Electroencephalogram Alarm Project:

High Level Design

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1 Introduction

Only sixteen percent of American adults report not feeling tired at all during the regular week. Daytime sleepiness can be caused by a variety of pathophysiologies; however, in some people it is simply due to waking up during certain stages of sleep. Many people hate the feeling of waking up when their alarm sounds. This is partly because they do not set alarms based off of their sleep cycles – they set them based off of when they need to wake up. This can lead to alarms going off while a person is in deep sleep which can cause symptoms of daytime drowsiness regardless of the fact that the person got their targeted number of hours of sleep needed last night.

2 Problem Statement and Proposed Solution

2.1 Problem Statement

United States adults need a personalized, comfortable, and high tech alarm system because waking up in the incorrect sleep cycle can lead to daytime sleepiness, less attention to detail, and worse mood.

2.2 Proposed Solution

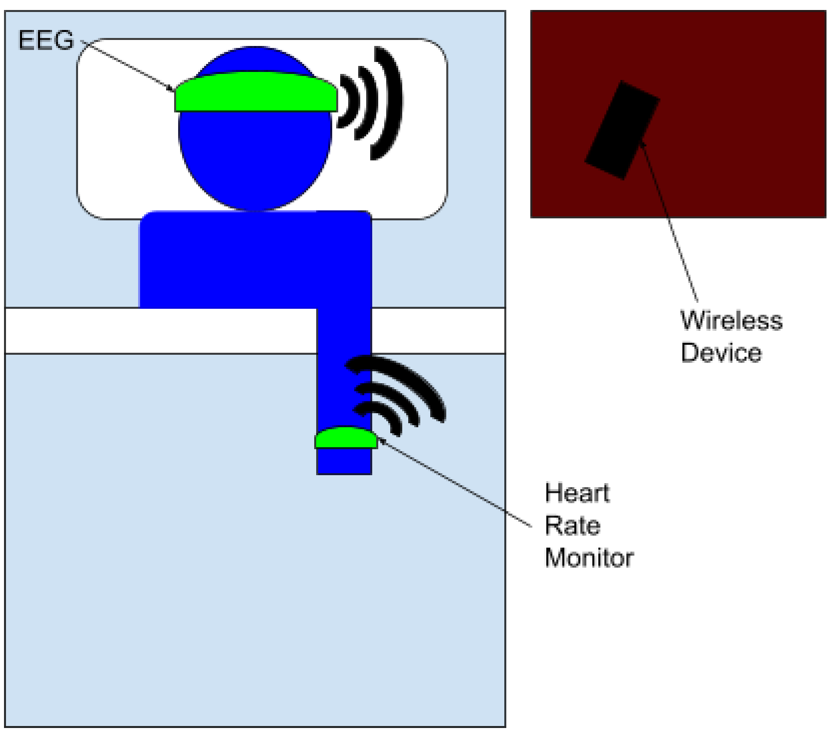
By tracking a person's sleep throughout the night to determine what stage of sleep they are in, an alarm system can ensure the user is not, whenever possible, awoken during slow wave sleep, or deep sleep. By using an electroencephalogram (EEG), the system can have insight into the user's current sleep stage. Typically, EEG's are performed by having the person wear a large, clunky headpiece with many wires extending from the headpiece to the complementary machinery. This would be extremely uncomfortable and unrealistic to use during sleep on a nightly basis. Because this solution is only providing insight into sleep stages and a couple of other key health metrics, only a handful of electrodes are needed instead of the vast array typically used by EEG devices. The electrodes will be placed within a flexible headband that minimizes irritation and ensures comfort during sleep. The need for wires can also be eliminated by using Bluetooth or Wifi to send data to a phone or computer. On the phone app or website, the user can input a time range they are okay with their alarm going off. Then, while the user sleeps, the device records what sleep stage a person is in and sets the alarm off when the person is not in deep sleep, avoiding the problem of daytime drowsiness from waking up during deep sleep. If the person remains in deep sleep throughout the entire desired wake up range, then the alarm will sound at the end of the period to ensure the user wakes up for their responsibilities that day, but the system will warn them that they woke in deep sleep and suggest a cup of coffee.

3 System Requirements

The necessary features of this system include EEG capabilities, heart rate monitoring, wireless communication, comfortable, non intrusive headband and wristband, and a user interface on a wireless device. The requirements of the EEG feature include converting brain signals into electrical signals and correctly decoding the signals to determine sleep stage. The heart rate monitoring feature requirements are sensing the fluctuations of blood flow in the user’s wrist, converting those fluctuations into an electrical signal, and decoding those signals into a heart rate. The requirements for the wireless communication feature include transmitting the earliest and latest wakeup times from the wireless device to the ESP32, transmitting the heart rate data from the wristband to the ESP32, and communicating the signal to the wireless device to set off the wake up alarm. This feature will require the headband, wristband, and wireless device to have bluetooth/WiFi capabilities. The comfortable, non intrusive headband needs to hide the electrodes, microcontroller, and wires in an aesthetically pleasing and comfortably fitting manner. Similarly, the wristband needs to hide the heart rate monitor and wireless transmitter in an aesthetically pleasing and comfortably fitting manner. The user interface is required to prompt the user to enter earliest and latest wakeup times, present current and average heart rate, present current or latest sleep stage, present time spent asleep, and do so in an aesthetically pleasing manner. A successful project would do all this in a space and data efficient manner.

4 System Block Diagram

4.1 Overall System



The overall system consists of 4 main subsystems: the EEG sensors, the heart rate sensors, the alarm, and the internet of things. The microcontroller(s) will be in charge of decision making and wireless communication over Bluetooth, WiFi, or both. Both the EEG and heart rate subsystem's power will be supplied by a battery.

4.2 EEG Subsystem Description and Requirements

The EEG Subsystem is the portion of this project that will detect and analyze the electrical signals in the brain in order to determine the user's current sleep stage. Requirements for this subsystem include:

- Sensitive to signals from user's brain
- Correctly diagnoses sleep stage
- Does not interfere with user's comfortability during sleep

An overview of the subsystem can be found below in Figure 1.

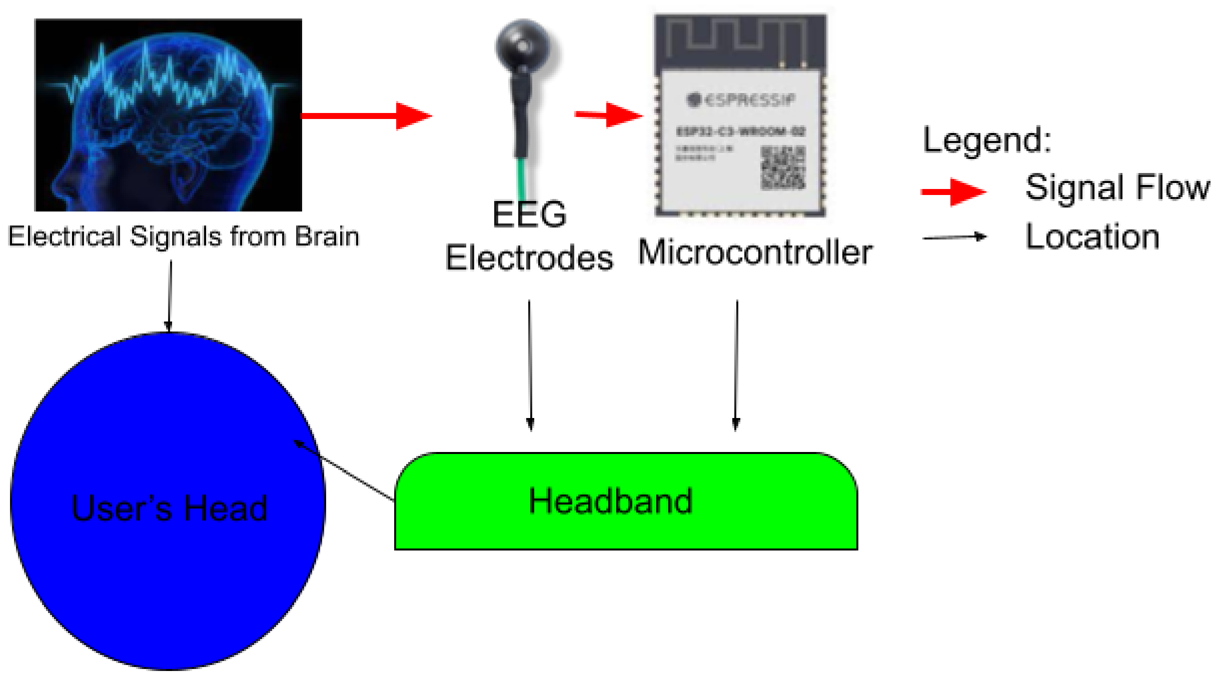


Figure 1. EEG subsystem block diagram

4.3 Heart Rate Monitor SubSystem Description and Requirements

The Heart Rate Monitor Subsystem is the portion of this project that will detect and analyze the fluctuating blood flow in the wrist in order to determine the user's current heart rate. The requirements for this subsystem include:

- Sensitive to signals from user's wrist
- Correctly diagnoses heart rate
- Does not interfere with user's comfortability during sleep

Figure 2 provides an overview of the heart rate subsystem.

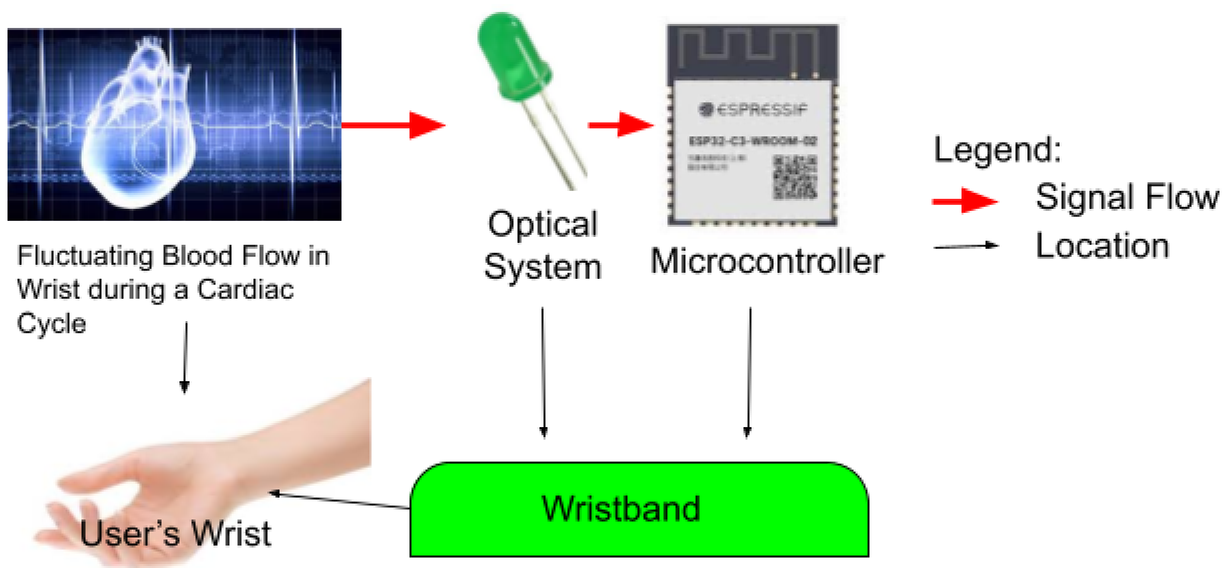


Table 2. Heart rate monitoring subsystem block diagram

4.4 Alarm SubSystem Description and Requirements

The Alarm Subsystem is the portion of this project that will alarm the user based on the signals that come from the other users. The requirements for this subsystem include:

- Audible alarm from wireless device
- Alarm during the correct sleep cycle
- Alarm during the desired time period

Figure 3 shows a block diagram of this subsystem.

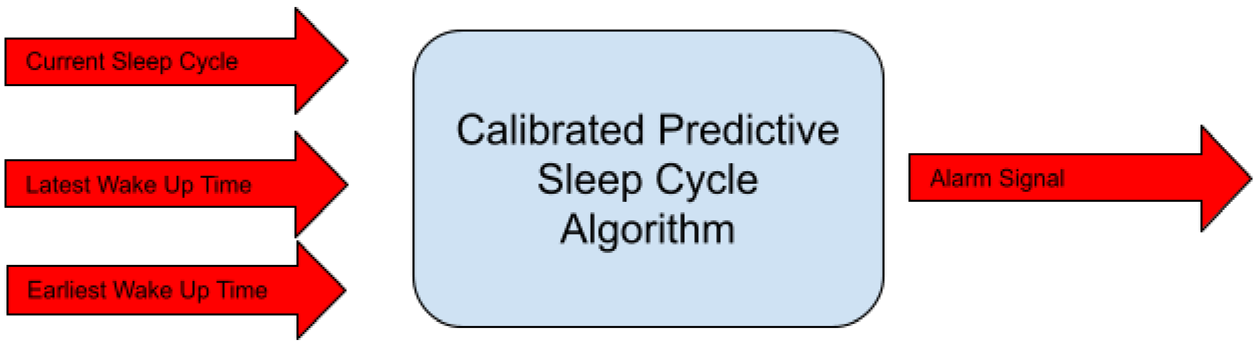


Figure 3. Block diagram of the alarm subsystem.

4.5 Internet of Things System Description and Requirements

The Internet of Things Subsystem is the portion of this project that will facilitate the communication between subsystems and other devices. The requirements for this subsystem include:

- Accept user input on desired wake up time period on wireless device display
- Communicate user inputs to microcontroller
- Communicate heart rate to wireless device display
- Signal Alarm application to set off alarm

Figure 4 shows a block diagram of this subsystem.

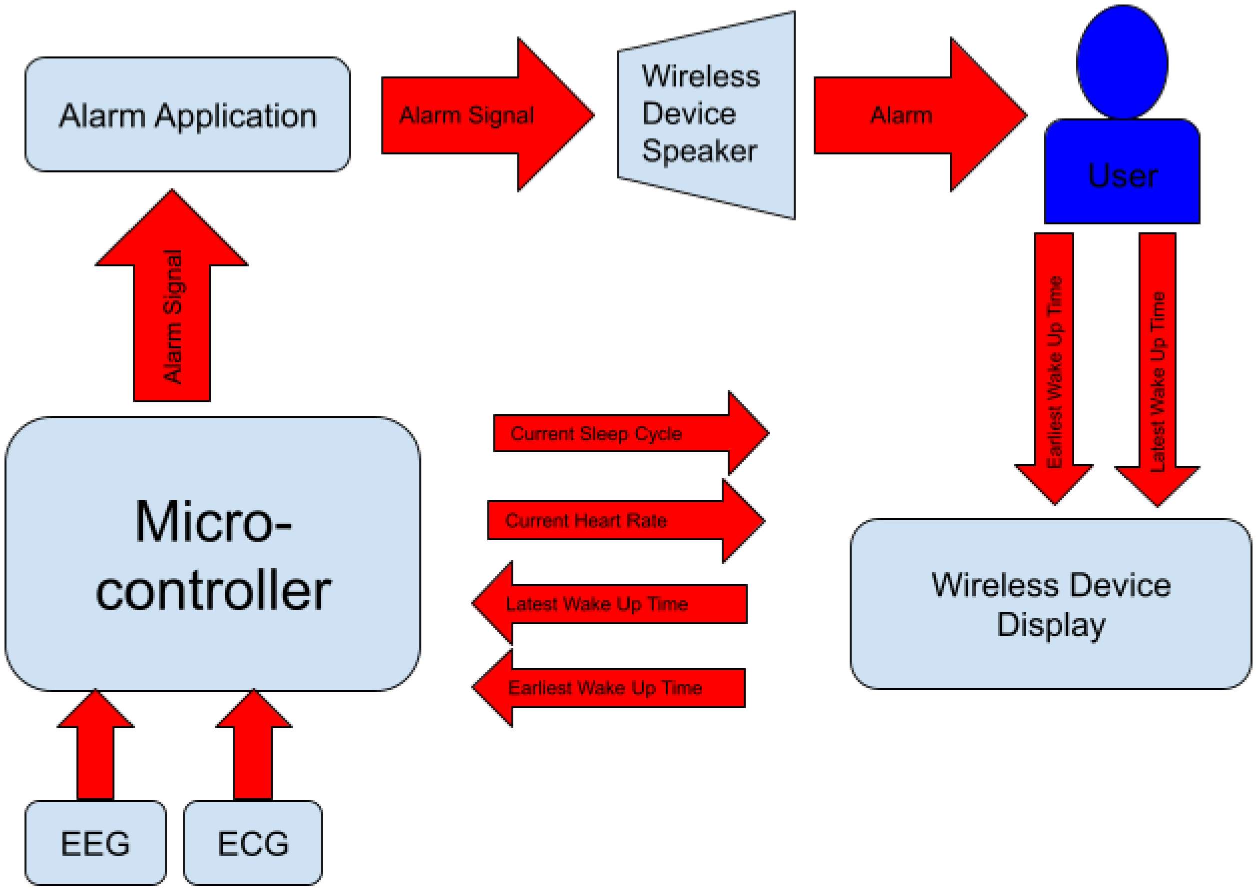


Figure 4. Overview of the Internet of Things Subsystem.

4.6 Future Enhancement Requirements

There are numerous enhancements that could be made in the future. For example, more EEG leads could be added so that the overnight EEG data is holistic enough that it could be given over to a clinician who can interpret more information on a user's sleep health. There could also be a way to integrate the EEG and heart rate devices into one, potentially by measuring blood flow somewhere on the head. Finally, it would be a great future enhancement to create an iOS compatible app to make the whole user experience more integrated with one's Apple phone.

5 High Level Design Decision

5.1 EEG Subsystem

Fundamental to this product is its ability to determine what stage of sleep the user is in. To accomplish this, an array of electrodes will be placed along the user's cranium to acquire an EEG in addition to an electrooculogram (EOG) lead that will record eye movements. It is unclear at this point just how many electrodes will be needed until further work is done. After obtaining the biopotential analog signal, it must be converted into a digital signal using an analog to digital converter then that digital information can be read by the ESP32. To determine what stage of sleep the user is in, the ESP32 will perform digital signal processing on the EEG data and obtain heart rate information from the heart rate monitor.

5.2 ***Heart Rate Monitoring Subsystem***

Heart rate is a vital piece of information when determining what stage of sleep a person is in as well as another piece of data that is important when monitoring the health of an individual. To acquire heart rate information, there will be a device the user wears on his or her wrist during the night. To determine heart rate, R peak detection will be employed by using a green LED alongside a photodiode that will be able to measure changes in blood flow in the wrist vasculature.

5.3 ***Alarm Subsystem***

Because the goal of this project is to allow users to wake up at an optimal time to reduce daytime drowsiness, there must be an alarm that will cause the user to wake up. There must be an option for the user to input a range of times he is willing to have his alarm go off. For example, if a user needs to wake up no later than 6:30 am, he will input that time and the alarm will go off sometime in a set range - such as from 6 am to 6:30 am - depending on when in that range is the optimal time for the person to wake up based on the user's brain activity.

5.4 *Internet of Things Subsystem*

Since this product consists of three separate devices: the headband, the heart rate wristband, and the user's wireless device, they all need to communicate with each other. Since they are in close proximity to each other, bluetooth can be used; however, they could all communicate over WiFi on a local web server where the user can access his sleep data from the night before. More research will need to be done to determine which is the best solution.

6 Open Questions

- How will the three separate devices communicate with each other? Is bluetooth or WiFi best?
- Could we run an R peak-to-peak detection algorithm on the EEG signal to determine heart rate instead of needing to use a separate optical system?
- How many leads are necessary for this project, and what are the exact electrode locations that are optimal for this device?

7 Major Component Costs

ESP32 C3 WROOM	$1.95
Instrumentation Amplifier	$12.53
EEG Electrodes	$27.00
Battery	$6.49

Table 2. Major components with cost and link to purchase from supplier

8 Conclusions

This EEG Alarm product can be extremely useful for those who feel especially unrefreshed after waking up from a full night of sleep. Being able to intelligently identify optimal times to wake up during the night can help with daytime drowsiness, and being able to monitor one's sleep outside of a sleep clinic will help more people track the health of their sleep.

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