UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

GRAINGER COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ECE445 Design Document

Real-time EEG Drowsiness Detection Device

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Chapter 1: Introduction

1.1 Problem Statement

Drowsiness is an extensive safety risk in shift-work, transportation occupations, or nighttime operations (eg, nurses, night-shift operators, and drivers). An estimate from the NHTSA says in 2017 reported 91,000 police-reported crashes, 50,000 injuries, and approximately 800 deaths involving drowsy drivers [1]. They also acknowledged these statistics are an underestimate of the impact of drowsy driving [1]. More recently, NHTSA reports on their website a total of 633 drowsy-driving-related deaths [1]. Surveys cited by the National Safety Commission show about 1 in 25 adults report of having falling asleep while driving in the past month [2], suggesting a much larger problem than factual surveys and reports can estimate.

In these situations where people may be subject to moments of fatigue or loss of focus, the consequences can result in catastrophic accidents. What if there is a device that can make sure we are alert at late hours or extreme exhaustion?

1.2 Solution

An electroencephalogram (EEG)-based drowsiness detector could be an assistive solution to these problems by continuously monitoring brain activity and alerting users at the onset of sleepiness. EEGs are a non-invasive medical device that measures brainwaves rather than relying on visual proxies such as blink rates, head positions or body posture. Our design integrates real-time EEG acquisition into a compact, wearable device capable of functioning with minimal obstruction to daily routines.

This technology is designed to constantly monitor the brain waves of the user and alert them back into consciousness when a change in pattern is detected. This bridges the gap between neuroscience and practical safety applications, offering a potentially life-saving tool in environments where attention is necessary.

1.3 Visual Representation

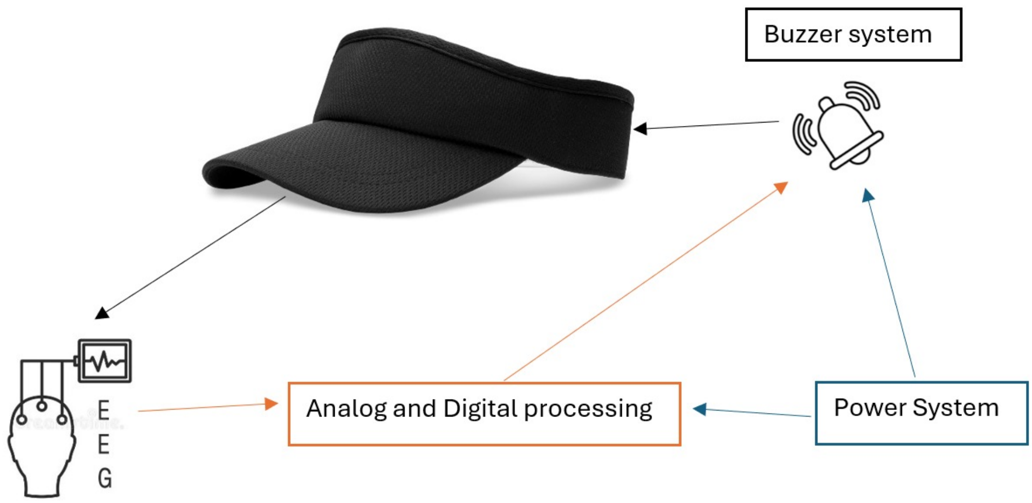

Figure 1.1: Visual representation of product

1.4 High Level Requirements

- **EEG acquisition:** The device must capture EEG signals with sufficient accuracy to reliably register events associated with drowsiness and microsleep. This can be tested through eye blinks which provide a detectable and significant voltage spike above baseline noise.
- **Real-time drowsiness detection:** The system must detect micro-sleeps or drowsiness with at least 90% accuracy and a false positive rate of <=2% when tested against open source data and user trials.
- **Prompt alerting:** The alert mechanism (buzzer) must activate within a timely manner <= 2 seconds) from the onset of detected drowsiness, measured by comparing EEG event timestamp with the output signal.
- **Wearability and safety:** The device must remain safe and comfortable for at least 8 continuous hours. We will verify this through randomly selected volunteers and quantify comfort through a number scale (1-5). For the product to pass, the average comfort level should be a 4/5.

Chapter 2: Design

2.1 Block Diagram

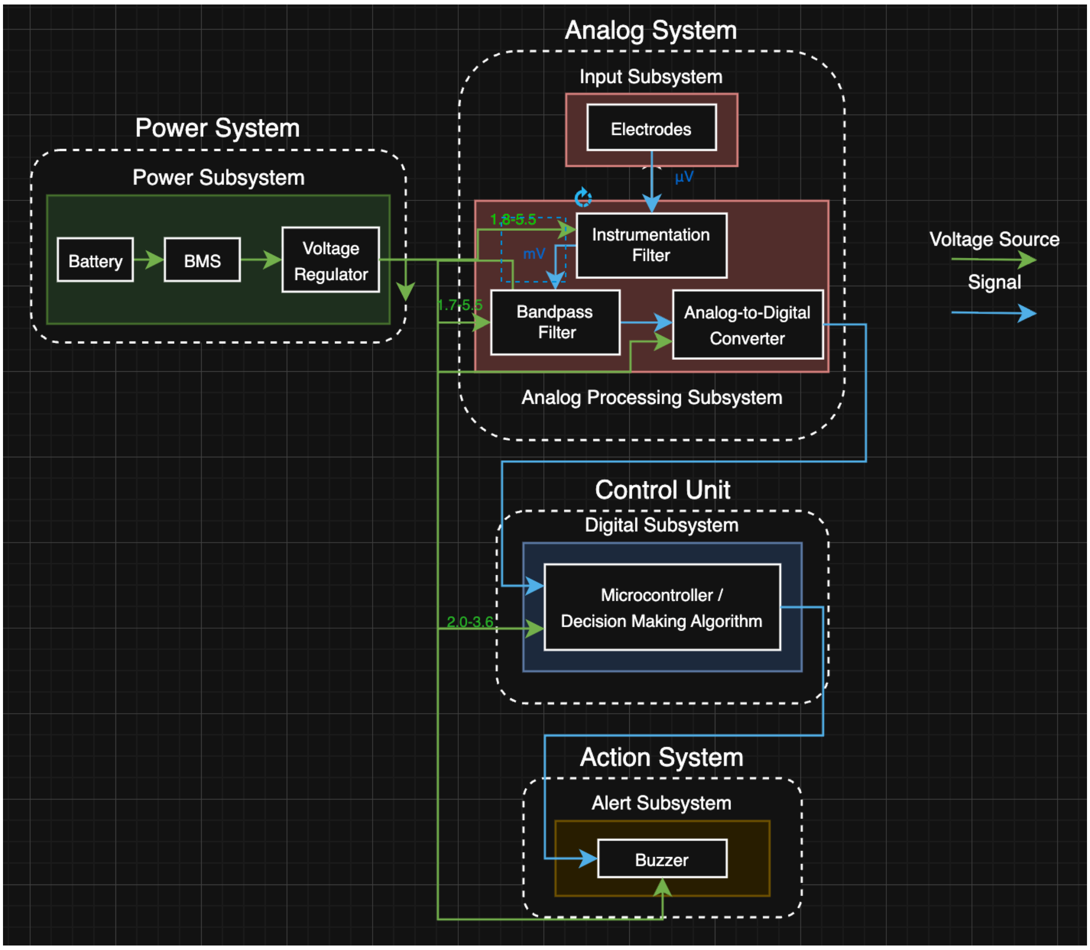

Figure 2.1: Block diagram of the system highlighting the subsystems and their interconnections

The block diagram highlights 4 main subsystems. The power subsystem, the signal acquisition subsystem, also labeled as the analog system, the control subsystem and the action sbusystem. The power subsystem powers the system as whole, with a battery, a battery management system(BMS) and a voltage regulator. The signal acquisition subsystem is comprised of electrodes and an analog-to-digital converter(ADC). The electrodes picks up the signal from the person and the ADC processes the signal, making it suitable for the next step, the digital processing. The digital processing is mainly done by the STM32F412RGT6. It uses specific algorithms to carry out the decision-making process, finalizing whether the buzzer needs to be sounded or not. Eventually, the buzzer will be activated to make noise by the STM32F412RGT6 when it detects microsleeps or drowsiness.

2.2 Subsystem Overview

2.2.1 Power System

The power system consists of a Lithium-Polymer (Li-Po) battery integrated with a Battery Management System (BMS), a boost converter and a buck converter. Li-Po batteries were chosen due to their high energy denThe power system consists of a Lithium-Polymer (Li-Po) battery integrated with a Battery Management System (BMS), a boost converter, and a buck converter. Li-Po batteries were chosen for their high energy density, light weight, and compact form factor, allowing the battery ($34.5 \times 51 \times 6.3$ mm, W×L×H) to fit seamlessly into the headband design. The nominal voltage of 3.7 V (operating range: 3.2–4.2 V) is compatible with most components, and the minimum capacity of 3600 mAh provides a battery life exceeding 8 hours. The battery is rechargeable and designed for easy replacement. While Li-Po batteries offer many advantages, they are sensitive to high temperatures and can be damaged by overcharging or over-discharging. This is where the BMS comes into play.

The BMS ensures safe operation by keeping the battery within its rated operating region, limiting both charging and discharging currents. The cascaded LM317 regulator restricts the current flowing into and out of the battery, while the BD140 transistor functions as a switch that disconnects the supply once the battery reaches its rated peak voltage of 4.2 V. At this point, the excess power is diverted to the diodes, lighting up an LED to signal that the battery is fully charged. A USB-A module is included to provide users with a convenient charging interface. A 1 A fuse and a capacitor are added near the input to suppress large current spikes and protect the circuit and power supply.

Additionally, a voltage regulation stage is implemented to provide the necessary voltages for the STM32F412RGT6 and ADS1299. The ADS1299 requires a 5 V analog rail and a 3.3 V digital rail, while the STM32F412RGT6 and the buzzer are both powered at 3.3 V. To achieve this, a boost converter steps up the nominal 3.7 V battery voltage to a stable 5 V, followed by a buck converter that steps it down to 3.3 V. This configuration ensures both required voltages are supplied with improved efficiency and stability.

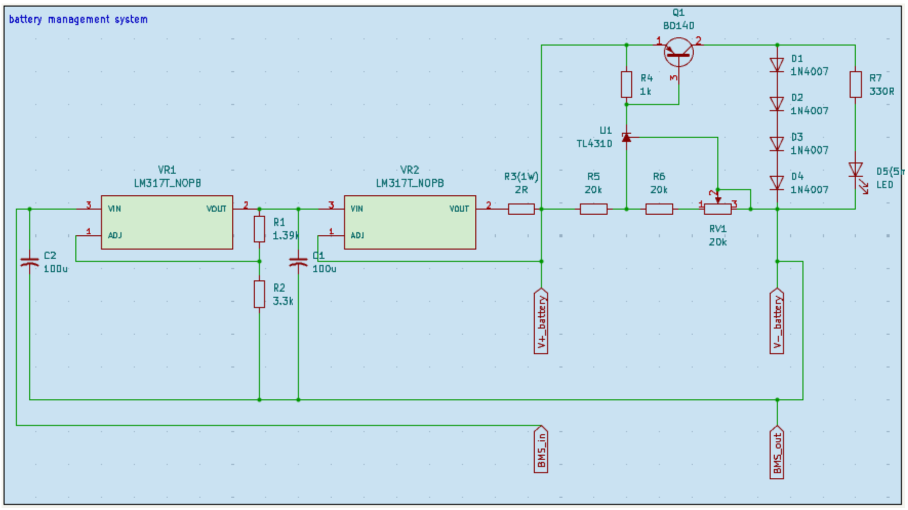

Figure 2.2: Battery Management System

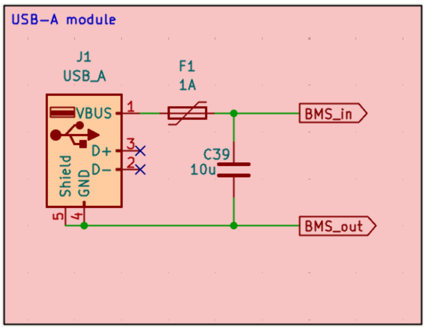

Figure 2.3: USB-A

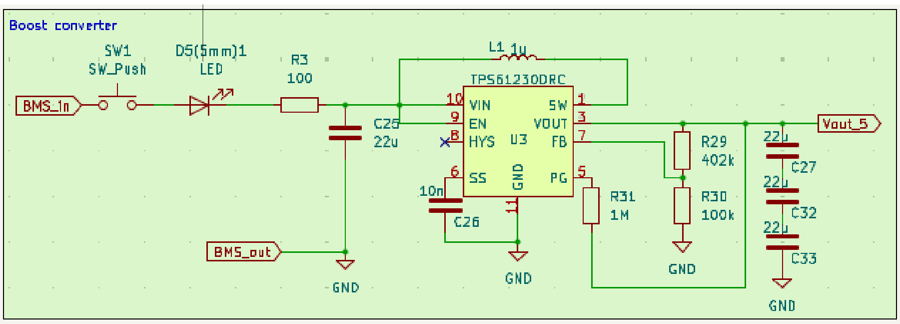

Figure 2.4: Boost converter

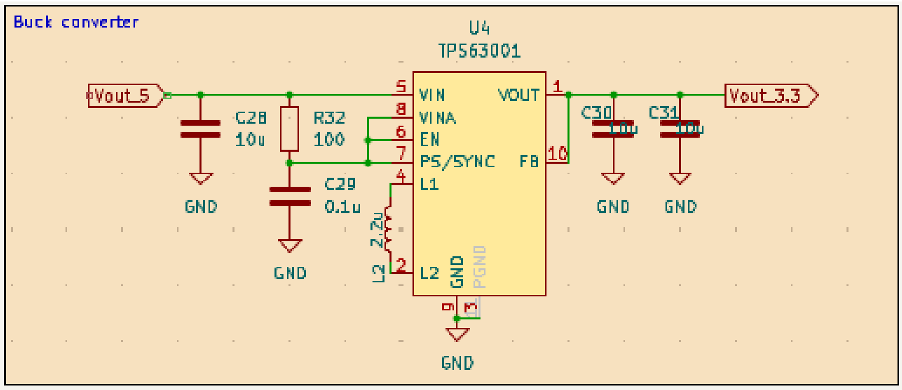

Figure 2.5: Buck converter

Requirements	Verifications	Success Criteria
Provide a minimum of 8 hours of continuous operation	• Power the system with just fully charged battery • Record how long before battery voltage drops below 3.2V	• The recorded time is more than 8hrs.
Maintain regulated voltage of 3.3V and 5V	• Observe 3.3V and 5V signals on the oscilloscope. • Record maximum and minimum of signal	• Signal minimum and maximum do not exceed 5% of signal.
Charge the battery to 4.2V	• Charge battery using USB-A • Record voltage across battery terminals after LED lights up	• The voltage recorded is between 4.1 to 4.2V

Figure 2.6: Requirements, Verifications and Success Criteria for Power system

2.2.2 Signal Acquisition

The signal acquisition subsystem is composed of reusable EEG electrodes, snap electrode cables, and a bio-potential-specific analog-to-digital converter (ADC), the ADS1299. The electrodes chosen are flat snap EEG electrodes (TDE-202), which are inexpensive, reusable, and widely adopted for non-medical EEG applications. They provide a reasonable trade-off between cost and signal accuracy. The flat snap lead wires are lightweight, well-shielded, and can be integrated neatly into the headband design. The acquired EEG signal is filtered using a first layer of RC filters that filter any frequency above $24Hz$ chosen using the given equation 2.1 before being supplied to the analog-to-digital converter, ADS1299.

$$f_{cutoff} = \frac{1}{2\pi R_{eff} C_{eff}} [Hz] \tag{2.1}$$

The ADS1299 is designed to accurately measure small bio potential signals such as EEG by minimizing external interference and common-mode noise. It features high common-mode rejection through its differential input amplifiers, which effectively cancel out noise that appears equally on both inputs, such as power line interference from the 60 Hz mains supply. Additionally, the ADS1299 includes an internal bias amplifier that computes the average of all electrode voltages, inverts this signal, and drives it back into the body through the bias electrode. This feedback loop actively stabilizes the body's potential and reduces common-mode noise before it even reaches the ADC inputs. Together, these mechanisms ensure that only the true differential EEG signals—primarily in the 0.5–13 Hz range—are preserved, while unwanted high-frequency or common-mode noise is strongly suppressed, resulting in a cleaner and more accurate neural recording.

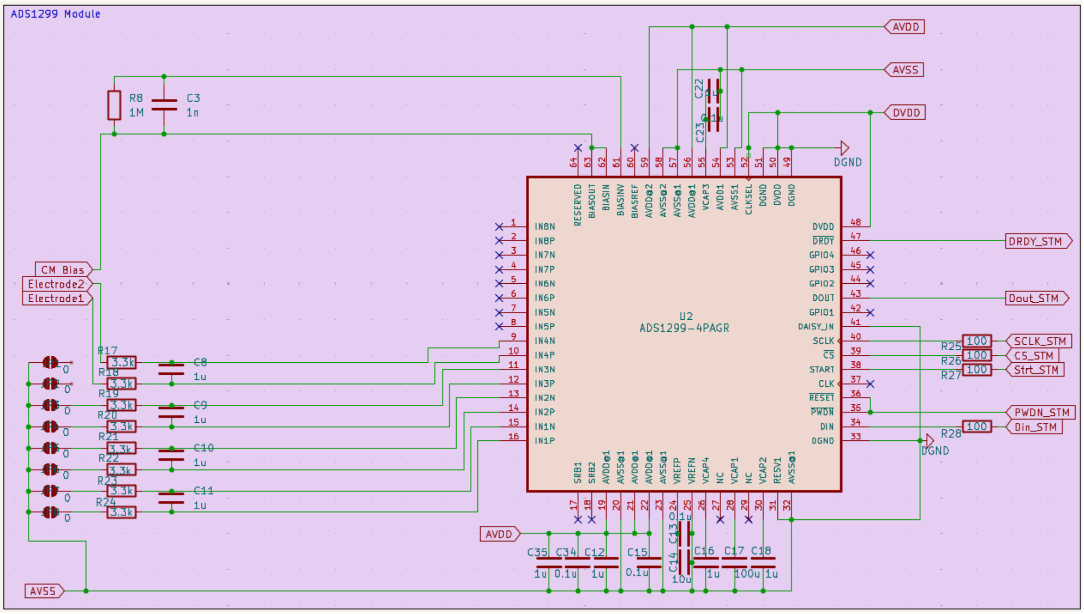

Figure 2.7: ADS1299 Module

Requirements	Verifications	Success Criteria
Accurately capture EEG signals in the 0.5–13 Hz range	• Provide sinusoidal signals of frequencies from 0 to 60Hz. • Record the peak voltage	• Signal attenuation past 20Hz is more than 30dB (1:1000 ratio) • Signal attenuation past 50Hz is more than 100dB (1:100000 ratio)
Amplification of the input signal by 10^3 with minimal distortion	• Provide sinusoidal signals in microvolt range • Record the peak output voltage	• The output-to-input ratio is around 1000.
Digital conversion occurs at over 240 Hz to prevent aliasing and maintain signal integrity.	• Probe the active low DRDY pin of ADS1299 during operation • Measure the period of the obtained signal	• The sampling rate is the inverse of the period obtained.

Figure 2.8: Requirements, Verifications and Success Criteria for Signal Acquisition System

2.2.3 Controller

The controller system is a microcontroller that ingests digital EEG samples from the ADS1299, executes our real-time processing and decision algorithm, and alerts the Alarm system (buzzer) based on the drowsiness detection. Upstream, it will interface to the ADS1299 via SPI (Serial Peripheral Interface) with data-ready interrupts and control sets. Downstream, it outputs a GPIO (General Purpose Input/Output) control signal to the buzzer. Internally, it will perform digital signal processing such as band-pass filtering, windowing and heuristic decision making.

We will be using the STM32F412RGT6 chip for our microcontroller. We chose this chip as it's a well-supported Cortex M4 with tons of open-source examples, STM32CubeIDE libraries, and clear documentation. Its fast and relatively low risk to develop in our short time frame. It has no WiFi/ Bluetooth (which is good for EEG safety and privacy) and has plenty of flash and RAM memory (1MB/256KB respectively). These all make it a perfect chip for real-time DSP and keep our product isolated from outside sources for better privacy and safety of users.

The schematic below shows our design. The STM chip connects to the ADS1299 via a standard link and 'data-ready' line to make sure data is only read when new samples are available. It also provides clock signals for the ADS through SCK. For our alarm system, the chip provides a simple GPIO output to the active buzzer to play a tune when drowsiness is detected. Our breadboard demo demonstrated the high volume and effectiveness of the buzzer sound through a nucleo board. Through STM32Cube software, we can produce any type of single-tone tunes and beats which will be tested later in the future. Power is provided from the battery system with a 3.3V line. Decoupling capacitors will be placed all around the microchip.

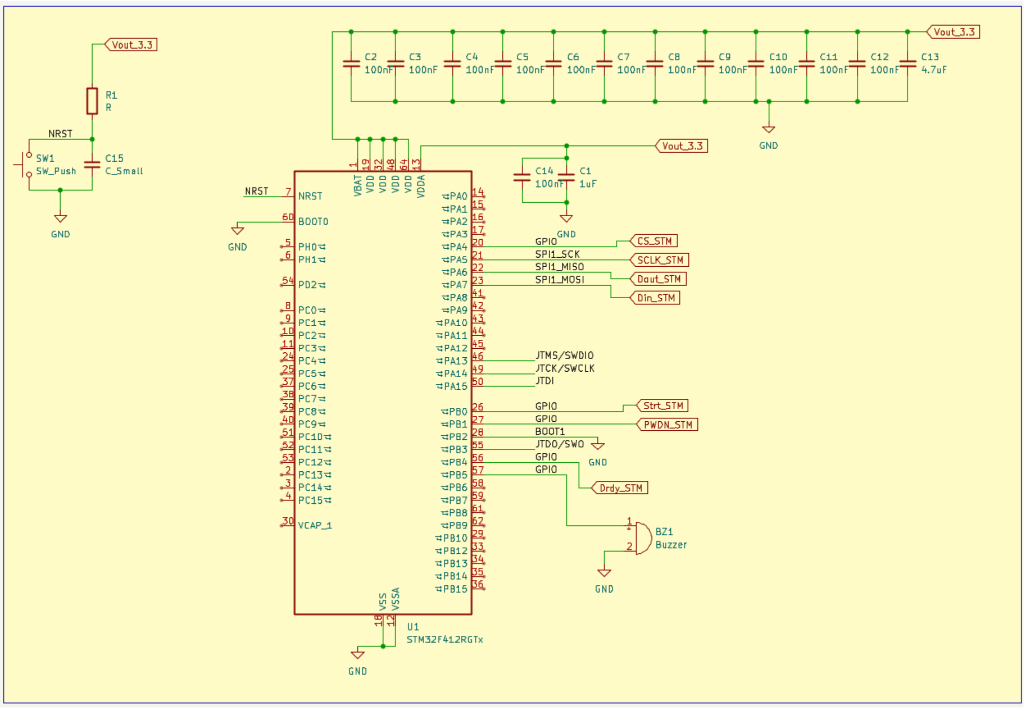

Figure 2.9: STM32F412RGT6 schematic

Requirements	Verifications	Success Criteria
MCU operates at 3.3V +-5%	• Use lab power supply and scopy • Measure using oscilloscope probes	• Observe no abrupt resets or trips • No flags by debug registers
Take every DRDY signal from ADS1299 at at least 256 samples per second (0 sample drops)	• Run for 5 minutes with data stream from ADS1299 • Measure overruns on software	• Overrun count = 0 after 5 minutes
Processing latency including DSP and decision making should be less than 2 seconds	• GPIO connection can be toggled on and off between process windows	• Low to high pulse on GPIO should be less than 2 seconds

Figure 2.10: Requirements, Verifications and Success Criteria for microcontroller

2.2.4 Alarm System

The alarm system uses a small and low-power active piezoelectric buzzer to alert the user when the device detects drowsiness. Since the buzzer can be placed close to the ears, it does not require large voltages to produce loud noises; instead, a smaller voltage is enough for a loud and alerting tune. This design reduces user discomfort and helps conserve battery power.

The MCU controls the buzzer through a GPIO pin, sending a signal to the buzzer as soon as the algorithm detects any drowsiness or micro-sleep. The piezoelectric buzzer is rated to draw 15 mA of current at 3.3 V. We aim to operate the buzzer at lower voltages, hence lower power consumption and longer battery life.

Requirements	Verifications	Success Criteria
Survive at least 1000 alert cycles with no degradation of volume or tone	• Automated cycling through STM software • Simple test script and power supply	• No drops in volume, audibility and tone frequency
System current draw is less than 15mA	• Measure current during a tune pattern (eg 10 150ms beeps) • Use power supply and Ammeter	• Meets the current limits stated

Figure 2.11: Requirements, Verifications and Success Criteria for buzzer

2.3 Tolerance Analysis

The decision algorithm is arguably the most important yet the most vulnerable to errors during use. Mains or motion noise, short sample windows, or timing jitter can cause an alert to be flagged as drowsy(false negative) or passed on as normal signals(false negative). Timing inconsistencies or overrunning data in the microcontroller can misalign the samples and further increase error rates. To fix these issues, we add band-pass filtering, feed 1 second windows at 256 Hz, and a bounded compute time to avoid overrun of data. We will also use temporal voting (approximately 5 windows) with hysteresis to make decisions ensuring stability, reliability and safety.

In addition to the digital subsystem, there are other sources of false positive/negatives. Eye blinks, poor electrode contact, head turns, chewing, or sudden posture changes could potentially cause false positives. On the other hand microsleeps caused by slow eye closure and coffee/stimulants that could affect baseline signals, can cause false negatives. To fix this, we can run calibration phases in the beginning when the user is alert to store baselines, temporal voting like mentioned above and quality checks for windows to ensure proper contact for the EEG signal.

Chapter 3: Cost and Schedule

3.1 Cost Analysis

Labor Costs	Column1	Column2	Column3	Column4	Column5	Column6
Team	**Salary by major**	**Hourly**	**Hours per Week**	**Weeks worked**	**Total Cost**	
Nikhil Talwalkar	CE ($92,430)	44	8	6	2,112	
Senturran Elangovan	EE ($76,079)	37	8	6	1,776	
	$84,254	41	8	6	1,944	**Average**
					3,888	**Total Costs**
Part Costs						
Description	**Manufacturer**	**Part Number**	**Quantity**	**Unit Cost**	**Total Cost**	
Micrcontroller	STMicroelectronics NV	STM32F412RGT6	1	7.76	7.76	
ADC and signal filter chip	Texas Instruments	ADS1299	1	39.31	39.31	
Battery Charger	Analog Devices INC	LT3652	1	9	9	
Electrodes	Florida Research Instruments	TDE-202	15	0.53	7.95	
Electrode Connectors	Florida Research Instruments	TDE-205XX	3	5.45	16.35	
Buzzer	Hyuduo	B082R4S4N8 (ASIN)	10	8.56	8.56	
Nucleo Dev Board	STMicroelectronics NV	STM32F411RE	1	29.38	29.38	
Battery	MakerFocus	B0DK5BBKM5 (ASIN)	2	15.99	15.99	
USB Solder Jacks	E-outstanding	B08XJN956J (ASIN)	10	6.99	6.99	
					6.99	**Shipping**
					148.28	**Total Costs**
				Final Costs:	**4,036**	

Figure 3.1: Costs table

The table above goes through the total costs of our project. We averaged out the hourly rate by researching the average salary for a computer and electrical engineer from UIUC (around $84,000). We estimated an average of 8 hours per week with 6 weeks remaining in the project schedule. We recognize that our part costs have exceeded our $100 (2 partner) UIUC budget with the ADS1299 chip and Nucleo Dev Board being the most expensive components. However, both are crucial for our projects performance and testing capabilities.

3.2 Schedule

Week of	Tasks
13-Oct	Design Document
	Order hat and finalize machine shop parts
	Finalize PCB for second pass
	Order additional parts for PCB if needed
20-Oct	Breadboard testing with electrodes
	Test BMS, buck and boost converters
	DSP on STM chip
27-Oct	Software work for STM chip
	Testing Electrode signals
3-Nov	Receive PCB
	Assemble PCB parts
	Assemble hat
10-Nov	Testing of each subsystem
	Finalize STM chip connections and firmware
	Test functionality
17-Nov	Testing phase
	Test comfort, durability, battery usage, extreme conditions
	Finalize for demo

Figure 3.2: Schedule

Chapter 4: Ethics and Safety

4.1 Ethical Guidelines

Our device is meant solely as an assistive aid to prevent loss of focus and microsleep. It is not a replacement for preparation and safe practices that help prevent loss of focus during hazardous situations, such as night-time driving conditions. This is in line with IEEE Code of Ethics 7.8.I.1 and ACM 1.1 [3] [4]. Our product will clearly list limitations in accuracy and any false negative/positive rates in line with IEEE Code of Ethics section 8.8.I.5 and ACM 1.3 [3] [4]. Regarding privacy and confidentiality, any EEG data used from volunteers during the development of the product is purely for research purposes and enhancement of our decision algorithms. In line with ACM 1.6 and 1.7, any EEG data received will be kept confidential, provided the person's consent is obtained [4]. Regarding fairness and non-discrimination, we will validate our product's performance across all skin tones, head sizes, hair types, etc., in line with ACM 1.4. We will document any disparities in performance and adjust our product accordingly before the final demo [4].

4.2 Safety Measures

Our device will be built with user safety as the foremost priority. As this is a wearable that involves direct skin contact and battery-powered electronics, the following safety measures have been taken into consideration:

4.2.1 Battery safety

The lithium polymer battery with a Battery Management System (BMS) that provides safe battery usage, such as short-circuit, charge, and discharge protection. The device will never charge while being used to eliminate any direct mains risk.

4.2.2 Electrode safety

Our device uses passive surface electrodes, which are inherently safe and do not apply current to the skin. To ensure user comfort, we will be testing for any potential skin irritation or sensitization during extended wear. Clear instructions will be provided on cleaning practices, recommended maximum wear time, and the use of skin-safe creams or preparation practices in the rare case such symptoms are found during testing.

4.2.3 Performance Safety

In alignment with our product's intended purpose as an assistive aid and not a medical device, we clearly state that it is intended to help users maintain focus but should not be relied upon as the sole measure for preventing drowsiness. All limitations in accuracy, including false positive (alert without drowsiness) and false negative (drowsiness not detected) rates, will be communicated transparently to users. We reiterate that the device cannot replace proper rest or safe practices.

4.2.4 Lab Safety

During design, development, and testing of our product, we will adhere to the strict UIUC and ECE445 lab safety policies. All soldering for the PCB will be performed in the lab, with proper eye protection and fume absorbers. Any EEG data collection with volunteers will be conducted with informed consent and the right to withdraw from the test at any time.

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