UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

GRAINGER COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ECE445 Project Proposal

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

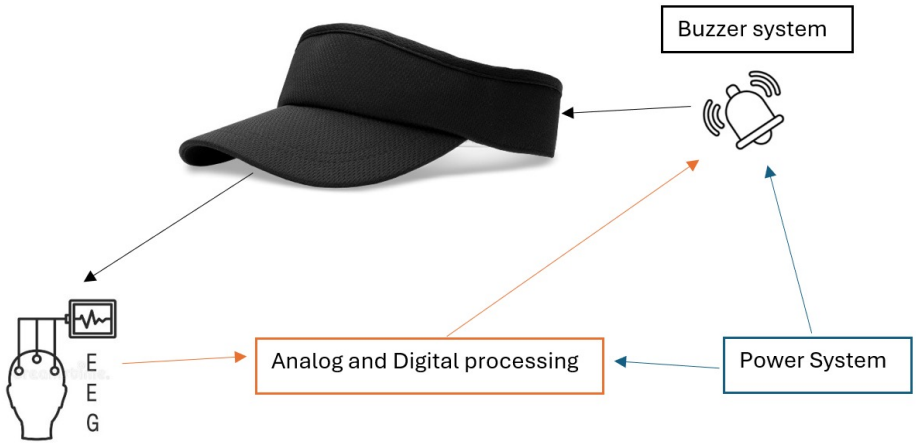

Figure 1.1: Visual representation of product

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

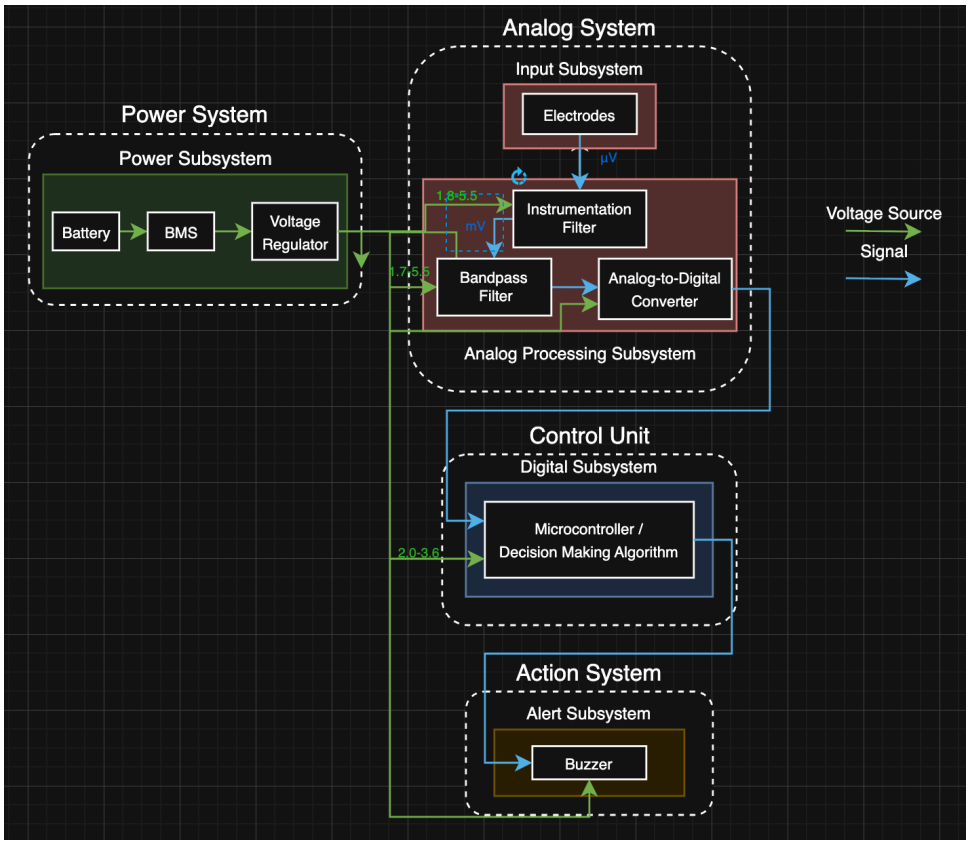

Figure 2.1: Block diagram of the system highlighting the subsystems and their interconnections

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). Li-Po batteries were chosen due to their high energy density, light weight, and compact form factor, allowing the battery (34.5 × 51 × 6.3 mm, WxLxH) to fit seamlessly into the headband design.

The nominal voltage of 3.7 V is compatible with most components, and the minimum capacity of 1000 mAh provides a battery life exceeding 12 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. The BMS ensures safe operation by keeping the battery within its rated operating region.

Additionally, a voltage regulator may be necessary to ensure that the supply voltage meets component requirements. For instance, the STM32F2xx/F4xx microcontroller has a maximum operating voltage of 3.6 V, so the 3.7 V battery must be regulated to safely power it.

Requirements:

1. Provide a minimum of 12 hours of continuous operation.
2. Maintain regulated voltage between 3.3 V and 3.6 V.
3. Fit within headband dimensions of $34.5 \times 51 \times 6.3$ mm.

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 ADS1229. 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 tradeoff 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 then fed to the ADS1229. This chip provides high common-mode rejection, rejecting noise that appears equally on both inputs through its differential amplifier. Power-line interference at $60Hz$ and low-frequency drift below $0.5Hz$ are filtered out. The filtered signal, spanning 0.5–$40Hz$, is amplified by a factor of 10^3 and converted into a digital signal for the microcontroller.

To ensure signal integrity, the sampling frequency must exceed twice the highest signal frequency over $80Hz$ to avoid aliasing. In practice, a sampling rate of $240Hz$ is used to preserve signal details. Although the ADS1229 incurs a higher cost, it simplifies the signal conditioning process and significantly improves signal accuracy, supporting more reliable drowsiness detection.

Requirements:

1. Accurately capture EEG signals in the 0.5–$40Hz$ range.
2. Amplification of the input signal by 10^3 with minimal distortion.
3. Reject power-line interference at $60Hz \pm 1Hz$ and signals below $0.5Hz$.
4. Digital conversion occurs at over $240Hz$ to prevent aliasing and maintain signal integrity.

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, and possibly UART/USB

logging for testing and analysis. Internally, it will perform digital signal processing such as band-pass filtering, windowing and heuristic decision making. The next case of the algorithm will be an ML based classification using TinyML.

Requirements :

1. Controller must operate within 3.3 V ± 5 % (Max voltage is 3.6 V)
2. Must computer a binary score (0-1) per sample window so the buzzer is asserted properly
3. MCU must enter sleep/stop mode between windows or there is a risk of exceeding battery targets

2.2.4 Alarm System

The alarm system uses a small and low-power 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 softer, sharper noise. This design reduces user discomfort and helps conserve battery power.

The MCU controls the buzzer through GPIO pins, 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 12 V. We aim to operate the buzzer at lower voltages, hence lower power consumption and longer battery life.

Requirements:

1. The buzzer must alert the user immediately upon detection of drowsiness, with activation delay under 100ms.
2. The buzzer must be loud enough at a low voltage compatible with the MCU GPIO output.
3. The buzzer must remain reliable over multiple activations.

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 ovverun 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: Ethics and Safety

3.1 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].

3.2 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:

3.2.1 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.

3.2.2 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.

3.2.3 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.

3.2.4 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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