Wearable Tech Device for Measuring Electrodermal Activity and Cardiovascular signals in Cognitive Learning Environments

(Hardware Proposal)

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3.1 Hardware Strategy

To address this issue, we propose creating a wearable tech device that is unobtrusive, allows patient mobility, lasts about 6-8 hours for an average research study, sends accurate data wirelessly, and is safety compliant with all wearable technical codes. For the purposes of this proposal, it will specifically talk about the hardware specifications, concepts, design, and deliverables. The strategic methods for data analysis will be referenced in the software team's paper.

3.2 Technical Specifications and Constraints

The goal of the wearable device is to meet all stakeholders' needs while meeting all safety and medical electrical requirements. The codes referenced are IEC 60601 (international standard with general requirements for basic safety and essential performance of medical electrical equipment), IEC 62133-2 (safety requirements and testing procedures for portable sealed secondary lithium cells and batteries, ensuring their safe operation under intended use and foreseeable misuse) ISO 9241(ergonomics of human-system interaction), FCC Part 15 Subpart C (regulation of intentional radiators), and ISO 10993 (biological evaluation of medical devices.

Parameter	Specification/Target	Code Referenced
Operating voltage	3.3 V DC (SELV safe)	IEC 60601-1
Battery Capacity	Minimum 6-8 hr run time	IEC 62133-2
Power Draw	< 80 mA active / 3 mA standby	IEC 60601-1-11
Skin Current (EDA)	≤ 10 µA	IEC 60601-1
Wireless Range	10-30m via BLE	FCC Part 15 Subpart C
Temperature Limit	< 42 ° C surface	IEC 60601-1
Material Compliance	ISO 10993 biocompatible textile	ISO 10993-1
Weight	< 80 g total	ISO 9241

Cost	< $ 2200 prototype and software	Drexel University
Data Accuracy	≥ 95% correlation between measured and reference heart rate	IEC 60601-1-2
Noise & Interference Rejection	Signal-to-Noise-Ratio ≥ 40 dB; hardware low-pass filter 5 Hz EDA, < 20 Hz PPG	IEC 60601-1-2

Table 1: System Requirements and Applicable Standards

3.3 Biological basis for Device Configuration

When deciding what kind of device to create for measuring electrodermal activity and heart rate, several physiological factors played a key factor. The goal is to measure skin conductance through the body's sympathetic nervous system arousal, specifically through the eccrine sweat glands. This immediately narrows the sensor placement to body areas where emotional sweating, or eccrine sweat, occurs most densely. The fingertips and palms are the optimal locations for measuring EDA due to their high concentration of sweat glands. (1)(Gamboa et al.) However, both minimal experimentation and peer-reviewed research revealed that measuring EDA at the fingertips was impractical for user comfort and the movement often introduced noise and unreliable signals. (2)(Bari) Consequently, the design shifted towards a wristband, which offers a more practical alternative for wearable EDA monitoring while still providing reliable signal quality in everyday use.

3.4 Design Concepts

3.4.1 Concept 1

For the initial conceptual design for our wearable device, we proposed a sensor integrated glove wristband hybrid. The glove would have two sensors, the electrodermal activity sensor located on the middle finger, middle phalanx and index finger middle phalanx and the heart rate sensor located at the fingertip of the middle finger. The glove would be a compression glove as the sensor needs to have some pressure applied to the skin to be effective, and the compression nature of the glove helps minimize movement. The glove would house the sensors while the wristband would house the other electrical components such as the microcontroller, Bluetooth module, battery, and boost converter. To optimize user comfort, we also removed the fingertip for the thumb and pointer finger so users could still use their LED screen devices without taking off the device.

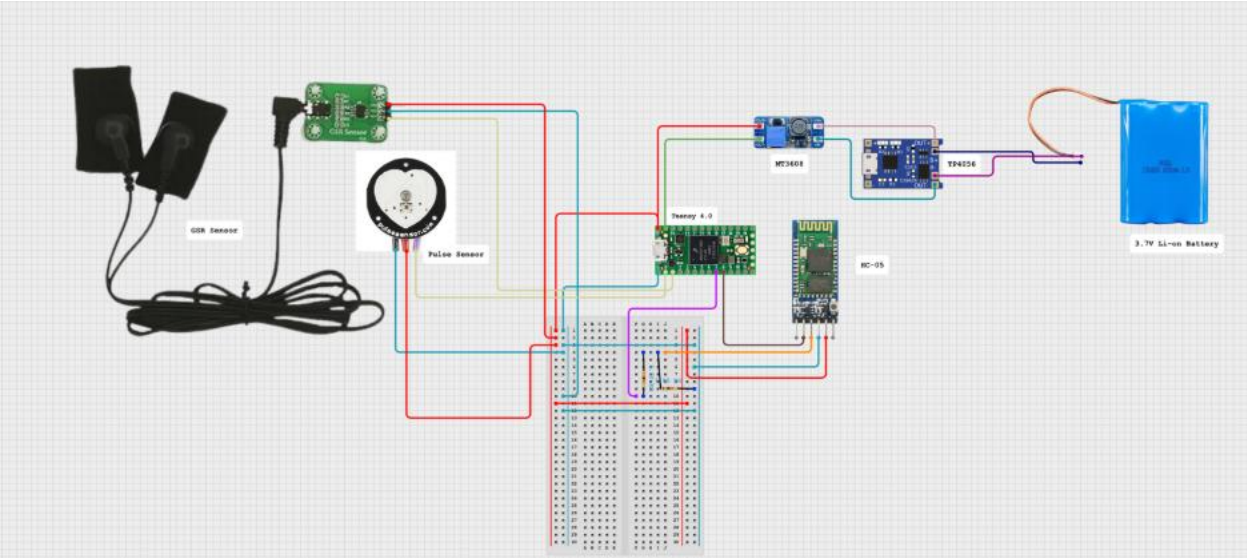

Figure 1: Wiring Diagram of Concept 1

The above figure shows the wiring diagram of components that would be integrated into compression glove/wrist band design concept 1. The components depicted in this diagram are illustrative and do not necessarily reflect the exact models chosen for the design.

Figure 2: Sample Prototype of Concept 1

Early Concept Fabric-Integrated Sensing Glove. (The sample prototype image is for visual purposes only and components depicted in the design may be located elsewhere on the glove)

The benefits of this first concept are the data analysis efficiency because the teensy 4.0 uses a 32-bit ARM Cortex-M7 clocked at 600 MHZ and 1MB of RAM, it can process the sensor signal at a significantly faster rate than competing microcontrollers such as the Arduino nano or ESP32-C3 Super mini. However, there are several drawbacks to the design such as its bulkiness due to the large number of components being used also the teensy 4.0 although very powerful is overkill for our sensors that send data at 4 Hz. The teensy 4.0 microcontroller is also very power hungry and requires a bigger battery than competing microcontrollers. Also, a big negative is that teensy 4.0 does not have Bluetooth capabilities and requires the external HC-05 Bluetooth module increasing costs, weight, and worsening comfort of the device

3.4.2 Concept 2

After reflecting all the cons of design configuration two we changed a lot. After realizing the Teensy 4.0 is very powerful microcontroller we realized it was unnecessary for our specific project and changed microcontrollers to the ESP32-C3 Super mini. This chip has BLE capabilities so along with being a third of the size of the teensy 4.0 it also removes the external Bluetooth module also it operates at 32-bit at 160Hz which is still much faster than our sensor frequency it uses significantly less power of only 32mA compared to Teensy 4.0 100mA. Along with changing microcontrollers, we opted for a more efficient heart rate sensor that will be pulling the beats per minute (BPM), and heart rate variability (HRV) from the sensor as well. The decrease in size of components and number of components allow for a much sleekier look and increased expected comfort of design concept 2 compared to design concept 2.

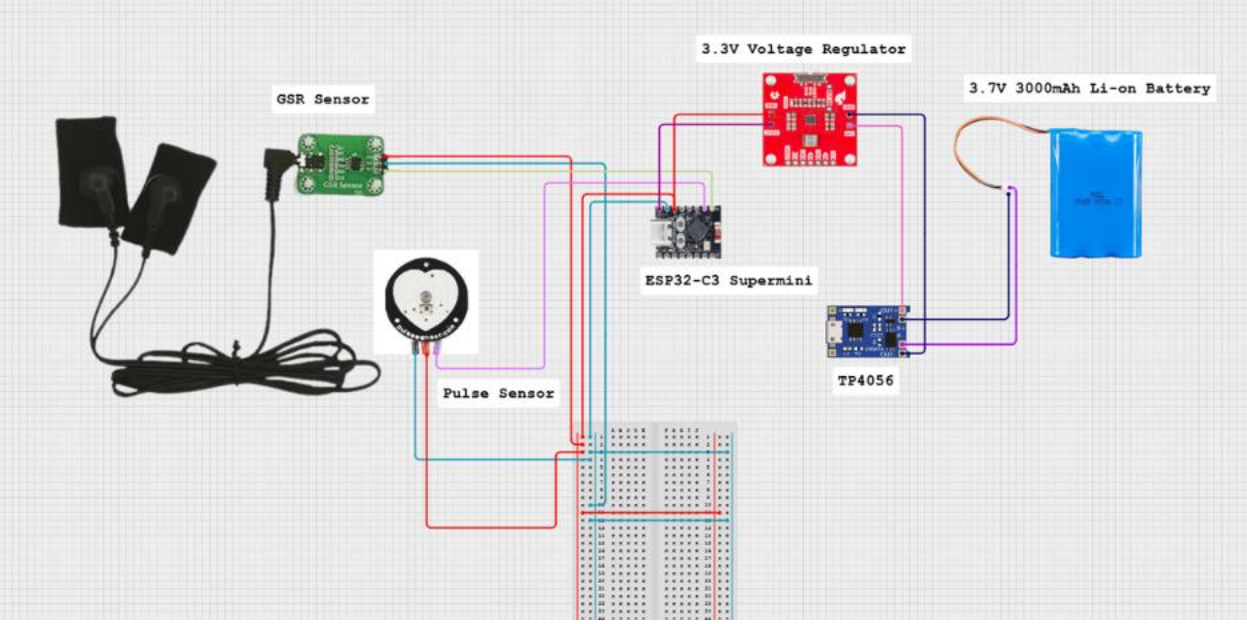

Figure 3: Wiring diagram of Concept 2

The above figure shows the wiring diagram of components that would be integrated into compression glove/wrist band design concept 2. The components depicted in this diagram are illustrative and do not necessarily reflect the exact models chosen for the design.

Figure 4: Sample Prototype of Concept 2

Early Concept Fabric-Integrated Sensing Glove. (The sample prototype image is for visual purposes only and components depicted in the design may be located elsewhere on or in the glove)

Design concept 2 was a major improvement from initial concept. The use of a different microcontroller reduced power consumption, weight of the device, and cost of the device. Cons of the device fails to address any noise filtration through physical components and purely relies on software to compute all filtration

3.4.3 Concept 3

For Design Concept 3 the power and space issues were solved so the main problem was how can we reduce noise or differentiate noise from a hardware perspective. Also through some testing of the EDA sensor we realized that if there was no way to differentiate temperature related sweating or thermal regulation sweat from nervous systema arousal sweating which led us to add a skin temperature sensor. The primary goal of the skin temperature sensor is to validate sympathetic sweating from thermal regulation. We also knew that the primary source of noise would be due to the movement of the patient and we needed a way to isolate noise related noise

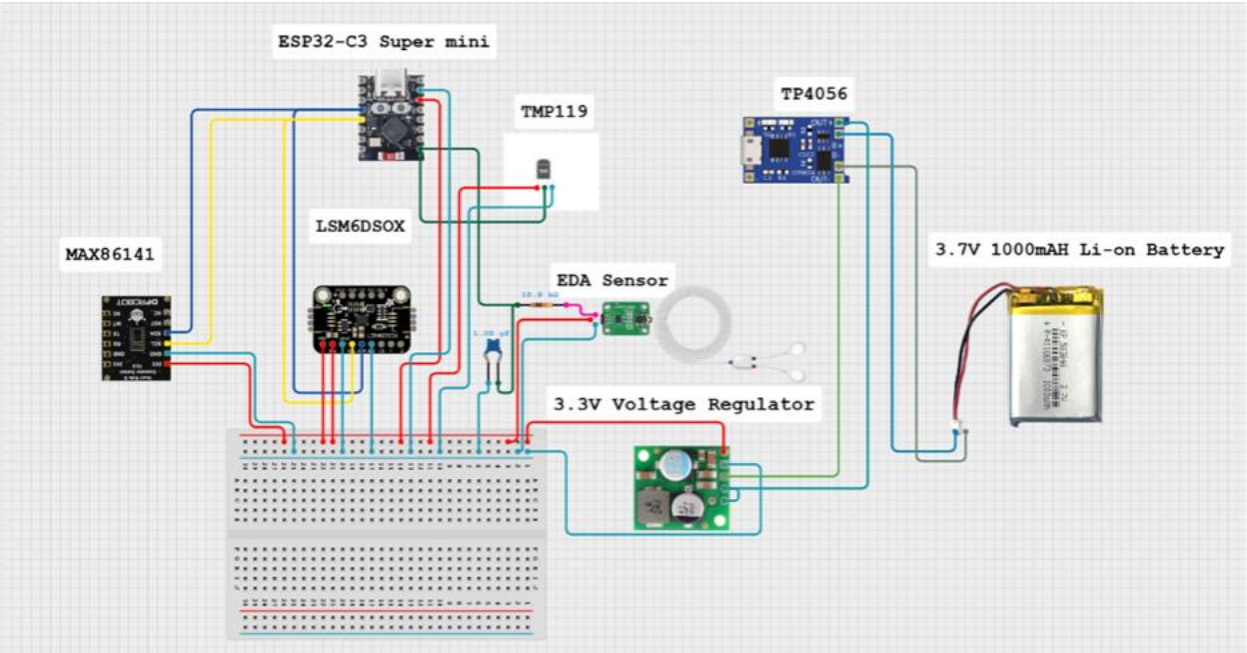

Figure 5: Wiring Diagram for Concept 3

System-Level circuit Concepts for wearable wrist band. The components depicted in this diagram are illustrative and do not necessarily reflect the exact models chosen for the design.

For design concept 3, the EDA sensor that was chosen is medical grade equipment from Bio signal Plux that can communicate with the Arduino, giving us stronger and more accurate signal than prior designs. Also, by adding additional sensors we can pinpoint exact moments of noise to more efficiently remove them when programming.

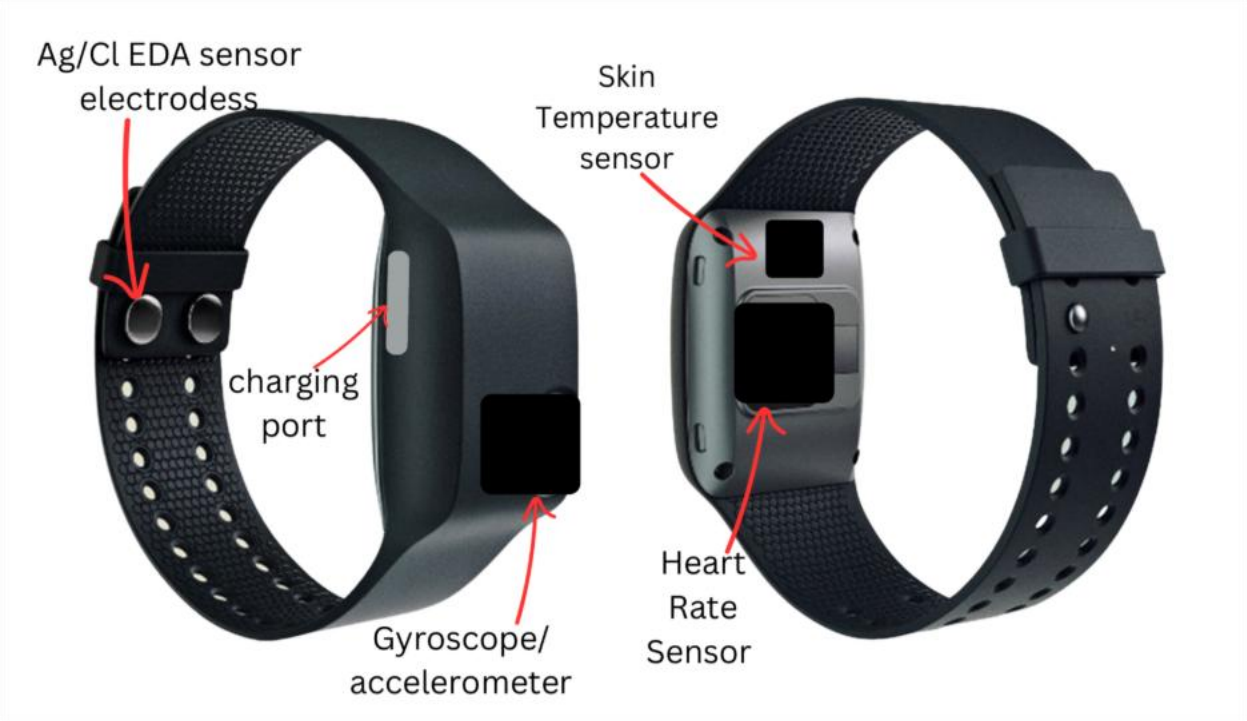

Figure 6: Sample prototype of Concept 3

The above figure shows a very general prototype design depicting sample wristband wearable device. Purpose is to show general sensor placement not indicative of final concept structure

3.5 Design Matrices

Parameter	Specification/Target	Design 1	Design 2	Design 3
Operating voltage	3.3 V DC (SELV safe)	Pass	Pass	Pass
Battery Capacity	Minimum 6-8 hr run time	Pass	Pass	Pass

Power Draw	< 80 mA active / 3 mA standby	Fail	Pass	Pass
Skin Current (EDA)	≤ 10 µA	Pass	Pass	Pass
Wireless Range	10-30m via BLE	Fail	Pass	Pass
Temperature Limit	< 42 ° C surface	Pass	Pass	Pass
Material Compliance	ISO 10993 biocompatible textile	Pass	Pass	Pass
Weight	< 80 g total	Pass	Pass	Pass
Cost	< $ 2200 prototype and software	Pass	Pass	Pass
Data Accuracy	≥ 95% correlation between measured and reference heart rate	Pass	Pass	Pass
Noise & Interference Rejection	Signal-to-Noise-Ratio ≥ 40 dB; hardware low-pass filter 5 Hz EDA, < 20 Hz PPG	Fail	Fail	Pass

Table 2: Design matrix

3.5.1 Design Matrix Evaluation Explanation

For the design matrix, each concept was evaluated against the required technical specifications to determine whether it was suitable for prototyping. Design Concept 1 failed the power-draw requirement because Teensy 4.0 consumes approximately 100mA when fully active, exceeding the recommended limit of 80mA according to IEC 60601-1. It also failed the wireless-range requirement since the HC-05 Bluetooth module provides only about 10 meters of reliable range, which is below the target 10-30 m Bluetooth low energy (BLE) performance. Additionally, Design 1 did not include a hardware low-pass filter on the EDA signal path, resulting in significant noise and an inadequate signal-to-noise ratio (SNR).

Design Concept 2 performed better in terms of power and wireless range but still failed to meet the noise and interference requirements. Although it met the electrical and runtime criteria, it was missing an appropriate low-pass filter to properly condition the EDA signal, leading to high frequency detection above the expected 5 Hz physiological range.

Design 3 successfully met all specifications. It used a medical-grade EDA sensor and incorporated a dedicated hardware low-pass filter implemented with a 33 KΩ resistor and a 1 µF capacitor, yielding a cutoff frequency close to 5 z. This significantly improved the SNR and ensured compliance with the noise rejection requirement, making DEsign3 the optimal device for prototyping.

4. Methods and Materials

4.1 Detailed Design

The detailed design integrates all electrical, mechanical, and safety subsystems necessary to create a functional wearable EDA and heart-rate monitoring device. This section expands the final concept by describing the complete electrical architecture, component interactions, signal pathways, microcontroller pin assignments, mechanical enclosure, safety provisions, and power budget validation.

4.2 Electrical Architecture Overview

The final hardware configuration consists of five major subsystems.

1. Power Subsystem – 3.7V Li-on battery, TP4056 charger/MS, 3.3V buck regulator
2. Signal Conditioning Subsystem – RC low-pass filter (5 Hz cutoff) for EDA
3. Sensor Subsystem – EDA sensor, MAX86141 pulse sensor, LSM6DSOX gyroscope/accelerometer, TMP119 skin temperature sensor
4. Processing Subsystem – ESP32-C3 Super Mini microcontroller
5. Communication Subsystem – BLE 5.0 Wireless transmission.

The architecture shown in the detailed hardware flow Diagram in Figure 5 and implemented on the breadboard in concept 3 prototype figure 3.

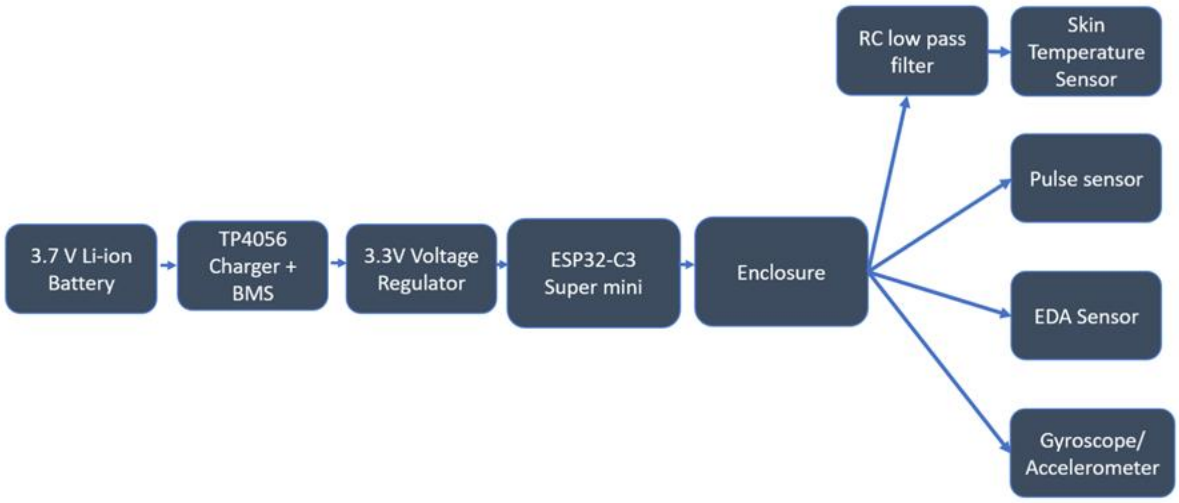

Figure 7: Electrical Architecture Overview

4.2.1 Power System Design

Battery Selection

A 3.7V 1000mAh Li-on cell was selected to meet the requirements of 6-8 hours of operation (IEC 62133-2). This capacity provides adequate energy storage while remaining light and thin enough for a wearable wristband.

Charging and Protection (TP4056 + DW01)

The TP4056 provides constant current/constant-voltage charging, overcharge protection, over-discharge protection, and short-circuit protection. These protections ensure compliance with IEC 62133-2 and IEC 60601-1 single fault conditions.

Voltage Regulation

A 3.3V buck regulator converts the variable battery output of (3-3.2V) to a stable SELV safe voltage for the ESP32-C3 and all sensors. The regulator is sized for ≥500 mA load, ≤ 50µA idle current which meets IEC 60601-1 SELV voltage limits and ensures stable analog sensor performance.

Power Budget

Estimated simultaneous draw

Component	Current
ESP32-C3 Super mini (Microcontroller)	40-80 mA
MAX86141 (Pulse sensor)	3-4 mA
LSM6DSOX (Gyroscope/Accelerometer)	1-2 mA
TMP119 (Skin temperature sensor)	<1 mA
Bio signal plux (EDA sensor)	2-4 mA
Idle Voltage Regulator	0.05 mA
Peak Total: ~80-90mA	

Table 3: Device Power Draw

Runtime estimate: 1000mAh / 90mA is about 11hours (meets specifications of 6-8 hours)

4.2.2 Signal Conditioning

Electrodermal activity is inherently low frequency to satisfy the shareholder's need of minimal noise and IEC 60601-1-2 electromagnetic disturbance requirement; the design includes a 5 Hz RC low pass filter.

RC Filter Calculation

$f_c = \frac{1}{2\pi RC}$ using R = 33k Ω and C = 1μF which makes

$$f_c = 4.82\ Hz \approx 5\ Hz$$

This suppresses motion-induced spikes, improves signal-to-noise ratio, reduces filtering load on software, and prevents high frequency artifacts.

4.2.3 Sensor System Design

Bio signal Plux (EDA sensor)

This sensor has medical-grade stainless steel AgCl electrodes, the hardware current limited to ≤ 10 μA which is required by IEC60601-1, can be mounted to the inner wrist band side.

It converts raw ADC value into EDA conductance using the formula

EDA(µs) =ADC2nx VCC0.12

$$EDA(\mu s) = \frac{\frac{ADC}{2^n} x\, VCC}{0.12}$$

where n is number of bits of the channel which the ESP32-C3 has 12 bits in the ADC Channel and VCC is 3.3V. The ADC is an analog signal read by the ESP32 microcontroller.

MAX86141 (Pulse Sensor)

This sensor provides heart rate and HRV, multiwavelength PPG, and we will use it for sympathetic and parasympathetic correlation.

LSM6DSOX (gyroscope)

It contains 3 axis accelerometers and 3 axis gyroscope which will detect motion artifacts for noise removal.

TMP119 (temperature sensor)

Digital high precision thermal feedback is used to differentiate emotional sweating vs thermoregulatory sweating.

4.3.4 Mechanical/Enclosure

Although the glove concept was explored, the final chosen form was the wrist band concept for comfort and reliability. The mechanical enclosure will be accomplished by fill in this part someone from mechanical

The mechanical design was developed to ensure comfort, safety, and durability. The full electronics housing remains under 80 g to meet ISO 9241 ergonomic limits, and all skin-contacting areas use breathable, ISO 10993–compliant textiles. The battery is insulated from the skin with foam and fabric, and wiring is strain-relieved through sewn channels to prevent pull-out during movement. EDA electrodes are placed on the underside of the wrist for stable contact, and sensors are spaced out to avoid bulk.

The enclosure protects the electronics from sweat, allows airflow for battery heat, provides an accessible USB-C charging port, and prevents cable stress during daily motion.

4.3 Deliverables

The goal of this project is to make a wearable tech device that using integrated sensors can reliably measure electrodermal activity wirelessly in real time so that researchers can analyze the phasic and tonic components of the bio signals to have a more defined view of how the brain works and learns. We will have a wearable wrist band that can measure electrodermal activity, skin temperature, heart rate variability, beats per minute, and uses the gyroscope, accelerometer, and the RC low pass filter to clean the raw signal for data analysis.

Codes Referenced

1. International Electrotechnical Commission. IEC 60601-1: Medical electrical equipment – Part 1: General requirements for basic safety and essential performance. 3rd ed. Geneva: IEC; 2012.
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2. Bari, Dindar S., Haval Y. Y. Aldosky, Christian Tronstad, and Ørjan G. Martinsen. “Disturbances in Electrodermal Activity Recordings Due to Different Noises in the Environment.” *Sensors*, vol. 24, no. 16, 2024, article 5434, https://doi.org/10.3390/s24165434. (mdpi.com)