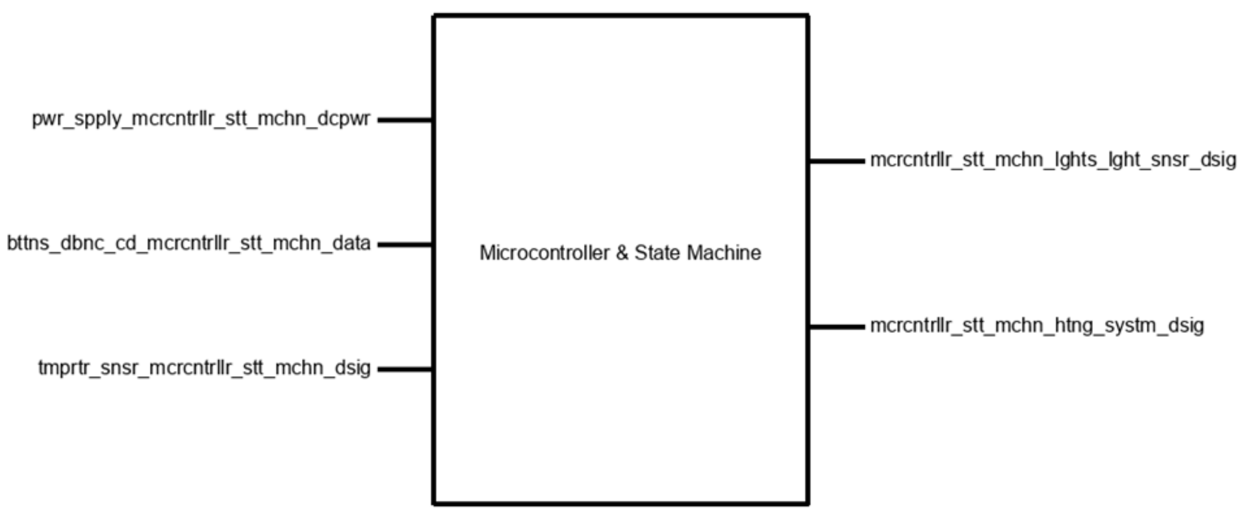
01/20/2023	First Edition - Qiu Junda
02/11/2023	Second Edition - Qiu Junda

4.4: Microcontroller and State Machine Block

4.4.1. Description

The microcontroller contains the button debouncing code, the state machine code, and the heating element feedback loop. It must support the operation of all code block simultaneously. It must receive sensor information from the external temperature sensor, the heating element internal temperature sensor, the buttons, and the light sensor. It must provide activation signals to the heating element feedback loop and the various lights. The state machine mediates the state of the lights and heating element. It must track changes in the button presses that alternate the state between passively responding based on external temperature and light sensing, all outputs being turned off, and any outputs being manually turned on.

4.4.2. Design



4.4.3. General Validation

The code can change the state of each system by checking whether the button is pressed. The system is divided into heating system and LED system. Each system has 3 states, they are, manual open, manual close, and controlled by sensor. Take the LED system as an example, when we press the button, the LED will be on all the time, when we press it again, the LED will be off all the time, when we press it again, the LED will be controlled by the light sensor, if the outside light intensity is strong, then the LED will be on Off, if the outside light intensity is low, the LED will turn on.

4.4.4. Interface Validation

pwr_spply_mcrcntrllr_stt_mchn_dcpwr	Inominal: 0.04A Ipeak: 0.06A Vmax:5.5V Vmin:4.5V
bttns_dbnc_cd_mcrcntrllr_stt_mchn_data	Messages: check_button1(): returns the state of button 1 Messages: check_button0(): returns the state of button 0 Protocol: Code is written in C
mcrcntrllr_stt_mchn_lghts_lght_snsr_dsig	Other: Logic level: Active high Other: threshold V of A0 = 150*5V/1024 = 0.75V +- 10% Vnominal: 4.7V
mcrcntrllr_stt_mchn_htng_systm_dsig	Logic-Level: Active high Vmax: 5V Vmin: 3.7V
tmprtr_snsr_mcrcntrllr_stt_mchn_dsig	Other: Baud rate: 9600 Other: Microcontroller supplies 5V nominal to power sensor Other: Data type: Serial.

4.4.5. Verification Plan

1. I applied 5V to the arduino and observed 0.04A, so multiply it by 1.5 to get Ipeak. Then when I put 5.5V on the arduino it works fine, and when I put 4.5V on it it still works fine. So I proved Vmax and Vmin

2. I can read the data of these equations from the serial monitor of arduino. So here we go. And all the files are written in C.

3. I can prove that when the voltage of A0 is higher than 0.75 the light will turn on and when it is less than 0.75 the light will turn off. And when it is turned on, the output will be around 4.7V.

4. When we give the Vin of arduino a voltage greater than 5V, the output voltage will be equal to 5V, and when we reduce the voltage Vin slowly, the output voltage can drop to 3.7V, and all the lights can work.

5. The voltage from arduino to the heating sensor is 5V, and the data we can read on the serial monitor is serial and the baud rate is equal to 9600.

4.4.6. References and File Links

None

4.4.7. Revision Table

2023/05/08	Junda Qiu: Revised the validation for this block.

5. System Verification Evidence

5.1: Universal Constraints

5.1.1: The system may not include a breadboard

The system Cannot use a breadboard. Breadboards were used early on in development of the system for testing but then were replaced with protoboards. The following figure shows the final image of the system:

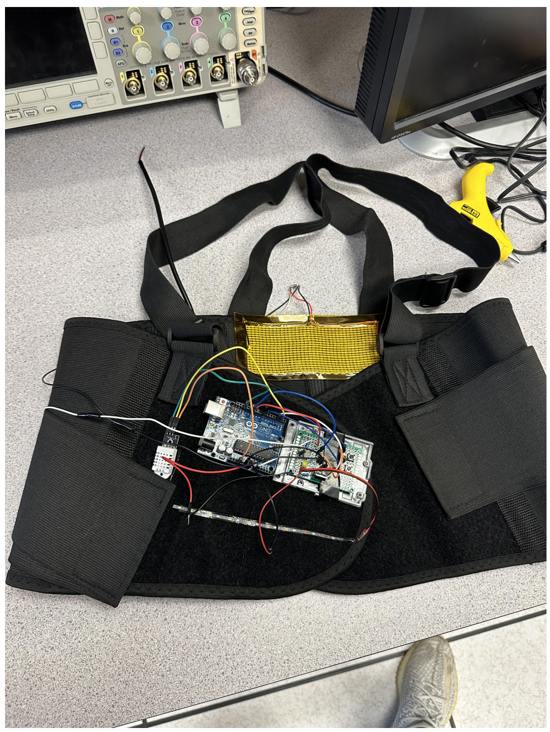


Fig.1. Figure showing the system used and no breadboards

5.1.2: The final system must contain a student designed PCB.

Due to a team member who was responsible for the pcb of the system separating from the team, the addition of a pcb in the last 4 weeks of the project's timeline was not making sense for our project and was not achievable. Designing and assembling a pcb would have been near impossible this late into the project.

5.1.3: All connections to PCBs must use connectors.

Due to the team not doing a PCB, this requirement is already met since the system is connected together. A pcb was not used in the system as a team member left the team in the last 4 weeks of the project.

5.1.4: All power supplies in the system must be at least 65% efficient.

The power supply of the system is a power bank which was integrated in the final system. Our team is not using any power conversion devices. Since we are not doing any power conversion we do not have to calculate the power efficiency. Measuring the efficiency of the power bank is not achievable at this stage, we cannot calculate the input power of the power supply because it is charged via USB, and the internal circuitry of the power supply is complex with varying operating conditions.

Fig.2. Figure showing the power supply of the system

5.1.5: The system may be no more than 50% built from purchased modules.

The system uses no more than 50% purchased modules. The blocks are the best way to show whether a module is purchased or built. The following table represents the blocks and says whether the blocks are purchased modules or built. The validation section of the document also helps show the purchased and built blocks.

Table I

Purchased or Built Block

Block	Purchased or Built	Validation
Heating System	Built	The heating system consists of more than one component and most were soldered into a protoboard. The circuit of the system was also designed.
Temperature Sensor	Purchased	The DHT22 sensor is a ready module that was purchased. It is a temperature sensor that connects to the microcontroller.
Buttons & Debounce Code	Built	The button debouncing code was written from scratch.
Power Supply	Purchased	The power supply is a power bank used to power the system.
Wire Routing	Built	The wearable is modified to fit the needs of the system and the wire routing was designed.
Lights & Light Sensor	Built	The light and light sensor block utilizes a protoboard and a designed circuit that has a light sensor and LED lights that are controlled by the state machine code.
Microcontroller & State Machine	Purchased	The microcontroller is the Arduino Uno which was bought and used in the system.

Percentage of purchased modules: 3/7 X 100 = 42.8%

Percentage of built blocks: 100 - 42.8 = 57.2%

5.2: Project Requirements

5.2.1: Buttons reaction

5.2.1.1: Project Partner Requirement: The user must be able to interact with the wearable.

5.2.1.2: Engineering Requirement: The system will respond to input presses with a 90% accuracy and will not change state more than once without input presses over a period of at least 10 minutes.
Testing Method: Test

5.2.1.3: Verification Process:
Step 1: Have the wearer press each button 11 presses to end with a passive state.
Step 2: Have the wearer wear the back belt for 10 minutes and register no more than 1 phantom button press.
Step 3: press each button twice to end on an On state.
Pass Condition: Buttons must react to at least 9 out of 10 presses. Buttons must experience less than 1 button press in 10 minutes. This would be shown by the led lights of the system which indicate the state of the buttons pressed not changing for 10 minutes meaning there were no phantom button presses that happened.

5.2.1.4: Testing Evidence:
The following video links:

- Video (Date: 4/28/2023)

5.2.2: Safety lights visibility

5.2.2.1: Project Partner Requirement: The project will provide visual feedback to the user.

5.2.2.2: Engineering Requirement: The system will be reported as visible by 9 out of 10 users up to 100 feet away in darkness (defined as the ambient light at 50 lux or less) when the safety lights are activated.
Testing Method: Demonstration

5.2.2.3: Verification Process:
Step 1: In a dark environment (50 lux or less) the wearer will stand 100 feet away from the tester.
Step 2: The tester will be able to see that the lights are visible with the naked eye from that distance.
Pass Condition: Light is visible by 9 out of 10 people.

5.2.2.4: Testing Evidence:
The following video and photo links:

- Video (Date: 5/1/2023)
- Photo (Date: 5/1/2023
- Form (Date: 5/6/2023)

5.2.3: Comfortability and efficacy

5.2.3.1: Project Partner Requirement: Project will be a wearable.

5.2.3.2: Engineering Requirement: The system will have a comfortable range of motion in the arms, spine and neck as reported by 9 out of 10 users of the system after they remove and replace a backpack.
Testing Method: Demonstration

5.2.3.3: Verification Process:
Step 1: The wearer will wear the wearable and a backpack on top of it.
Step 2: The wearer will replace the backpack they were wearing with another one.
Pass Condition: The whole range of motion specified in the requirement will be affirmed by the wearer and 9 out of 10 people.

5.2.3.4: Testing Evidence:
The following video links:

- Video (Date: 5/6/2023)
- Form (Date: 5/6/2023)

5.2.4: Heat sensing responsiveness

5.2.4.1: Project Partner Requirement: The wearable will sense the environment of the user and respond to it.

5.2.4.2: Engineering Requirement: The system will be heating when the temperature reaches 17C or below and is not on when the temperature is 23C or above.

Testing Method: Demonstration

5.2.4.3: Verification Process:
Step 1: The wearable will be placed in an environment where the temperature is 17 degrees C or below.
Step 2: The wearable will be placed in an environment where the temperature is 23 degrees C or above
Pass Condition: Heating element will turn on in an environment where the temperature is 17 Or less and turn on in an environment where the temperature is 23 degrees C Or more.

5.2.4.4: Testing Evidence:
The following video links:

- Video (Date: 5/2/2023)

5.2.5: Light response

5.2.5.1: Project Partner Requirement: The wearable will sense the environment of the user and respond to it.

5.2.5.2: Engineering Requirement: The system will respond to change in ambient light conditions by turning on lights when the ambient light available is 50 lux or less.

Testing Method: Demonstration

5.2.5.3: Verification Process:

Step 1: The light sensor of the system will experience less than 50 lux of light.

Step 2: The lights will turn on.

Pass Condition: Lights should turn on in dark conditions.

5.2.5.4: Testing Evidence:

The following video links:

- Video (Date: 4/20/2023)

5.2.6: Removable parts

5.2.6.1: Project Partner Requirement: Project will be a wearable.

5.2.6.2: Engineering Requirement: The system will have any parts needing to be removed before washing removable in under 15 minutes by 9 out of 10 users.
Testing Method: Test

5.2.6.3: Verification Process:
Step 1: Electric parts that will be subjected to water damage will have velcro straps that will enable the user to remove the parts within a 15 minute time span.
Step 2: The user will be able to remove the parts in under 15 minutes.
Pass Condition: Parts can be removed within a 15 minute time period by 9 out 10 people.

5.2.6.4: Testing Evidence:
The following video links:

- Video (Date: 5/6/2023)
- Form (Date: 5/6/2023)

5.2.7: Running time

5.2.7.1: Project Partner Requirement: The project will be energy efficient.

5.2.7.2: Engineering Requirement: The system will remain operable for four hours per charge, including 30 minutes with active safety lights and 20 minutes with active heating element.
Testing Method: Inspection

5.2.7.3: Verification Process:
Step 1: The wearable will be turned on and operate in that mode for 4 hours.
Step 2: During the four hours, the wearer will operate the wearable for 30 minutes using the safety lights and for 20 minutes using the heating element.
Pass Condition: The wearable will operate for four hours including the heating element for 20 minutes and lights for 30 minutes.

5.2.7.4: Testing Evidence:
The following video links:

- Video (Date: 5/4/2023)

5.2.8: Safe temperature

5.2.8.1: Project Partner Requirement: Project will be a wearable.

5.2.8.2: Engineering Requirement: The system will operate with the heating element actively enabled from full battery charge to empty without exceeding the safe temperature of 35 (+/- 3) degrees C.
Testing Method: Test

5.2.8.3: Verification Process:
Step 1: Measure the temperature of the heating element while the wearable starts operating.
Step 2: After a period of four hours which is the period of battery life for our project, the temperature of the heating pad will be measured again.
Pass Condition: Temperature did not exceed the specified limit.

5.2.8.4: Testing Evidence:
The following video links:

- Video (Date: 5/4/2023)

5.3: References and File Links

5.3.1: References

5.3.2: File Links

[1] https://drive.google.com/file/d/1W3rvzZc2vrrA-0OcrEUM3YcN6CsgI5is/view?usp=sharing

[2] https://drive.google.com/file/d/104GItHFQJzGu2PQIIHdBm6ImRZJyQBWf/view?usp=sharing

[3] https://drive.google.com/file/d/12Wu_F9DGGASzk9W_mSa69WmWkD0ILkNd/view?usp=sharing

[4] https://drive.google.com/file/d/1LijcDk3CVGCx04IshEKy-GHWy6i119Dq/view?usp=sharing

[5] https://drive.google.com/file/d/1vkjj8kovopER1X96OUO8qKJOZMIaLsbq/view?usp=sharing

[6] https://drive.google.com/file/d/1_EAE_stF1K26KEv8nRQ_xFRBsLJHi7Sg/view?usp=sharing

[7] https://drive.google.com/file/d/1-xq6Zi_Ponbv_HLw9QZIKSPN9s4qIayJ/view?usp=sharing

[8] https://drive.google.com/file/d/1iewzq1G-8j-5zvYVXHWXSs-8XHD8MPrr/view?usp=sharing

[9] https://drive.google.com/file/d/1vXfOIgT28v-KFt-YK3cIaS8pJiI7Dfmt/view?usp=sharing

[10] https://drive.google.com/file/d/1dRFf_hEB2Kxn6q4wdqV6az_Y5te6sIvd/view?usp=sharing

[11] https://drive.google.com/file/d/1rQDlRJi-2o9Oz4vykisQ0whG1y2bB7RD/view?usp=sharing

[12] https://drive.google.com/file/d/1kEIvFsAnjD0DetrkFZoxR8tkh-7lp8tl/view?usp=sharing

5.4: Revision Table

4/28/2023	Hassan: Edited the first subsections of section 5 and made some changes.
5/7/2023	Hassan: Finalized the requirements and added links.

6. Project Closing

6.1: Future Recommendations

6.1.1: Technical recommendations

The first technical recommendation given by the team is having an additional temperature sensor that is used to measure the temperature of the heating pad [1]. This would provide better safety precautions as it will help regulate the heating pad other than turning it on and off. So the integration of a second temperature sensor to the system would be very helpful.

Another recommendation would be having a power supply pcb that charges the battery instead of using a power bank. This option of using a battery would be cheaper and it would improve the system by having a charging circuit [2] which would be external and easier to access rather than having internal circuitry with a power bank that is really difficult to access. The pcb would help by being a more efficiency option as the power bank efficiency can vary with charging or discharging conditions.

For the LED we think we need to add a button that can adjust the brightness of the LED [3]. In this way, when the surrounding environment is dark, we can lower the brightness, which can not only save energy and prolong the usable time of the system, but also allow people to find our equipment at a glance in dark conditions.

For the button, our suggestion is that we can use some adjustable buttons, such as potentiometer. In this way, we can adjust the heat of the heating system, etc., and even we can adjust the color of the LED. The use of colored LEDs would be a great addition to the system. Adjusting the voltage and current would help change the temperature generated by the heating pad [4].

6.1.2: Global impact recommendations

We suggest that we can use environmentally friendly batteries [5] or other parts in the future, because it cause less damage to the environment when recycling. Environmentally friendly batteries are crucial when it comes to the sustainability of our environment, the batteries themselves can be recyclable which would be a great improvement for the project.

We hope we can use cheaper, lighter and more reliable materials. For example, we can design the microcontroller ourselves and reduce the length of the wires used, so that we can reduce system resistance and increase system efficiency while saving costs. In this way, we can sell more products, so that we can promote the mountaineering culture [6] all over the world and activate the market economy which is something we would strongly recommend doing.

We recommend always going for recyclable materials and recycling E-waste as it can contribute to polluting the earth. Some materials that can be burnt may cause greenhouse gas emissions which can damage the environment so we suggest keeping a lookout for these harmful materials.

6.1.3: Teamwork recommendations

For teamwork, we recommend doing mandatory team meetings [7] every single week, so that the team is on the same page and shares the same vision for the project. We also think that in the future we can define what we need to accomplish before each meeting. In this way, we can have a clearer direction and improve efficiency.

We think that in the future, when there are conflicts among members of the group [8], the team members can hold a group meeting to help resolve conflicts between the group members, so that the efficiency will be improved and the cohesion of the group will increase.

6.2: Project Artifact Summary with Links

The Main artifacts of our project are the project's code, all schematics regarding the project and the final image of our system. Firstly, the schematic of our temperature sensor circuit is shown below then followed :

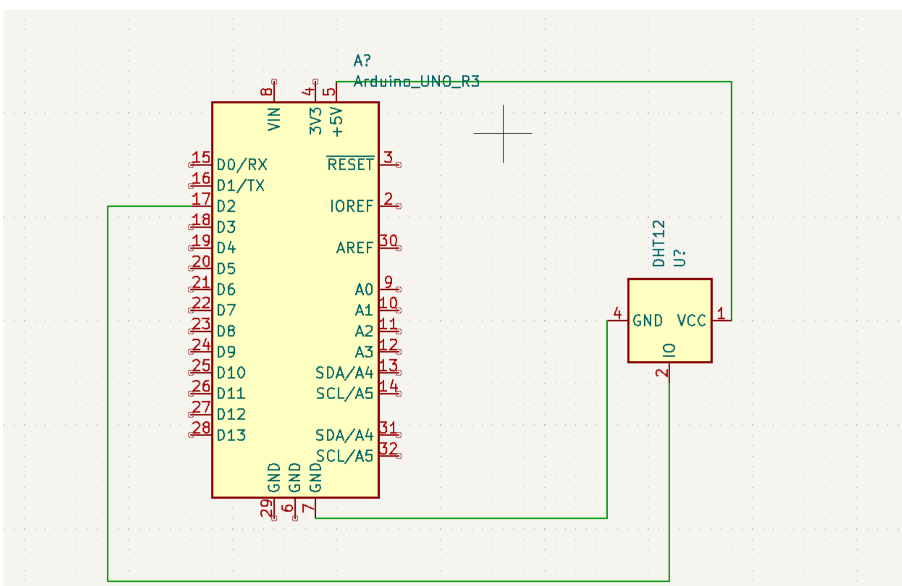


Fig.1 Temperature sensor schematic

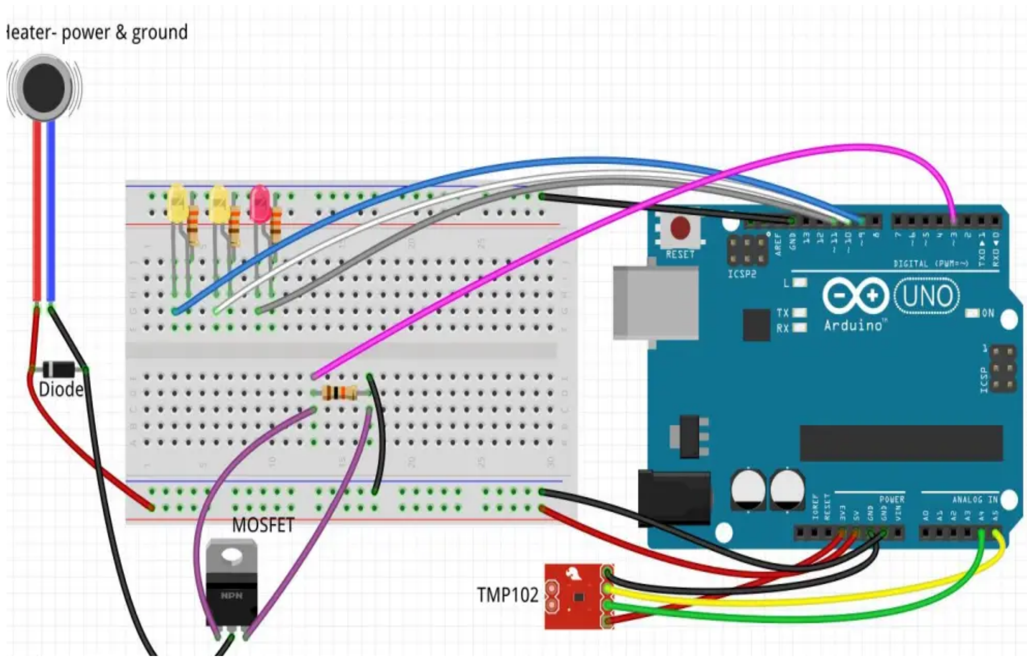


Fig.2 Heating element schematic

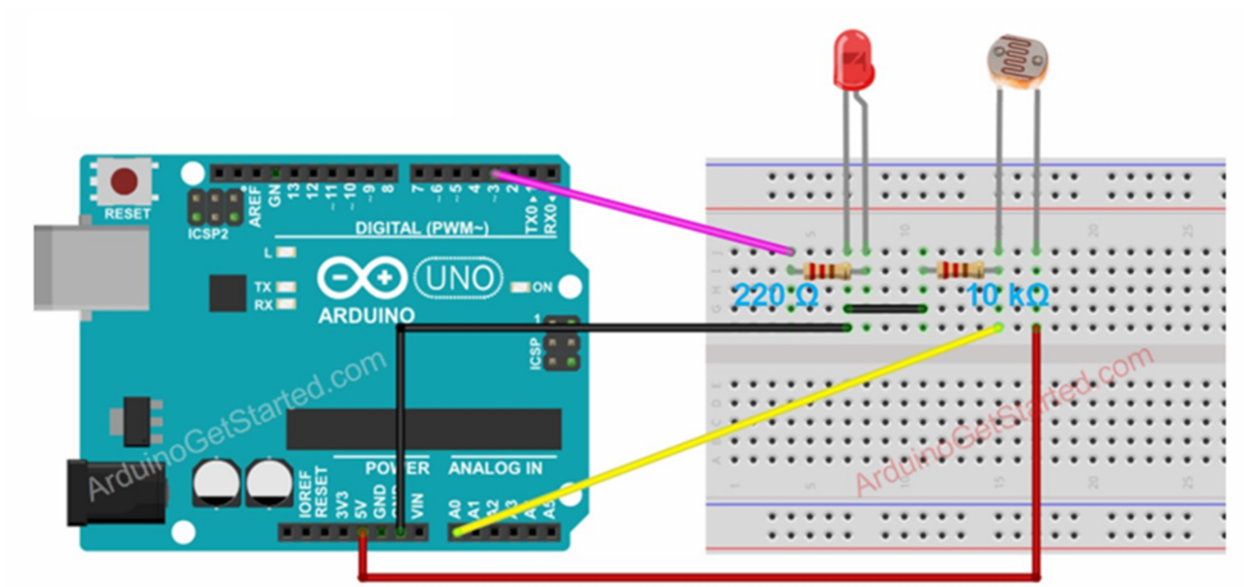


Fig.3 Light sensor schematic

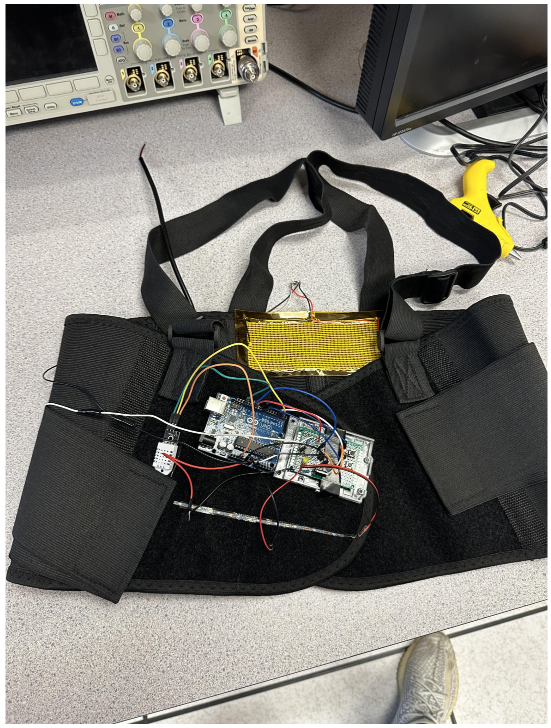


Fig.4 Final image of the system

The final code file of the system is provided here.

6.3: Presentation Materials

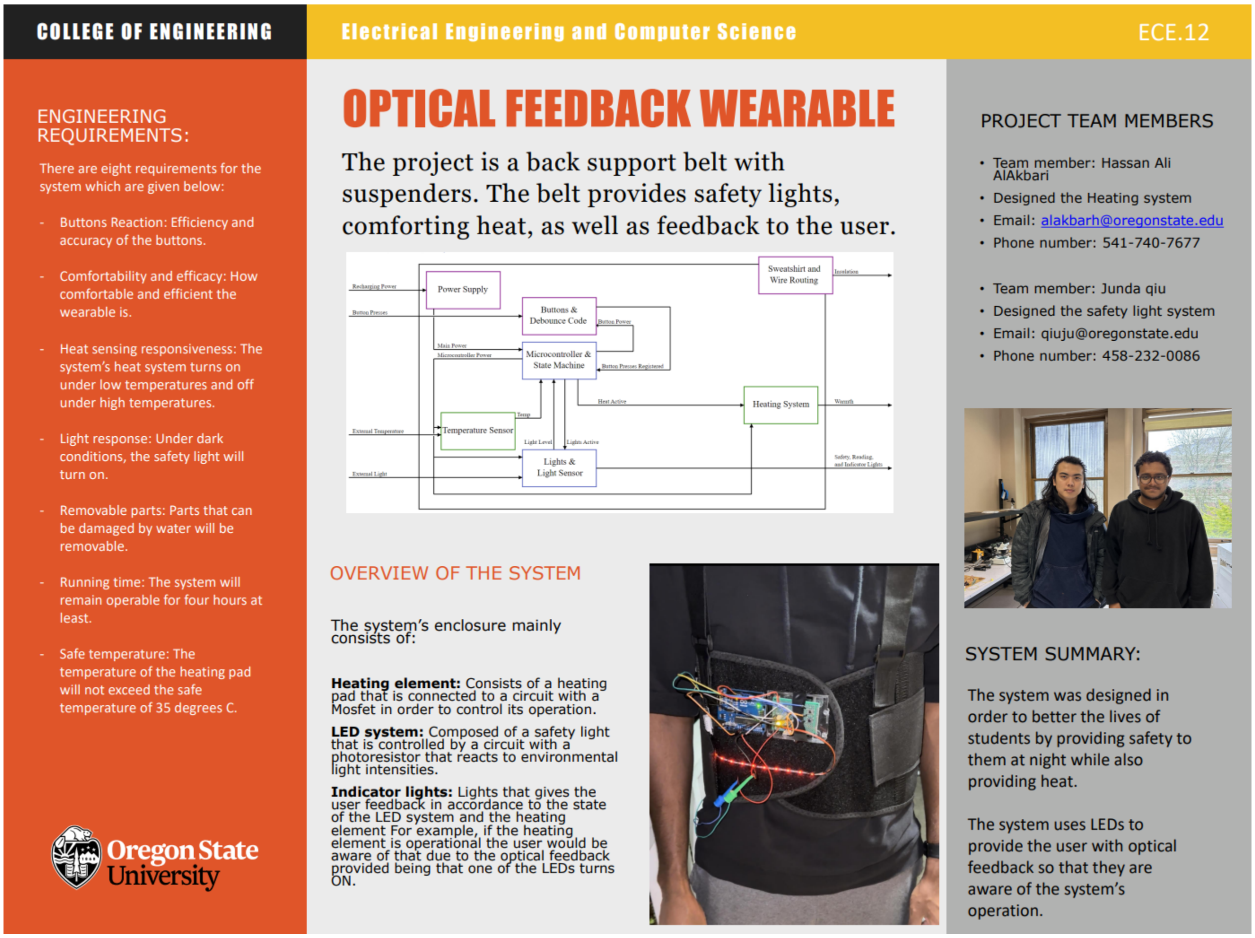


Fig.5 Final image of the project poster

6.4: References and file links

6.4.1: References

- [1] M. #759817, “Heating pad - 5x15cm,” *COM*. [Online]. Available: https://www.sparkfun.com/products/11289. [Accessed: 28-Apr-2023].
- [2] “Five steps to a good PCB layout of the boost converter - Texas Instruments.” [Online]. Available: https://www.ti.com/lit/an/slva773/slva773.pdf. [Accessed: 28-Apr-2023].
- [3] Bancroft, “How to make the brightness of the led change?,” *Electronics Forums*, 23-Sep-2022. [Online]. Available: https://maker.pro/forums/threads/how-to-make-the-brightness-of-the-led-change.295541/. [Accessed: 28-Apr-2023].
- [4] “How to use potentiometers to adjust current and voltage,” *Techwalla*. [Online]. Available: https://www.techwalla.com/articles/how-to-use-potentiometers-to-adjust-current-and-voltage. [Accessed: 28-Apr-2023].
- [5] J. Weber, “Batteries that are good for the environment,” *Batteries that are good for the environment at Batteries Plus*. [Online]. Available: https://www.batteriesplus.com/blog/power/environmentally-friendly-batteries#:~:text=Lithium%20batteries%20are%20also%20considerably,they%20are%20more%20environmentally%20friendly. [Accessed: 28-Apr-2023].
- [6] Vince, “Is mountain culture inclusive and supportive or exclusive and competitive?,” *Mountain Culture Group*, 26-Nov-2020. [Online]. Available: https://mountainculturegroup.com/is-mountain-culture-inclusive-and-supportive-or-exclusive-and-competitive/. [Accessed: 28-Apr-2023].
- [7] R. Lynn, “What is a project meeting? tips and types,” *Planview*, 11-Jan-2021. [Online]. Available: https://www.planview.com/resources/guide/what-is-project-management/project-meeting/#:~:text=A%20project%20meeting%20facilitates%20collaboration,hallmark%20of%20excellent%20project%20managers. [Accessed: 28-Apr-2023].
- [8] J. Farrington, “Ways to deal with Team Conflict effectively: Sandler training,” *Sandler*, 09-Nov-2022. [Online]. Available: https://www.sandler.com/blog/ways-to-deal-with-team-conflict-effectively/. [Accessed: 28-Apr-2023].

6.4.2: File links

- https://drive.google.com/file/d/1x4SpL9s63PZdWX4uN8NK4bns_NXCKR95/view?usp=sharing

6.5: Revision Table

5/14/2023	Hassan: Revised section 6.1.2 and added a new poster image.