Team 32 Project Document

Optical Feedback Wearable 2

Mae Graham

Project Partner: Ingrid Scheel

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 students in interacting with their environment. This system is intended to be used in casual campus environments to enhance comfort and safety.

The form factor for this project is a sweatshirt 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 sweatshirt to place batteries and peripheral devices.

To address the limitations imposed by the need for the project to be wearable, this project makes use of flat-body lithium ion batteries, flexible conductive fabric or insulated wire, and a small, well-contained printed circuit board for the power supply. Two batteries are anticipated for use in order to provide adequate power to heating elements while still ensuring that after a reasonable duration of use some power remains to sustain safety light features and the control system. Power supplies are encased in water resistant pockets to prevent water damage and shorting of the device, while insulated wire and heat shrink tubing provides some water resistance at peripheral contact locations.

1.2: Team Contacts and Protocols

Contact Information:

Table I: Contact information

Name	Email	Role
Mae Graham	grahabra@oregonstate.edu	Documentation, System Engineering

Team Protocols:

Table II: Team protocols

Topic	Protocol	Standard
Openness and Accountability	We (the royal "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	Full and timely communication is required regarding any failures to complete work to the standards set out by assignment descriptions.

	supersedes any deadlines or project goals.	
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

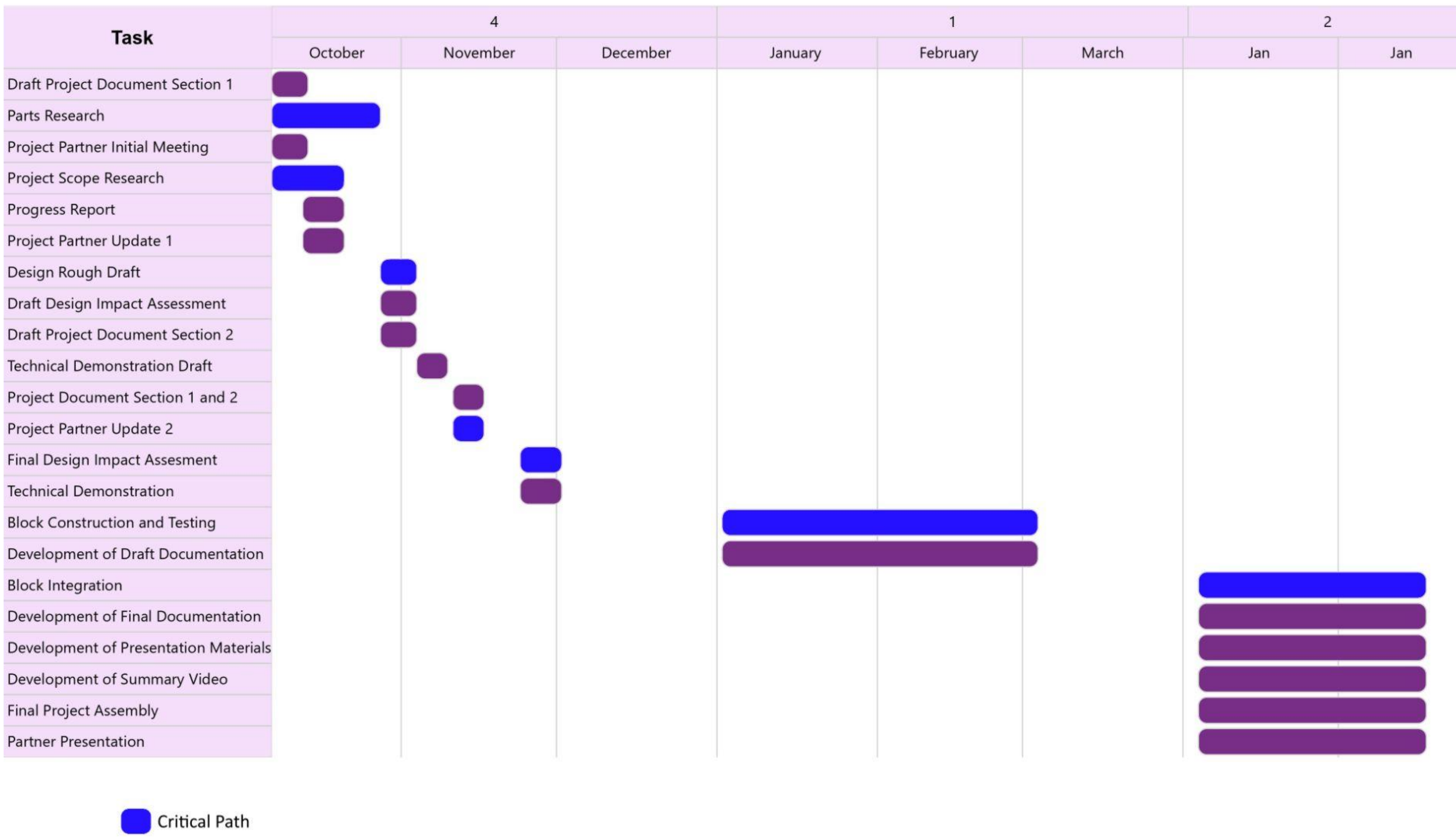


Figure 1: Proposed timeline

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.
4/28/2023	Mae: Updated cover page to reflect team changes. Updated wording in executive summary and removed section on sensors. Updated contact list.

2. Impacts and Risks

2.1: Design Impact Statement

2.1.1: Introduction

This statement reflects efforts to evaluate the ethical impacts of the project. It is vital to reflect consciously on the engineer’s role in maintaining ethical standards in design. This wearable sweatshirt prompts concerns for the safety of the wearer as well as any individual attempting to modify or duplicate the design. The wearable is intended to be a convenient and comfortable sweatshirt that is designed with the intention of making a student’s life easier by providing safety lights and a heating element for warmth. However the presence of a heating pad and lithium ion batteries presents a concern for the potential of fire and burns. The presence of deadlines and team dynamics proved to be detrimental to the students involved in the process of designing the system. The cost of materials may leave the design inaccessible for the full spectrum of financial situations that are represented by the student cohort it’s designed for. Disposal of the device and its parts raises concerns for the environment. Sourcing fabric and electronic parts has an economic impact with regard to the conditions of workers in the chain of production.

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. 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]. Additionally, should errors arise in the use of the heating pad or strain on the power supply circuitry, the temperature of each component may increase to a point that could burn the user.

In addition to potential users of the device, the development process was impactful to 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]. This exacerbated disagreements throughout the team and multiplied pressures to meet deadlines. This resulted in a four person team breaking down completely into a single person team (represented here) and a two person team, increasing the stress and mental anguish of every participant that set out to design this wearable.

2.1.3 Cultural and Social Impacts

A device intended for students needs to be designed with respect for the divide of affluence throughout the cohort and maintain a low cost to ensure wide availability. Soaring student loan debts are becoming a problem, and higher education is becoming more and more unattainable by people of lower socioeconomic status [3]. The tools for success that some students are able to obtain have been demonstrated to create a new sense of normalcy that can leave some feeling left out and even impact academic success [3]. An item proposed as an improvement to life on campus should be affordable to improve a student’s sense of access and belonging at the university. Unfortunately this wearable sweater comes at a fairly high cost to replicate. Were it to become a popular addition to campus life, a subset of the student population would find this design too expensive to participate in the trend.

2.1.4 Environmental Impacts

E-waste unfortunately has the potential to be disposed of with ordinary garbage due to momentary negligence of the user. This in turn releases toxic chemical elements such as lead or mercury, impacting soil, contaminating plant life, entering the food chain, and potentially existing for thousands of years. Because e-waste is not biodegradable, it damages the ecosystem and disturbs biodiversity [4]. Typical garbage may also be burned, releasing these gasses from burnt plastic, glass, and metal that can lead to ozone depletion and an increase in greenhouse gasses. This project uses electronic parts, and anyone who recreates the design could potentially trigger this cascade of impacts by improperly disposing of many components in this system. While the system designed here used lead-free solder and rechargeable batteries to somewhat mitigate these issues, the design is fully compatible with leaded solder and non-rechargeable batteries.

Some parts had to be re-made for the system designed here. While proper disposal protocols and maximal reuse of parts like batteries and heating pads will be employed by the team, even proper disposal doesn’t mitigate the environmental harm of discarding something that didn’t absolutely have to be purchased.

2.1.5 Economic Factors

The use of textiles in the system invokes a concern over the economic exploitation involved in the manufacturing process. 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 [5]. The production of fabric is a component of the apparel manufacturing process that’s vulnerable to these issues, any support for the textile industry exacerbates potential exploitation.

2.1.6: Conclusion

The design of this wearable device was susceptible to a number of problematic ethical impacts, with further potential for harm should the design be replicated. Potential burn risks from lithium ion batteries, power supplies, and heating pads pose a serious danger to the user. The design is not fully accessible to be replicated by students of all socioeconomic backgrounds due to its cost. The system turns an ordinary sweatshirt into a potential e-waste disaster, and uses commercially produced fabric that may have been produced as a component of an economically exploitative supply chain.

2.2: Risks

The following table lists a set of potential risks associated with the design, fabrication, and use of the system.

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: 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 f 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] "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].

[4] 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].

[5] 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

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.
4/28/2023	Mae: Modified previous work on a design impact statement to reflect the resulting impacts which were not mitigated effectively throughout the project.

3. Top-Level Architecture

3.1: Block Diagram

3.1.1 Black Box Diagram

The black box diagram gives a simplistic view of the system and shows the interfaces that connect it to the outside world. The following figure the black box diagram for the system:

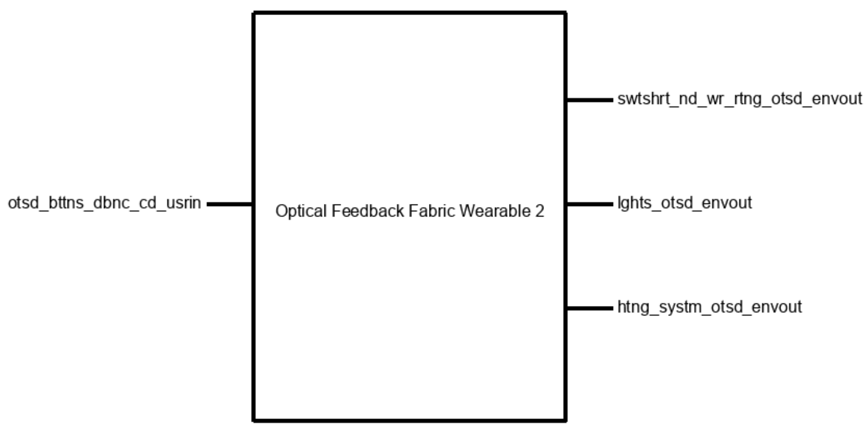


Figure 1: System black box diagram.

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.

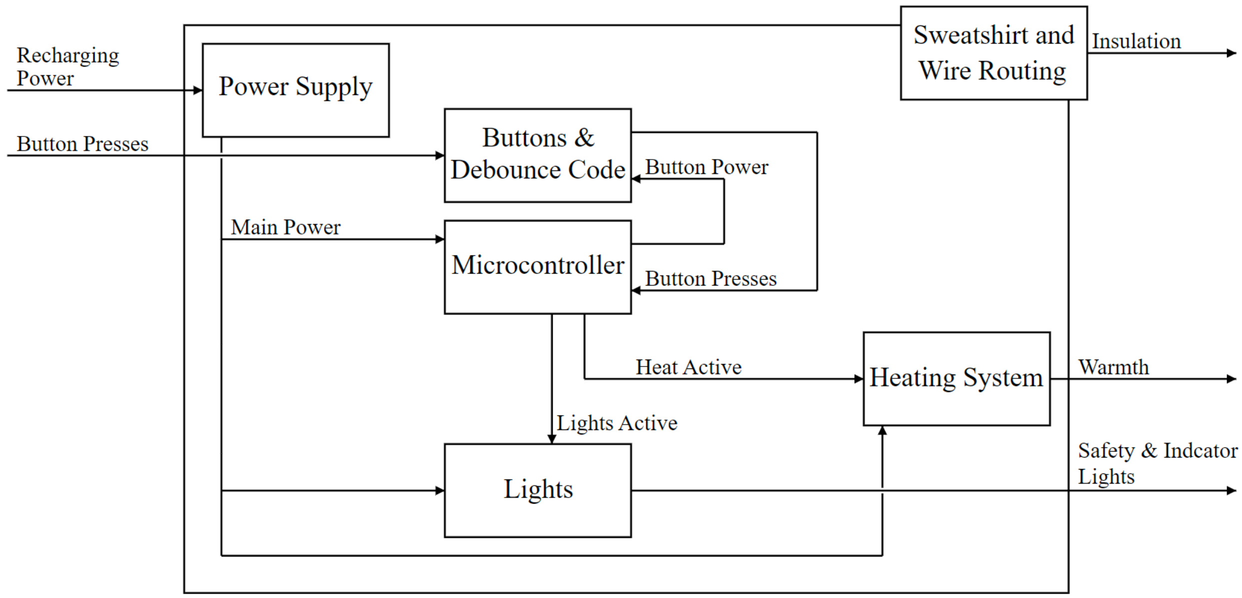


Figure 2: Top level diagram (all blocks championed by Mae Graham)

3.3: Block Descriptions:

The block descriptions provide an overview of the fundamental subsystems that make up the main system. The following table gives a description of each block.

Table I
Block Descriptions

Name	Description
Power Supply Champion: Mae Graham	The power supply block contains a charging and voltage boosting PCB, a battery, and connectors. The connectors must provide a connection between the circuit and the battery, charging cable, and device peripherals. The batteries are two flat lithium ion cells, supplying 3.7V of power each to the circuit. The circuit is responsible for intaking charge to recharge the battery, and outputting a 5V regulated power supply to the device.
Buttons & Debounce Code Champion: Mae Graham	Separate buttons must exist to control the lights and heating element, altering each state between on and off. The buttons are made of flexible material capable of being sewn into the sweatshirt itself, and thus are composed of conductive fabric contacts which are pressed together to register a button press. The button debouncing code is responsible for detecting button presses from the fabric 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 apply intentional control to the lights and heating element.
Sweatshirt and Wire Routing Champion: Mae Graham	The sweatshirt 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	The microcontroller contains the button debouncing code, the state machine code, and the heating element feedback loop. It must provide activation signals to the heating element

Champion: Mae Graham	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.
Lights Champion: Mae Graham	The light sensor detects the ambient light around the wearer of the sweatshirt. This input is used in the passive light sensing mode to automatically activate the safety lights in low light conditions. The lights consist of two 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 set are indicator lights which allow the user to determine the current state of the device, distinguishing whether the heating element and safety lights are in an active state.
Heating System Champion: Mae Graham	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.

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 sweatshirt fabric. Usability: The button exists on the collar for easy access.
pwr_spply_mcrcntrllr_stt_mchn_dcpwr	Inominal: 0.04A Ipeak: 0.06A Vmax: 5.5V Vmin: 4.5V
pwr_spply_lghts_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	Insulation provided
mcrcntrllr_stt_mchn_lghts_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_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 say the intensity of light is bright enough to indicate the system is turned 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.

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

4/28/2022	Mae Graham: Updated block descriptions and interfaces to reflect removal of sensors.
5/14/2023	Mae Graham: Removed unused interfaces in updated design. Added new black box diagram.

4. Block Validations

4.1: Buttons and Debounce Code Block

4.1.1. Description

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 buttons must be made of flexible material capable of being sewn into the sweatshirt itself, and thus will be comprised of conductive fabric contacts which are pressed together to register a button press.

The button debouncing code is responsible for detecting button presses from the fabric 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.

4.1.2 Design

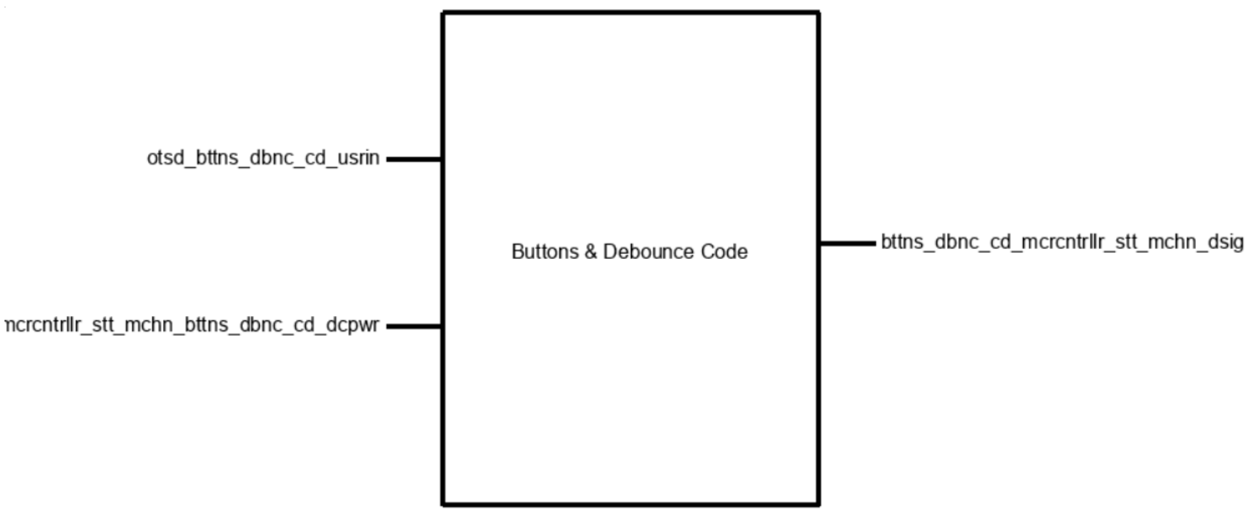


Figure 1: Black box diagram of the buttons and debounce block.

The button block must address the system engineering requirement for button reactions. This requirement stipulates a 90% accuracy of intended buttons being registered, and a false register of button presses no more than once every ten minutes. The design must accommodate this intended level of accuracy in registering intended button pushes. The block also must not impede the engineering requirements for comfort which includes aims for full range of motion while in the sweatshirt containing the buttons and the requirement that non-washable parts be removable within a reasonable time span. Thus the buttons aim to be machine washable parts. These requirements define the interoperability of the button block within the larger aim of the sweatshirt to be a wearable device that provides light and warmth to the user with interactive controls of those elements.

The code for button debouncing exists within the main code uploaded to the microcontroller, representing the interface bttns_dbnc_cd_mcrcntrllr_stt_mchn_data. Debouncing involves waiting several cycles to distinguish an intentional button press from a momentary contact of the fabric switches, thus it must be called periodically by a function in active polling. Debouncing code will be modeled after code from Ganssle's "Guide To Debouncing" to ensure minimal CPU overhead and quick responsiveness to button presses [1]. The code shifts ones into an 8-bit variable until a sufficient number of cycles have registered the button as pressed. An example of C code successfully applied in the past to work with other button types is shown below.

```c
uint8_t chk_buttons(uint8_t button) {
  static uint16_t state[8];
  state[button] = (state[button] << 1) | (! bit_is_clear(PINA, button)) | 0xE000;
  if (state[button] == 0xF000) return 1;
  return 0;
}
```

Figure 2: C code for button debouncing adapted from Ganssle's "Guide To Debouncing".

The button construction must fit easily into the collar of the sweatshirt and respond adequately to user input, representing the interface otsd_bttns_dbnc_cd_usrin. To respond adequately, it must return to a passive state of non-contact when not actively being pressed and register button presses by providing a minimal amount of resistance between the DC power's VCC and LOW, obtained from the interface mcrcntrllr_stt_mchn_bttns_dbnc_cd_dcpwr, when the contacts are pressed together. The VCC signal may not originate from a separate connection, but from internal pull-up resistors in the Arduino's digital input pins. This allows the microcontroller pin connection at the interface bttns_dbnc_cd_mcrcntrllr_stt_mchn_dsig to register at VCC when the contacts aren't pressed together, and LOW when they are. A diagram of the circuit connections to achieve the active low button logic is shown below, with the digital input labeled as DSIG connecting to the microcontroller along with VCC and ground being supplied as well by the microcontroller. The button is identified by the circuit symbol for a switch, with the state shown in the diagram as open, or the passive un-pressed state of the button.

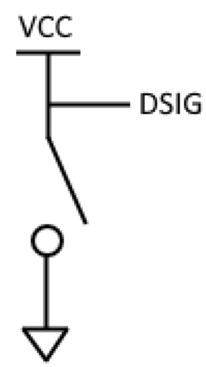


Figure 3: Diagram of circuit connections in an active low switch.

Achieving the fabric form factor will be done by following guides similar to push_reset's soft switch design from Instructables [2]. An example soft switch is shown below. The contacts represent the part of the button which must connect when the button is pressed, the leads connect to the ground, DSIG, and VCC connections linked to the microcontroller which will be soldered to wires that run through the sweatshirt to the area containing the microcontroller. The spacer provides a gap between the contacts such that they don't connect when the button is not actively being pressed, and the casing represents the fabric of the sweatshirt which will surround the button and provide a housing.

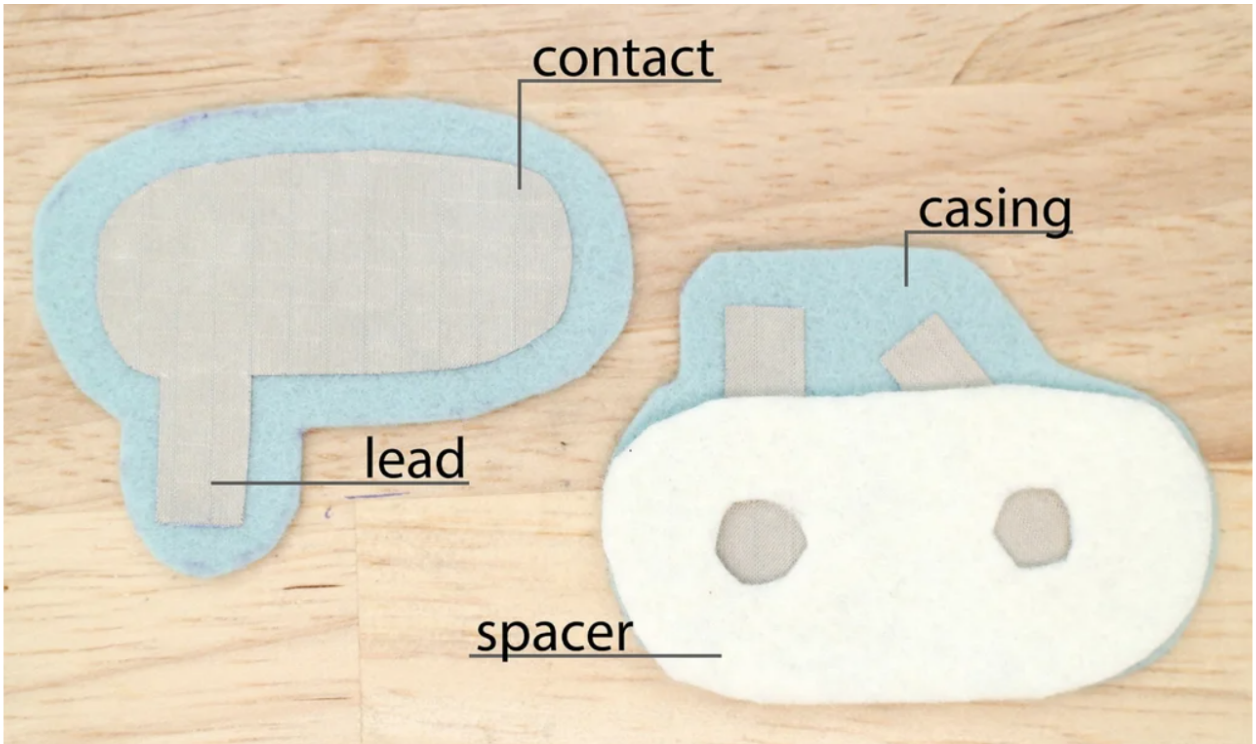


Figure 4: An example of a soft switch design from push_reset's article "Introducing the Soft Switch".

Variations will be made. First by adding a plastic boning structure or fusible interfacing (a special kind of fabric which provides a stable backing to softer more bendable fabric on the surface of the clothing article) to provide more stability, bounce back, and separation between contacts during passive wear. Second by using thicker, more conductive switch material as the buttons are not intended to need to bend with the motion of the user's body, a part of the reason for placement of the buttons in the collar of the sweatshirt which should limit the number of false presses registered to the system.

4.1.3 General Validation

This block connects fabric buttons to debouncing code, allowing accurate determination of button presses from user input to change the state of the lights and heating elements on the wearable electronic sweatshirt. Two buttons will exist on the collar of the sweatshirt, one for the heat, and one for the lights. Each interface will have modes switchable by button presses including always on, always off, and passively responding to sensed temperature and light conditions.

The model for debouncing code was selected to provide flexibility in determining how many cycles are needed to register the button press exactly once when the user intends to press it. It has the added benefit of not using much time on the CPU to run, keeping the processing time consumption needed to operate the buttons low. The code is adapted into C for AVR, which suits the utility of an Arduino as it uses a subset of C code and an avr-g++ compiler [3].

The design selected for the fabric switches is compact and designed to be sewn into wearable electronics. They comprise materials that can easily be sewn or bonded with adhesive to fabric bases. Variations of plastic stabilizing joints and firmer contact material are intended to account for the location of the buttons in the collar of the sweatshirt needing extra stability as these buttons will not exist pressed up against the user's body for stabilization as in the referenced designs. An active low design was chosen due to the presence of pull-up resistors in Arduino microcontrollers, making it easy to keep the voltage at a high level when contacts are not pressed together. Similar designs to the one referenced may be located in Make: Wearable Electronics showing the ubiquity of such designs in existing wearable projects [4]. Those directions more specifically reference use with Arduino microcontrollers, showing the applicability to this particular use case.

Alternate solutions to the needs of this block include embedding pre-made buttons inside of fabric pockets, sewing buttons directly onto the collar of the wearable, changing the location of the buttons within the wearable, and seeking out alternate sources for referencing debouncing code. Pre-made buttons should be used in the event that too little accuracy is detected in verification. Changes to the location should be made in case too little stability is obtained or the button locations get in the way of the comfortable range of motion of the wearer. Alternate debouncing code should be crafted in case of failure to run effectively on the microcontroller or repeat registers of the buttons occur even with changes to the current intended structure of the code.

4.1.4 Interface Validation

The interface table describes the interfaces that connect the button block to the other blocks in the system. The purpose of these interfaces is to ensure that the block is able to coexist with other blocks when the full system is constructed and connections are made. Anticipating the properties of each interface allow it to connect to other blocks, such as the power supply, in predictable ways, for example that the intended voltage supplied by the power supply block will be sufficient for use with the peripherals connected to it such as the button block described here. Explanation is included to describe why the properties are included, making reference to connected blocks, and how the design will fulfill the properties to provide justification for the design included above.

This table describes first the properties of the user input, such that the system interacts with the user in anticipated ways concerning the requirements for usability described previously. It then covers properties pertaining to the digital signal provided to the microcontroller, to ensure the response is able to be registered properly by the microcontroller intended for use. It then covers the code based response intended to classify the interaction of the button debouncing code within the larger scope of the code uploaded to the microcontroller. Finally, the power supply is covered to discuss accepted ranges for blocks within the system that are powered by an agreed upon voltage level and within feasible current limitations the power supply block is anticipated to be capable of supplying.

Table 1

Buttons and Debounce Block Interface Properties

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?
otsd_bttns_dbnc_cd_usrin	**Input**	
Timing: The switch does not remain in contact when not pressed	This allows the switch to act as a button.	Plastic boning and denser contact material will hold an open form when not bent.
Type: The switch may be embedded in fabric	The switch will thus fit in the wearable.	The referenced design is compact and comprised of fabric.
Usability: The switch may be closed by human hand strength	The user can operate the button.	Small plastic boning for stability will be easy to bend.

bttns_dbnc_cd_mcrcntrllr_ stt_mchn_dsig	**Output**	
Logic-Level: Active Low	The realm of voltages registered as low are wider than those registered high.	The digital signal will be read from the side connected to the pull-up resistor or VCC supply.
Vmax: 5V	Logic high should not exceed the system's supplied voltage.	The voltage will originate from the microcontroller.
Vmin: 0V Low 3V High	Arduino pins register high starting at 60% of VCC [5].	The contacts will not be touching unless pressed, so current should not leak sufficiently to drop below this.
bttns_dbnc_cd_mcrcntrllr_ stt_mchn_data	**Output**	
Other: Code references the port connected to each button	The code can determine which button is pressed.	The code uses variables which may represent the digital inputs for each button.
Other: Code is callable by the state machine	This enacts a polling scheme to reduce false button presses relative to interrupts.	The code will be placed in a function.
Protocol: Code may be uploaded to an Arduino	The code must run on the intended microcontroller.	The code is C based, which may be used on an Arduino.
mcrcntrllr_stt_mchn_bttns_ dbnc_cd_dcpwr	**Input**	
Inominal: 10mA	This is enough current to drop the voltage low when contacts meet.	Arduino is capable of supplying this current through a digital signal pin.
Ipeak: 20mA	This is the maximum supplied current from an Arduino digital signal pin [6].	The buttons are a passive element which will not draw excessive current.
Vmax: 5V	The voltage should not be higher than system VCC.	The voltage will be supplied by the microcontroller.
Vmin: 3V	Arduino registers a high signal at 60% of VCC [5].	The voltage will be supplied by the microcontroller.

4.1.5 Verification Plan

The verification plan intends to rely on LED outputs to indicate to the tester when button presses have been registered, and how many. Tests are included to verify the interfaces connected to the power supply, ensuring that the intended voltage and current limitations are met. Finally, tests that show the block may be washed and worn with respect to the larger system goals of being implemented into a wearable device are met by this block.

1. Upload code that uses a polling scheme to call the debouncing function in between periodically doing other CPU work to model time consumed by the state machine and polling for and responding to sensor inputs, enabling simulation of the interface bttns_dbnc_cd_mcrcntrllr_stt_mchn_data. Create a response in the main function such that the code lights up a set of three LEDs in series, changing the LED lit when a single button press is registered.

2. Press each button by activating the user interface otsd_bttns_dbnc_cd_usrin and record button presses registered intentionally and unintentionally.

3. Use a voltmeter and current meter along the connection between the buttons and the microcontroller to confirm voltage and current values are in line with anticipated results.

4. Affix the button to the collar of a shirt or jacket and wear it around while walking and taking a backpack on and off, checking the LED indicators for unintentional button presses registered.

5. Wash the collar of the shirt or jacket and check the construction for damage.

4.1.6 References and File Links

[1.] J. Ganssle, “A guide to debouncing - part 2, or, how to debounce a contact in two easy pages, by Jack Ganssle,” Debouncing, hardware and software, part 2. [Online]. Available: http://www.ganssle.com/debouncing-pt2.htm. [Accessed: 20- Jan-2023].

[2.] push_reset and Instructables, “Introducing the soft switch,” Instructables, 29-Sep 2017. [Online]. Available: https://www.instructables.com/Introducing-the-Switch/. [Accessed: 20-Jan-2023].

[3.] “Can I program the Arduino Board in C? – arduino help center.” [Online]. Available: https://support.arduino.cc/hc/en-us/articles/360018448219-Can-I-program-the-Arduino-board-in-C-. [Accessed: 21-Jan-2023].

[4.] K. Hartman, Make: Wearable electronics. Beijing: O'Reilly, 2014.

[5.] holmes4, “At what voltage is a digital pin high?,” Arduino Forum, 15-Oct-2012. [Online]. Available: https://forum.arduino.cc/t/at-what-voltage-is-a-digital-pin- high/124761. [Accessed: 20-Jan-2023].

[6.] The Arduino Team, “Uno R3: Arduino documentation,” Arduino Documentation | Arduino Documentation. [Online]. Available: https://docs.arduino.cc/hardware/uno-rev3. [Accessed: 20-Jan-2023].

4.5.7 Revision Table

1/20/2023	Mae Graham: Rough draft created with new content in all sections.
2/11/2023	Mae Graham: Added discussion on system requirements and referenced larger scope of project in Design section. Added more context to figures used. Added introduction to interfaces table and verification plan. Added steps to verification plan to align with requirements and interfaces. Changed indentation on verification plan and references. Expanded on alternative options. These changes address instructor and peer feedback and implement changes to the intended design from continued work on the block.
5/14/2023	Mae Graham: Updated formatting.

4.2: Power Supply Block

4.2.1. Description

The power supply block contains a charging and voltage boosting PCB, a battery, and connectors. The connectors must provide a connection between the circuit and the battery, charging cable, and main device to supply power. The battery will be a flat lithium ion variety, supplying 3.7V of power to the circuit. The circuit is responsible for intaking charge to recharge the battery, and outputting a 5V power supply to the device.

4.2.2 Design

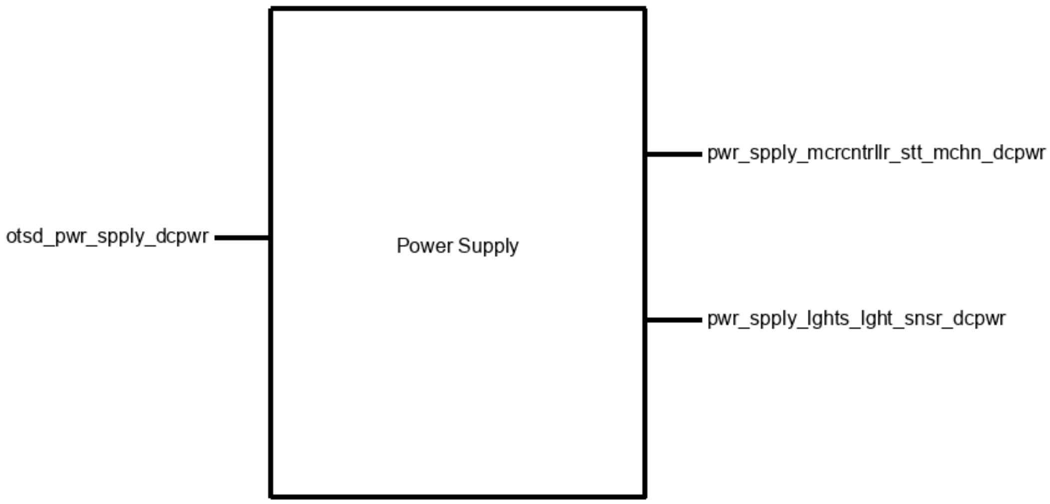


Figure 1: Black box diagram of the power supply block showing block inputs and outputs.

The power supply block must adhere to a number of universal constraints and engineering requirements. Per the universal constraints, the system must contain a student designed PCB with at least 30 non-connector surface mount pads which connects to other blocks exclusively through the use of connectors. Another universal constraint stipulates that the power supplies in the system must be at least 65% efficient. The engineering requirements which concern the power supply block include the comfort provided by the wearable, meaning the power supply must compactly fit into the sewn sweatshirt enclosure, removable parts which cannot be machine washed, and the overall running time of the system which this block must have sufficient battery capacity to support. These requirements define the qualities needed of the power supply to support the larger aim of the sweatshirt to be a wearable device that provides light and warmth to the user over a reasonable length of time.

The power supply design selected is a boost converter circuit designed to run on one flat pack lithium ion battery, with circuitry for charging that battery included. This allows the use of one thin battery with a small PCB, suitable for fulfilling the engineering requirement that the wearable be comfortable and promote full range of motion as it wont take up an excess of volume or weigh much. Lithium ion batteries come in a wide variety of capacities, allowing the selection of a battery which fulfills the duration of use requirement. The selection of a boosting circuit prevents the power supply from heating up excessively, which could harm the wearer of the sweatshirt.

The battery charging controller selected is the MCP73831. The circuit for incorporating this module was based on the design for typical application from the data sheet, shown below.

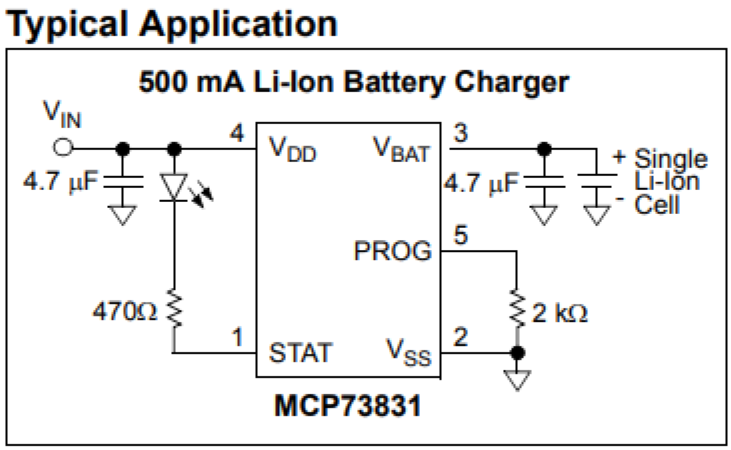


Figure 2: Typical application circuit from the datasheeet for the MCP73831 battery charging controller [1].

The datasheet also includes a typical layout for PCBs including the MCP73831 module, which was used when devising the final PCB layout for the power supply.

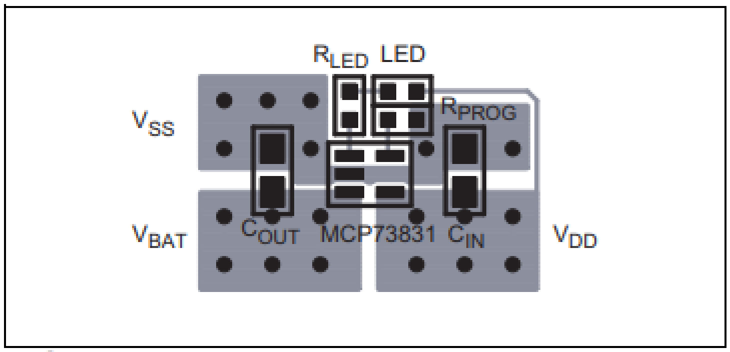


FIGURE 6-4: *Typical Layout (Top).*

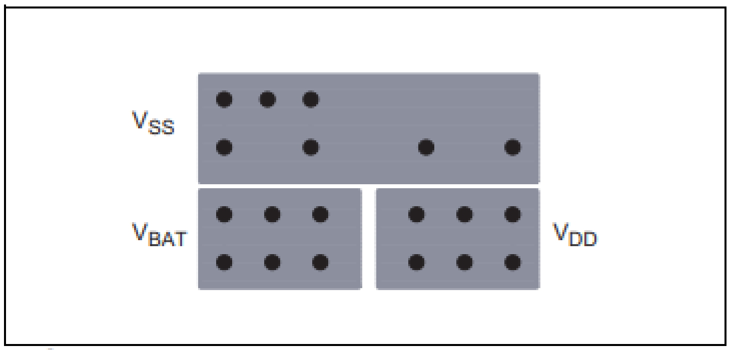


FIGURE 6-5: *Typical Layout (Bottom).*

Figure 3: Typical surface mount layout from the datasheet for the MCP73831 battery charging controller [1].

The boost converter selected is the AP3012 which features high efficiency, adjustable output voltage, and a 500mA switching current limit [2]. This current should be sufficient to support the lights and microcontroller which the power supply supports. The typical application circuit supplies a converted 24V output, and will be modified for the 5V target output by using 33Kohm and 100Kohm resistors to fulfill the design such that Vout = 1.25V * (1 + R4/R5) = 1.25V * (1 + 3) = 5V. The typical application schematic from the datasheet is shown below.

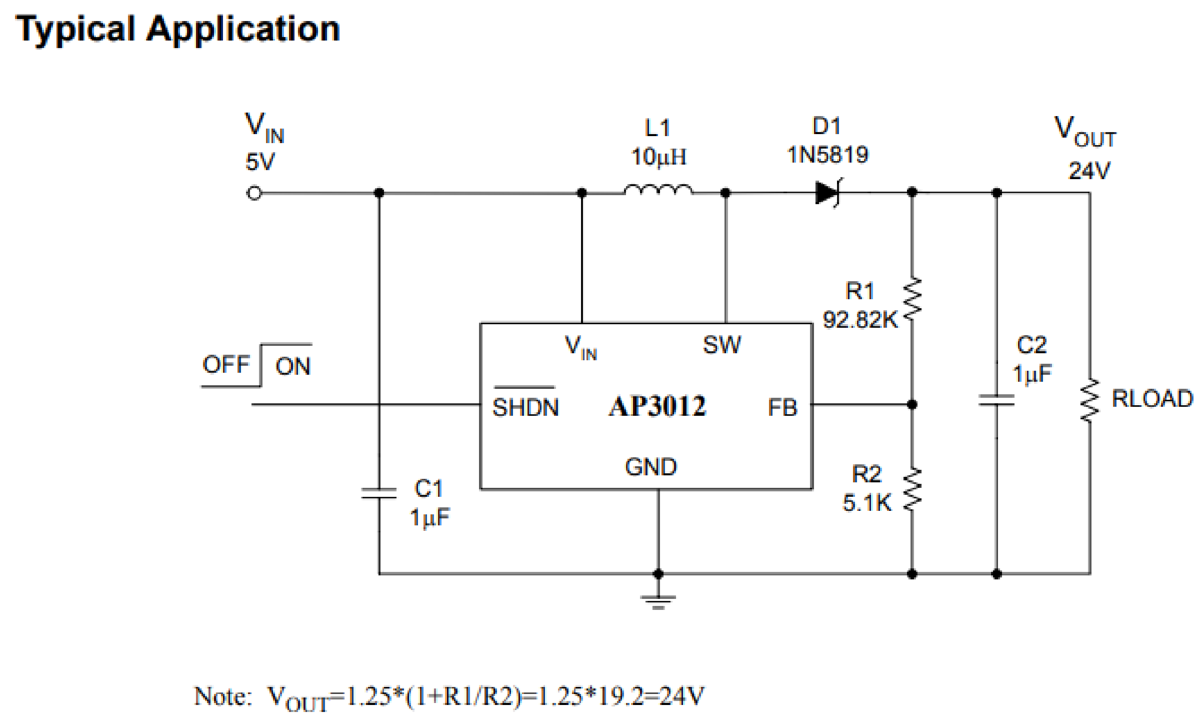


Figure 4: Typical application circuit schematic from the datasheet for the AP3012 boost converting module, in this case converting a V_{in} of 5V to a V_{out} of 24V.

The final schematic features the combination of these two modules with the components required for their adjusted typical applications with appropriate connectors. The final schematic is shown below.

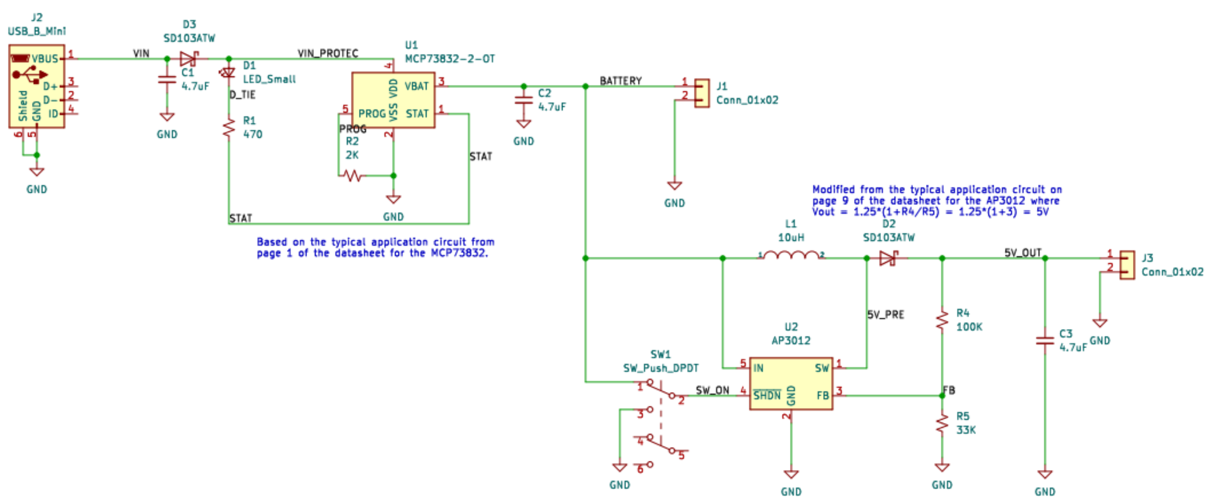


Figure 5: Schematic for the PCB power supply connecting the battery charging controller with the boost converter, supported by applicable components and connectors.

The PCB layout is designed to have a wide spanning ground plane which occupies the bulk of the lower layer. The connectors are located on different sides of the edges, allowing one side of the PCB to be devoted to connecting to the battery, another to allow access to the charging connector, and a final one to connect upward from the pocket of the sweatshirt toward the parts that need supplied power. The layout generated in KiCad is shown below.

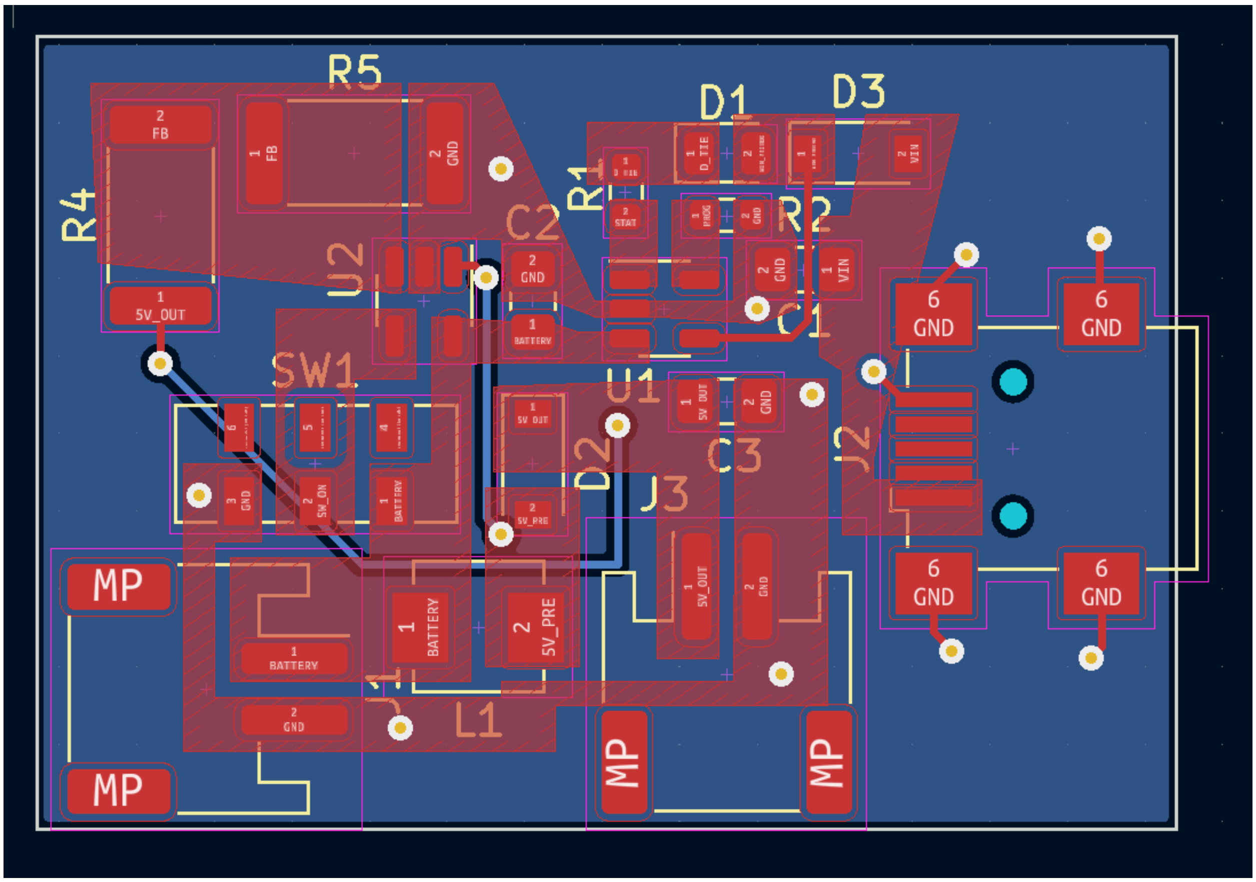


Figure 6: PCB layout designed in KiCad showing the typical layout for the MCP73831, a created layout for the AP3012, and the placement of the connectors for the battery, power supply, and charging cable.

4.2.3 General Validation

The connectors were selected to suit the needs of the power supply block within the context of the wearable sweatshirt. The battery and power supply connectors are two-pronged JST connectors which work with most lithium ion flat pack batteries, and the battery charging connector is a standard USB-B mini which allows the circuit to be charged by standardized, easily available USB cables which easily plug into computers and USB wall warts for convenient charging access. The locations allow for the placement of batteries in the pocket below the PCB, the charging port to stick out the side of the pocket, and the power supply to flow upward into the rest of the sweatshirt.

The design is compact to minimize the space occupied within the pockets by the power supply PCB. Guidelines from the datasheet are carefully followed, including the typical application schematics and the typical layout provided for the battery charging controller.

The voltage is suitable for supplying power to both typically available light arrays and traditional Arduino microcontrollers at 5V. The current limit of 500mA should supply plenty of power to the LEDs as well as the microcontroller.

4.2.4 Interface Validation

The interface table describes the interfaces that connect the power supply block to the charging supply, microcontroller, and lights block. These interface properties classify the connections such that the power supply is created to support the requirements of those blocks for power consumption. Explanations are included to support the reason for the properties existing as they are as well as justification that the design of the block will fulfill these requirements.

The table covers first the input providing power to charge the battery, followed by the output power supplied to the safety light LED arrays, and finally the output power supplied to the microcontroller.

Table 2

Power Supply Interface Properties

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?**
otsd_pwr_spply_dcpwr : Input		
Inominal: 510uA	Datasheet rating for the battery charging controller [1].	The parts used rate the nominal current input at this quantity.
Ipeak: 1500uA	Datasheet rating for the battery charging controller [1].	The parts used rate the peak current at this quantity.
Vmax: 6V	Datasheet rating for the battery charging controller [1].	The parts used rate the max input voltage at this quantity.
Vmin: 3.75	Datasheet rating for the battery charging controller [1].	The parts used rate the minimum input voltage at this quantity.
pwr_spply_mcrcntrllr_stt_mchn_dcpwr : Output		
Inominal: 0.04A	Microcontroller block has tested at this value.	The maximum current supplied by the AP3012 is 500mA, this does not exceed that [2].
Ipeak: 0.06A	Microcontroller block has tested up to this value.	The maximum current supplied by the AP3012 is 500mA [2].
Vmax: 5.5V	Maximum input voltage from Arduino USB inputs [3].	The voltage is regulated at 5V by the AP3012 [2].
Vmin: 4.5V	Microcontroller block has tested at this value.	The voltage is regulated at 5V by the AP3012 [2].
pwr_spply_lghts_lght_snsr_dcpwr : Output		

Inominal: 120mA	This is sufficient to supply a short span of the intended light array [4].	The maximum current supplied by the AP3012 is 500mA [2].
Ipeak: 140mA	The lights should not waver from their typical current draw substantially.	The maximum current supplied by the AP3012 is 500mA [2].
Vmax: 5.5V	Testing of the lights will has shown they will operate at this voltage.	The voltage is regulated at 5V by the AP3012 [2].
Vmin: 4.5V	Testing of the lights has shown they will operate at this voltage.	The voltage is regulated at 5V by the AP3012 [2].

4.2.5 Verification Plan

The verification plan involves plugging in connectors with a battery, load generator, and plugging a wall wart. The battery supplies the power to be boosted, the load generator tests the current draw by the system of the power supply, and by plugging it into a wall wart with the battery connected the recharging of the system may be tested.

1. Plug the battery into the battery port, and a JST-PH connector with open wires into the power supply port.

2. Connect the power supply wires to the load generator and set the load to the sum of Inominal values, 160mA. Run for 30 seconds at this load and record any changes to the output voltage read by the load generator. Turn the load off.

3. Set the load generator to the sum of Ipeak values, 200mA. Run for 5 seconds and record any changes to the output voltage read by the load generator. Turn the load off.

4. Disconnect the power supply port and read the battery voltage at the pins of the battery connector.

5. Connect the charging port to a wall wart using a USB standard to USB-B mini cable and record the voltage at the pins of the battery connector. Note any differences in voltage while charging versus not charging and detect whether the charging LED turns on.

4.2.6 References and File Links

[1.] “Miniature Single-Cell, Fully Integrated Li-Ion, Li-Polymer Charge Management Controllers”, Microchip, [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/20001984g.pdf. [Accessed: 12-Mar-2023].

[2.] “1.5MHz STEP-UP DC-DC CONVERTER AP3012 DATASHEET”, BCD, [Online]. Available: https://www.diodes.com/assets/Datasheets/AP3012.pdf. [Accessed: 12-Mar-2023].

[3.] “Arduino Uno R3 Product Reference Manual”, Arduino, [Online]. Available: https://docs.arduino.cc/static/a982e774fb10a4a89c78a3993853080d/ A000066-datasheet.pdf. [Accessed: 12-Mar-2023].

[4.] “5V Flexible LED Strip (60 LEDs) – Red”, DFRobot, [Online]. Available: https://www.dfrobot.com/product-2397.html. [Accessed: 12-Mar-2023].

4.2.7 Revision Table

3/12/2023	Mae Graham: Created with new content in all sections.
5/14/2023	Mae Graham: Updated formatting.

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 a protoboard and a PCB. The PCB is shown in further sections of the universal constraints. The following figure shows the protoboard used for distribution of power and data signals in the system:

`

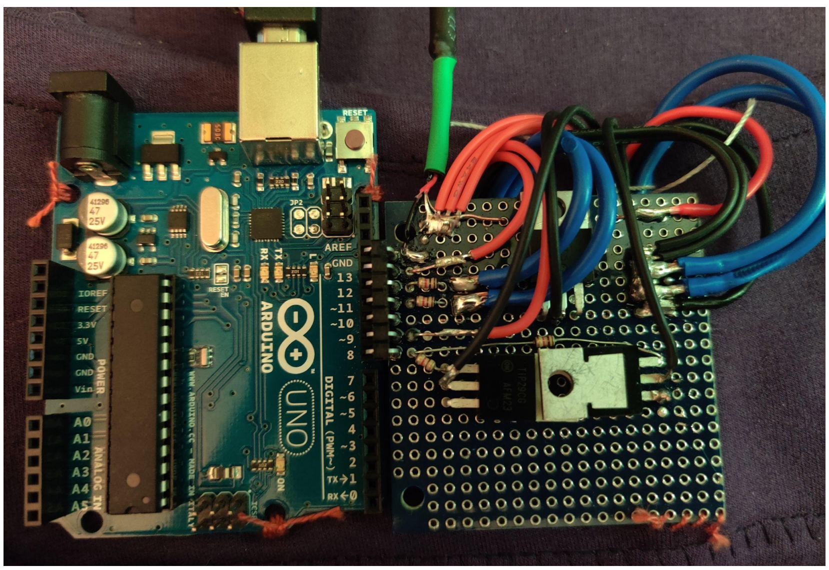


Figure 1: Top view of the protoboard and Arduino showing power and data connections.

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

The system contains a student designed PCB to supply power to the system. The PCB is a buck converter that takes an input of 7.4V in the form of two battery packs and outputs 5V to the rest of the system. The PCB contains more than 30 non-connector surface-mount pads annotated in the figure below.

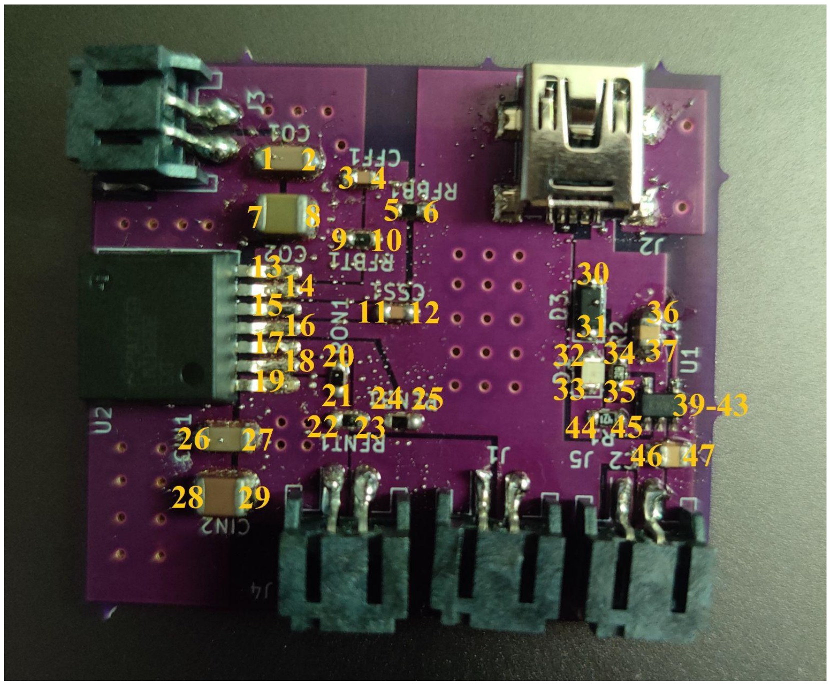


Figure 2: Image of the power supply PCB with pads 1 through 47.

5.1.3: All connections to PCBs must use connectors.

The PCB referenced in Figure 2 uses five connectors. The connector on the upper right is a USB-B mini port which allows the use of USB charging cables compatible with this standard to charge a battery connected to the lower right JST-PH connector. The two connectors on the bottom left are JST-PH connectors which connect to two lithium ion flat pack batteries to supply power for DC-DC conversion. The JST-PH standard is frequently used in compact flat pack batteries supplied by companies such as Adafruit and Sparkfun who carry a wide variety of batteries specifically designed for wearable projects such as this one. The upper left JST-PH connects the power supply to the rest of the system.

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

Efficiency can be extrapolated from the datasheet values for the main power converting element in the power supply PCB. Below is a chart for the efficiency over current at 8V, slightly above the input voltage used here of 7.4 V. The power supply in standard use provides 0.8 A, and the chart shows greater than 65% efficiency at that current.

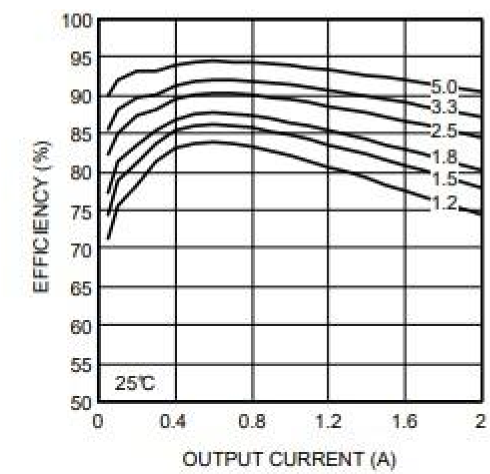


Figure 7. Efficiency 8-V Input at 25°C

Figure 3: Efficiency at 8 V input at room temperature for the LMZ12002 voltage regulator chip from Texas Instruments [1].

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 unit of module used to assess this constraint. The following table lists the blocks and whether each one is purchased or built.

Table 1

Purchased or Built Blocks

Block	Purchased or Built	Validation
Heating System	Built	The heating system consists of more than one component, with a transistor soldered onto a protoboard. The circuit of the system was designed to activate and deactivate the heating pad.
Buttons & Debounce Code	Built	The button debouncing code was written from scratch and the buttons themselves were hand made and not purchased.
Power Supply	Built	The power supply is a PCB built and designed by a single team member.
Sweatshirt and Wire Routing	Built	The sweatshirt is hand and machine sewn and the wires are routed through it with hand soldered connections and connectors.
Lights	Built	The light block utilizes a transistor soldered to the protoboard and clear heat shrink tubing affixed to the surface of the LED arrays.
Microcontroller & State Machine	Purchased	The microcontroller is the Arduino Uno which was bought and used in the system.

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.

Verification Method: Inspection

5.2.1.3: Verification Process

Step 1: Have the wearer press the buttons more than ten times and record the phantom button triggers that occurred. Step 2: Have the wearer wear the sweatshirt for 20 minutes and register no more than 2 phantom button presses.

Pass Condition: Buttons must react to at least 9 out of 10 presses. Buttons must experience less than 2 button presses in 20 minutes.

5.2.1.4: Testing Evidence

Evidence of the test passing is found at the following video links:

- First Video
- Second Video

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 4 out of 5 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: Test

5.2.2.3: Verification Process

Step 1: In a dark environment (50 lux) 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: If 4 out of 5 users report the safety lights on the system are visible from 100ft or more away in at least 50 lux, this requirement will be satisfied.

5.2.2.4: Testing Evidence

The test was performed with five users participating, reporting a yes or no response to whether the lights were visible from 100ft away. The distance was measured using a tape measure as shown in Figure 4. The environmental light was ensured to be above 50 lux at the time of measurement using the phone application "Light Meter" for Android devices. An example of the light measurement taken at the time of the first test is shown in Figure 5. The listing of users participating in the user tests is included in Figure 6, with their responses displayed in the table. Video evidence of the first and second user test show an example of how this user test was conducted and can be found at the following link:

- Video 1

Figure 4: Measuring procedure for the light visibility user testing.

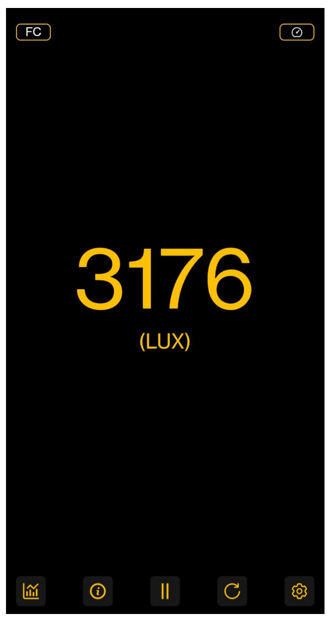
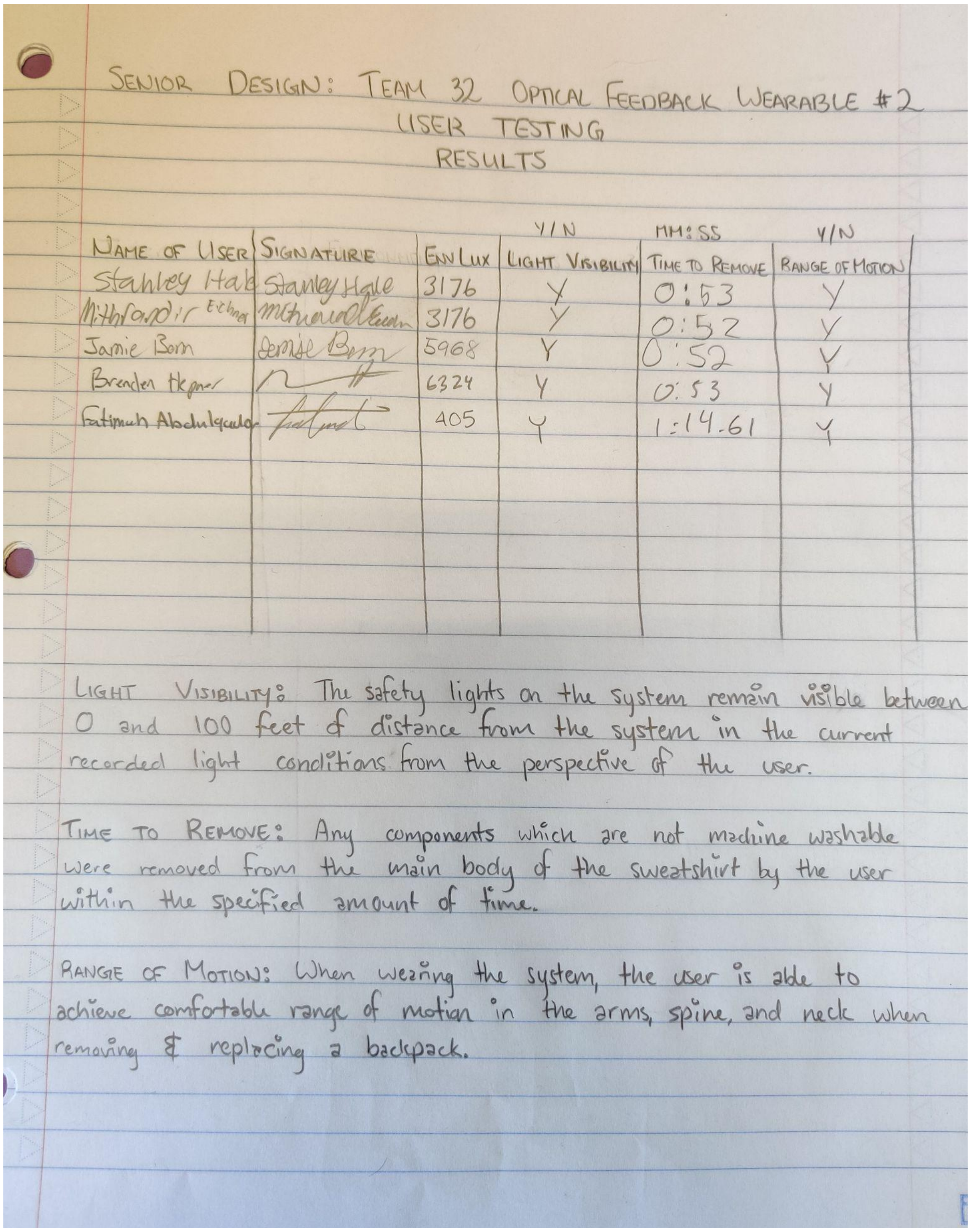


Figure 5: Screen capture of the light level measured by the Light Meter application for the first test.



SENIOR DESIGN: TEAM 32 OPTICAL FEEDBACK WEARABLE #2
USER TESTING
RESULTS

NAME OF USER	SIGNATURE	ENV LUX	Y/N LIGHT VISIBILITY	MM:SS TIME TO REMOVE	Y/N RANGE OF MOTION
Stanley Hale	Stanley Hale	3176	Y	0:53	Y
Mithrandir Eichner	[illegible]	3176	Y	0:52	Y
Jamie Born	Jamie Born	5968	Y	0:52	Y
Brenden Hepner	[illegible]	6324	Y	0:53	Y
Fatimah Abdulqader	[illegible]	405	Y	1:14.61	Y

LIGHT VISIBILITY: The safety lights on the system remain visible between 0 and 100 feet of distance from the system in the current recorded light conditions from the perspective of the user.

TIME TO REMOVE: Any components which are not machine washable were removed from the main body of the sweatshirt by the user within the specified amount of time.

RANGE OF MOTION: When wearing the system, the user is able to achieve comfortable range of motion in the arms, spine, and neck when removing & replacing a backpack.

Figure 6: User test form showing participant name, signature, environmental light test results, light visibility response (yes/no), time to remove non-washable parts, and range of motion response (yes/no).

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 comfortable range of motion in the arms, spine and neck as reported by 4 out of 5 users of the system after they remove and replace a backpack.

Testing Method: Test

5.2.3.3: Verification Process

Step 1: The wearer will wear the sweatshirt and a backpack on top of it.
Step 2: The wearer will move with a full range of motion to express their feelings of wearing the sweatshirt. Only one person will demonstrate the requirement.

Pass Condition: The requirement will be satisfied if 4 out of 5 users report a comfortable range of motion in the arms, spine, and neck when removing and replacing a backpack.

5.2.3.4: Testing Evidence

The test was performed with five users, each of whom tried on the sweatshirt. While wearing the sweatshirt, they put a backpack on, moved their arms around, and reported whether they maintained a comfortable range of motion before removing the backpack. The users recorded a yes or no response to the testing prompt with results reported in the table shown in Figure 6. An example video of the first user participating in the test is found in the following video:

- Video 1

5.2.4: Removable parts

5.2.4.1: Project Partner Requirement

Project will be a wearable.

5.2.4.2: Engineering Requirement

The system will have any parts needing to be removed before washing removable in under 15 minutes by 4 out of 5 users.

Testing Method: Test

5.2.4.3 Verification Process

Step 1: Electric parts that will be subjected to water damage will have velcro straps that will enable the tester to remove the parts within a 15 minute time span.
Step 2: The sweatshirt will be washed in a regular washing machine.

Pass Condition: If 4 out of 5 users can remove any parts needing to be removed before washing in under 15 minutes, this requirement passes.

5.2.4.4: Testing Evidence

This test was performed with 5 users following directions to dismantle the system, separating the power supply and batteries first followed by detaching the velcro on the collar and pulling out the heating element and LED arrays. This leaves the main body of the sweatshirt entirely composed of velcro and fabric, ready for washing. The time it took to deconstruct the sweatshirt is recorded for each of the user tests performed, with results listed in the user testing document shown in Figure 6 in the previous section. A video of the first user test performed is included below to show an example of how the user test was performed.

- Video 1

5.2.5: Running time

5.2.5.1: Project Partner Requirement

The project will be energy efficient.

5.2.5.2: 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

5.2.5.3: 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, heating element for 20 minutes and lights for 30 minutes.

5.2.5.4: Testing Evidence

The running time test ran for four hours, with the first 50 minutes alternating between the safety lights being on and the heating element being on, as indicated by visible safety lights and indicator lights in the video. For brevity, the video was sped up to 16 times faster. A link to the video of the test is shown below.

- Video 1

5.3: References and File Links

5.3.1: References

[1] "LMZ12002 2-A SIMPLE SWITCHER® Power Module With 20-V Maximum Input Voltage." [Online]. Available: https://www.ti.com/lit/ds/symlink/lmz12002.pdf?ts=1683427449901#:~:text=The%20LMZ12002%20can%20accept%20an,accurate%20output%20voltage%20as%20low. [Accessed: 07-May-2023].

5.3.2: File Links

[1] https://www.youtube.com/watch?v=ggnl34T4jG8

[2] https://drive.google.com/file/d/1oRyE85LGotSQsBe_WgqsRWe032mEUjEi/view?usp=sharing

[3] https://youtube.com/shorts/W7dHGluSJqY

[4] https://youtube.com/shorts/fW2v6uPzyaI

[5] https://youtube.com/shorts/goXzqgULL7E

5.4: Revision Table

5/7/2023	Mae Graham: Updated section to provide further evidence of universal constraints met and aligned requirements testing with current standards.
5/14/2023	Mae Graham: Updated content in the universal constraints section 5.1 to resemble present system design. Updated content in verification section 5.2 to include testing results. Added file links.

6. Project Closing

6.1: Future Recommendations

6.1.1: Technical Recommendations

While several blocks received a second revision, the design has great potential for further improvements.

The electronics on the sweatshirt are intended to be as compact as possible. A custom surface mount PCB kept the power supply relatively small and flat, not taking up excessive space in the pockets of the sweatshirt. However the decision to use a standard Arduino UNO board made the microcontroller much less flat than it could have been. Implementing a smaller Arduino board or creating a custom PCB for the microcontroller would have significantly improved the impactfulness of this block to minimize the space taken up by electronic parts. The protoboard used for the power and signal distribution could also have been done with a PCB and connectors, cutting down on space.

The connectors ultimately employed were not ideal. JST-PH 2 pin connectors were very effective for interfacing with standard flat pack batteries, but did not suit the connection of the PCB to the main power supply of the device. The cables in JST-PH connectors are thin, and the connector doesn't unplug very easily, making this a point of potential failure in the device. Employing a 3.5mm jack (as originally intended on the outset of the design) or other connector may have worked better for removability of the power supply as well as durability of the wires through the front of the sweatshirt [1]. Alternate connectors may also have been useful for the peripherals to assist in the ease of removing them for washing the sweatshirt.

The waterproofing in this design was insufficient. While this wasn't a focus of the engineering requirements, it would have served the audience well to include it as one. Use of ripstop or other water resistant fabric was employed to contain the power supply, while clear heat shrink tubing was employed to waterproof the light array. However no attempt was made to waterproof the protoboard which housed the power and signal distribution and the Arduino. While they do rest underneath the hood, more steps could have been taken to contain this section with ripstop or a plastic housing. Additionally a more water resistant material could have been used to house the power supply.

The use of insulated wires added bulk to the design. While useful for the current requirements of the power supply and peripherals, sufficient use of flat braided copper, thick conductive thread, or strips of conductive fabric to connect electronic devices would improve the flexibility and durability of the wearable. The insulated wires added some water resistance to the design, but this could have been achieved with solutions more suited to a wearable.

6.1.2: Global Impact Recommendations

While this project focused on the creation of a proof of concept or prototype, a better application of this technology would be a kit of parts that functions to upgrade existing sweatshirts with the safety lights and heating pads. This would reduce waste needed to create new sweatshirts, reduce the cost of the system, and be more widely distributable.

The location of the heating pad was intended to support the aches that often come with sitting for long periods of time to address a student audience. Heating pads are a meaningful tool for a variety of audiences who may get more out of it. Individuals use heating pads for pain relief to address a wide range of ailments, but the medical community is still hesitant to apply them due to concerns for the safety of currently available products [2]. Tackling safety issues of heating pads and targeting certain areas of the body that need the most relief for various medical applications would be an excellent way to extend the target audience of this device or reframe the goals of the wearable to have a greater impact.

6.1.3: Teamwork Recommendations

The original team behind this project experienced a significant breakdown of teamwork that resulted in it splintering off into multiple teams. The recommendations this team has for preventing this may be blunt and go without saying, but are vital nonetheless. They concern the respect of individual autonomy, meeting standards in a nonproductive environment, and starting with a simple design.

An incident occurred in the original team in which the freedom of movement was limited for one team member whose transportation was entrusted to another team member. They were not permitted to leave the lab at the time they wished to return home for family obligations until they completed work requested by another team member and suffered penalties in their personal life due to this matter. This is harassment and is absolutely unacceptable. The basic respect that you must show another team member includes treating them as an individual with full autonomy.

Unfortunately, in some teams, nearly all group work may fall on a single team member. Should you find yourself in this position, consider that a passing grade may be preferable to completing the level of work that you would feel satisfied with or that would get you a higher mark. It feels degrading and distressing to be let down in this way, and a high mark in a class is simply not worth it. As the adage goes, C's get degrees.

One successful technique this team employed to be prepared for a breakdown of team dynamics was to start small. The design originally proposed was the absolute minimum that any one team member felt they could achieve on their own without help. There is ample opportunity to add more complexity later in the design process should your team participate meaningfully and come prepared for a greater challenge.

6.2: Project Artifacts

6.2.1: Arduino Code

The code uploaded to the Arduino to control the peripherals on the system is included below.

```
// Constants for pin assignment
const int LIGHT_INDICATOR_PIN = 13;
const int LIGHT_BUTTON_PIN = 12;
const int HEAT_BUTTON_PIN = 11;
const int HEAT_ACTIVE_PIN = 10;
const int LIGHT_ACTIVE_PIN = 9;
const int HEAT_INDICATOR_PIN  = 8;

static int LIGHT_STATE = 0;
static int HEAT_STATE = 0;
```

```
int BUTTON_COUNT = 0;

//////

int chk_button0() {
  static uint16_t state;
  int buttonVal;

  buttonVal = digitalRead(LIGHT_BUTTON_PIN);

  //Serial.println(buttonVal);

  state = (state << 1) | (buttonVal == LOW) | 0xE000;
  if (state == 0xF000) { return 1; }
  return 0;
}

int chk_button1() {
  static uint16_t state1;
  int buttonVal1;

  buttonVal1 = digitalRead(HEAT_BUTTON_PIN);

  //Serial.println(buttonVal1);

  state1 = (state1 << 1) | (buttonVal1 == LOW) | 0xE000;
  if (state1 == 0xF000) { return 1; }
  return 0;
}

///////////

void setup() {
  Serial.begin(9600);
  // Set button pins to use pull-up resistors
  pinMode(LIGHT_BUTTON_PIN, INPUT_PULLUP);
  pinMode(HEAT_BUTTON_PIN, INPUT_PULLUP);
  // Set the peripheral activation and indicator light pins as outputs
  pinMode(HEAT_ACTIVE_PIN, OUTPUT);
```

```
  pinMode(HEAT_INDICATOR_PIN, OUTPUT);
  pinMode(LIGHT_ACTIVE_PIN, OUTPUT);
  pinMode(LIGHT_INDICATOR_PIN, OUTPUT);
}

void loop() {
  int LIGHT_PRESS = chk_button0();
  int HEAT_PRESS = chk_button1();

    if(LIGHT_PRESS == 1)
    // Switch state when button pressed
    //   0 - OFF
    //   1 - ON
    {
        BUTTON_COUNT++;
        LIGHT_STATE = ~LIGHT_STATE;
    }

    if(HEAT_PRESS == 1)
    // Switch state when button pressed
    //   0 - OFF
    //   1 - ON
    {
        BUTTON_COUNT++;
        HEAT_STATE = ~HEAT_STATE;
    }

  if(LIGHT_STATE) { //turn on
    digitalWrite(LIGHT_ACTIVE_PIN, HIGH);
    digitalWrite(LIGHT_INDICATOR_PIN, HIGH);
  } else {                // turn off
    digitalWrite(LIGHT_ACTIVE_PIN, LOW);
    digitalWrite(LIGHT_INDICATOR_PIN, LOW);
  }

  if(HEAT_STATE) {   //turn on
    digitalWrite(HEAT_INDICATOR_PIN, HIGH);
    digitalWrite(HEAT_ACTIVE_PIN, HIGH);
  } else {
    digitalWrite(HEAT_INDICATOR_PIN, LOW);
```

```
    digitalWrite(HEAT_ACTIVE_PIN, LOW);
  }

  Serial.println(BUTTON_COUNT);

}
```

6.2.2: Final Power Supply Schematic and Layout

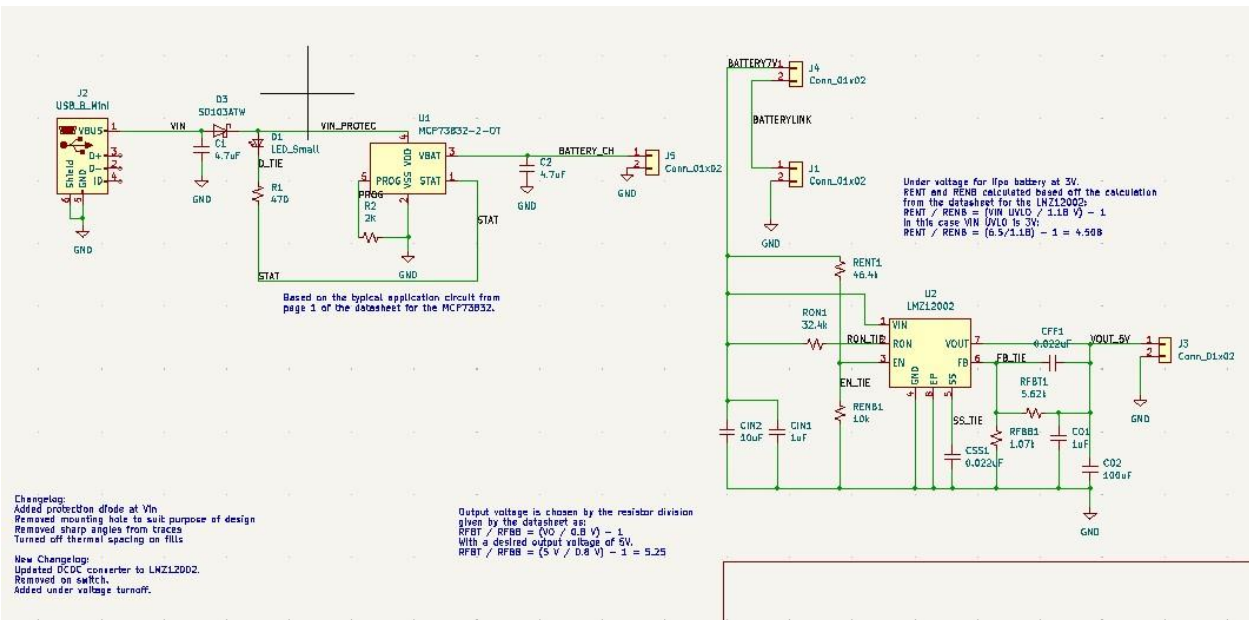


Figure 1: Power supply schematic

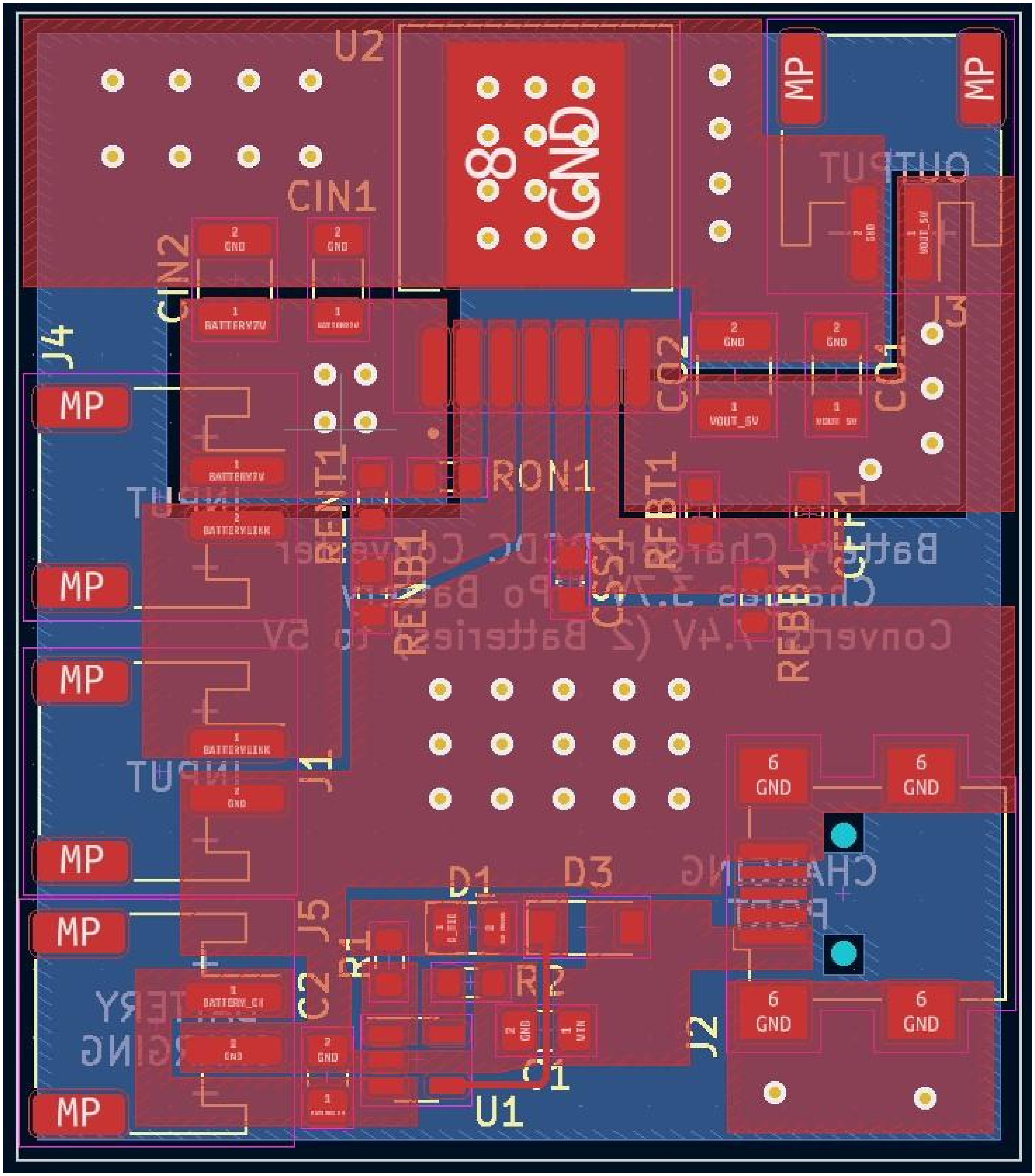


Figure 2: PCB Layout

6.3: Presentation Materials

6.3.1: Expo Poster

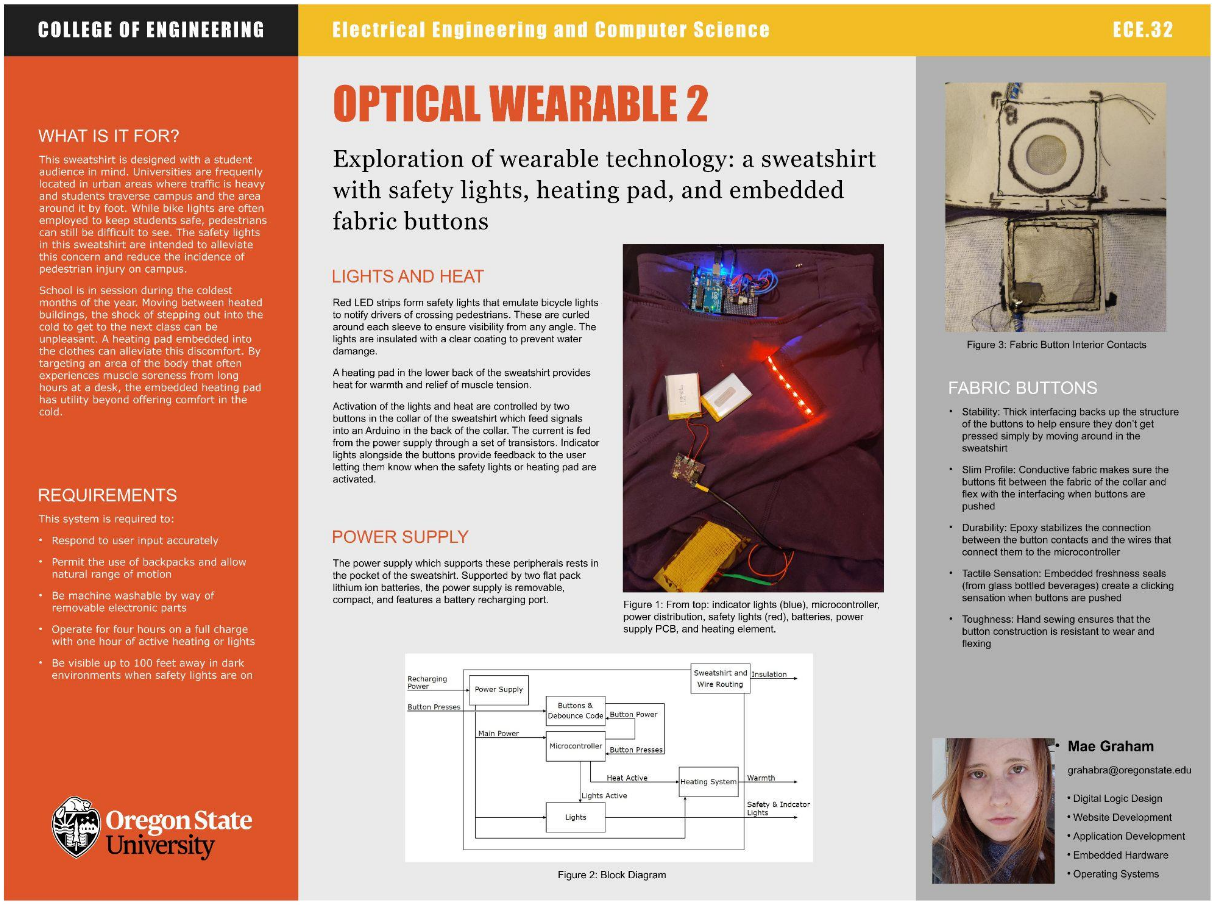


Figure 3: Expo Poster

6.3.2: Project Showcase Link

https://events.engineering.oregonstate.edu/expo2023/project/optical-feedback-wearable-2

6.3: References and File Links

6.3.1: References

[1] “Working with Spaghetti Monster,” HOW TO GET WHAT YOU WANT,

https://www.kobakant.at/DIY/?p=9137 (accessed May 14, 2023).

[2] A. Chandler, J. Preece, and S. Lister, “Using heat therapy for pain management. (clinical practice)”, Royal College of Nursing Publishing Company (RCN), (Nov. 13, 2002). *Nursing Standard*, vol. 17, issue 9. https://link.gale.com/apps/doc/A94820820/AONE?u=oregon_oweb&sid=googleScholar&xid=26fd0106 (accessed May 14, 2023).

6.3.2: File Links

6.4: Revision Table

4/28/2023	Mae: Added rough draft of recommendations, artifacts, and project poster. Added project showcase link.
5/5/2023	Mae: Added references and updated the recommendations.
5/14/2023	Mae: Updated references, added recommendation content, updated code section of artifacts to be more compact.