ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

ZZZ-Mate: Pulse Driven White Noise Generator

Team #20

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1 Introduction

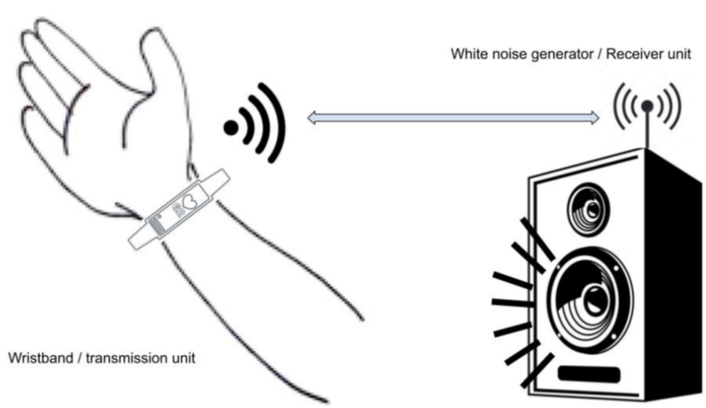
1.1 Problem

According to the CDC, about 70 million Americans suffer from sleep deprivation. Lack of sleep causes various issues in our daily lives such as tiredness, lack of concentration, and in extreme cases, heart failure, diabetes, and various serious conditions.Some of us rely on external sound sources for falling asleep. Currently, there are various white noise machines out in the market. However, most of these devices output a single, continuous signal. According to one article [1], "the continuous background noise also known as white noise which comes from machines and other appliances, can harm your brain, it does so by overstimulating your auditory cortex." According to one Healthline article [2], a 2014 study concluded that "regular exposure to these sound pressure levels may be damaging to infant hearing and auditory development."

1.2 Solution

White noise is typically beneficial during the earlier sleep stages, when people are more likely to be awoken by distracting noises or thoughts. However, rather than continuously playing background noise through the night and overstimulating the auditory cortex, our design aims to combat typical sleep deprivation issues by supporting users through all stages of their sleep cycle: Wake, light sleep, deep sleep, REM, and repeat. By taking pulse rate measurements as an indicator of the user's current sleep stage, our sound generation device will adjust the volume of the white noise. A wristband with a photosensor will be used to detect the user's heart rate and will wirelessly relay the information to the white noise generator to adjust the volume as necessary. We quantified each stage of sleep and their correlated heart rate ranges based on personal datasets and published research, starting with 60 beats per minute (bpm) and below at the deepest sleep stage and building up to 75 bpm and above at the wake/REM stage.

1.3 Visual Aid



1.4 High-level Requirements List

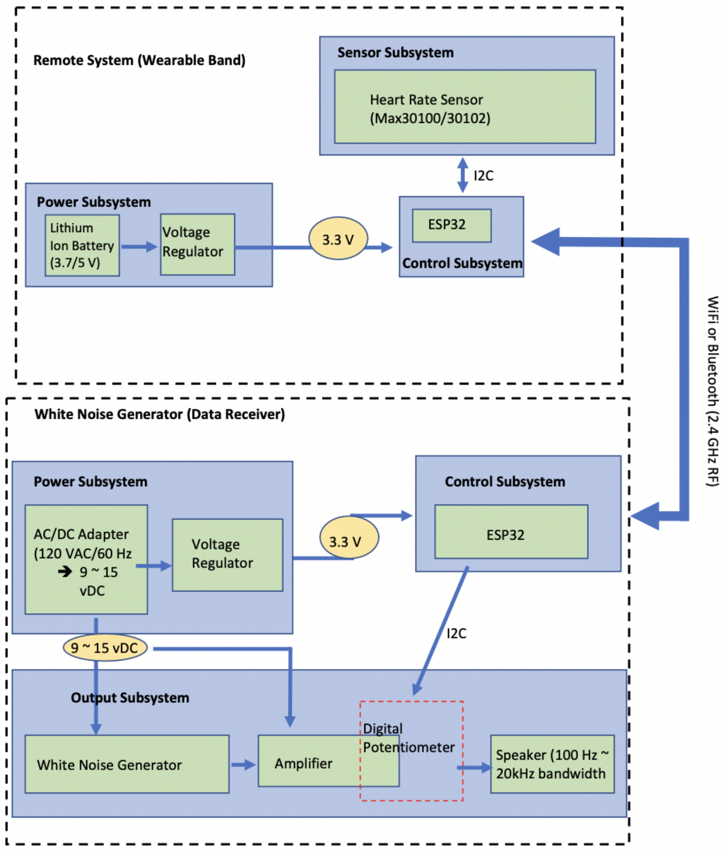
- Average heart rate measurement (BPM) measured over the course of five minutes must be within ±5% tolerance against a third party pulse measurement device (i.e. fingertip pulse sensor, Apple Watch, FitBit, etc).

- The output volume will range from 0 to 30dB (this is a reference decibel level whose range goes from no output to the maximum output from the speaker) with 10dB tolerance. Change in the volume should also decrease by 10dB for every 5 bpm drop with 3dB tolerance.

- Wristband circuitry will be enclosed to fit within an 85mm(L) x 55mm(W) x 40mm(H) case. White noise generator must fit within the dimensions of 300mm(L) x 300mm(W) x 300mm(H).

2 Design

2.1 Block Diagram



2.2 Subsystem Overview and Requirements

2.2.1 White Noise Generator/Data Receiver

One of the two components of our system is the main white noise generator. This unit will contain one of the two microcontrollers, along with the main audio source and a loudspeaker. The microcontroller will communicate wirelessly with the wearable wristband and process the provided heart rate information to determine the output audio level.

i. Power Subsystem

Overview

The main source of power to this unit will be provided via an AC to DC converter. This will be used to power the audio source circuit as well as the power amplifier in the output subsystem. A voltage regulator will also be incorporated to power the microcontroller.

Requirements
- 115/120VAC to 9-12VDC (±0.5V tolerance) AC to DC converter with supply current of 500mA (±25mA tolerance)
- Voltage regulator rated to step down DC voltage to 3.3/5VDC (±0.2V tolerance)

ii. Control Subsystem

Overview

This is the main interface of the entire system, where the ESP32 microcontroller will be utilized to receive the heart rate data from the wristband and apply appropriate change to the output noise level. Communication between the paired microcontrollers will be performed wirelessly via WiFi. The microcontroller will also be responsible for adjusting the output volume with the utilization of digital potentiometer via I2C communications.

Requirements
- Successful wireless communication with another ESP32 is a crucial function requirement
- ESP32 WiFi development kit capable of 2.4GHz transmission frequency

iii. Output Subsystem

Overview

This subsystem is responsible for the white noise generation/amplification and the loudspeaker output for the sonic performance of the system. The white noise generation circuit will be constructed with a general purpose NPN BJT transistor. The power amplifier section will be built around the LM386 audio power amplifier chip. This portion of the output system will interact with the control system to allow for a varying output level using digital potentiometer.

Requirements
- Loudspeaker rated for 100-20kHz bandwidth (±30% tolerance on the bandwidth edge; 70-130Hz on lower end, 14k-26kHz on higher end). Impedance of 8 and power rating ¡1W (per LM386 datasheet)
- LM386N-3, which is rated for 9V supply voltage, 8 load impedance and 500mW minimum output power rating
- Digital potentiometer capable of I2C communication to be used in conjunction with ESP32

2.2.2 Wearable Band

The other major system of the ZZZ-Mate system is the wearable wristband. This device will be worn around the user's wrist to track the heart rate and transmit the collected data to the microprocessor in the white noise generator. The heart rate sensor will be utilized for data collection.

i. Power Subsystem

Overview

The main source of power for this unit will come from a coin cell lithium ion battery, as its size allows for it to fit in the wristband. Since the 3.3V coin battery is not commonly available for the consumer market, a voltage regulator will again be used to step down the voltage level for providing power to the microcontroller and the heart rate sensor.

Requirements
- Lithium ion coin battery, commonly available in 3.7V/5VDC
- Voltage regulator rated to step down DC voltage to 3.3/5VDC (±0.2V tolerance)
- SPST latching type switch as ON/OFF switch. This will connect/disconnect the battery itself from the main circuit to conserve the limited battery life
- Easy access to the battery compartment and snap on battery socket for user to easily replace the battery

ii. Control Subsystem

Overview

This is the interfacing portion of the wristband portion. Using I2C communication, The ESP32 microprocessor will receive data from the heart rate sensor and transmit the information wirelessly to the noise generator/receiver unit.

Requirements
- ESP32 WiFi development kit capable of 2.4GHz transmission frequency
- Successful wireless communication with another ESP32 is a crucial function requirement

iii. Sensor Subsystem

Overview

This is the main sensor module to be used to collect the heart rate information. MAX30100 oximeter sensor module will be used for this application to collect the data. The embedded LED will be emitted through the users' skin, and photodetector will measure the blood's absorbance of such lights.

Requirements
- MAX30100 with operating voltage less than 3.3V
- Measured heart rate with 5% tolerance.

2.3 Tolerance Analysis

Excluding the power tolerances for the white noise generator and wristband systems, the aspect most likely to pose a risk to the successful competition of our project is the wristband/heart rate monitoring system. As the goal of the project is to have an accurate variable speaker system that adjusts to the user's heart rate, high accuracy of the heart rate sensor is a requirement for the project. To verify the accuracy of this system, testing using a waveform generator can be used. The waveform generator can be used as an input voltage supply for an LED, which as a result will flash periodically at the set frequency of the generator. Using that LED and a heart rate sensor, a simulated heart rate measurement can be taken and compared with the input voltage waveform of the LED. With both waveforms fed into separate oscilloscope channels, an accurate comparison between the two signals could be calculated. Alternatively, the device accuracy could be tested against another pulse tracking devices (i.e. Apple Watch, FitBit, a fingertip pulse meter). Tolerance deviation could be determined based on the compared result against these devices. Physically feeling and counting the pulse within a 5-minute timer could also be a method to accurately test the BPM value.

3 Ethics and Safety

3.1 Ethics and Safety

3.1.1 Ethics and Safety

Our team will strive to uphold the standards of ethics and safety outlined by IEE and will take precautions "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices." [3] The overall design of ZZZ-Mate will be constructed upon a relatively low voltage and power level, minimizing the potential physical hazard. In terms of circuit protection, various components will be added, such as a reverse polarity protection diode for the main DC source in the noise generator unit. Another concern for potential physical hazard includes the wristband device, whose circuitry could be harmful if any external contents come into contact with the PCB. The PCB can be encased in a housing to prevent any damage to the device, as well as protect the user. Another potential hazard for the ZZZ-Mate is the audio level of the white noise generator. Since the user will be exposed to speaker sounds for a prolonged period of time, these decibel levels cannot exceed dangerous levels.

3.1.2 Data Privacy

Our design includes collection of personal health data in the form of the user's continuous heart rate throughout the night. This information is very sensitive as it could also be used to calculate a person's heart rate variability (HRV), which has been known to be used to identify a variety of diseases affecting the heart, lungs, and mental health. [4] In addition to ensuring that the data is only used to calculate the appropriate volume of our white noise generator, we are responsible for protecting the data and its owner's privacy. According to the ACM code of conduct, we must take "precautions to prevent re-identification of anonymized data or unauthorized data collection, ensuring the accuracy of data, understanding the provenance of the data, and protecting it from unauthorized access and accidental disclosure." [5] We will take extra precautions not to attach any identifying information to a user's heart rate data and make sure that the data is not being accessed by any outside entities.

References

[1] T. Abdulgafar. “”How Background Noise is Secretly Killing You”.” (2021), [Online]. Available: https://krisp.ai/blog/background-noise-impact/ (visited on 09/15/2022).

[2] Healthline. “”The Pros and Cons of Using White Noise to Put Babies to Sleep”.” (2019), [Online]. Available: https://www.healthline.com/health/parenting/white-noise-for-babies (visited on 09/15/2022).

[3] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 09/15/2022).

[4] D. Brennan. “”What is Heart Rate Variability”.” (2021), [Online]. Available: https://www.webmd.com/heart/what-is-heart-rate-variability (visited on 09/15/2022).

[5] A. for Computing Machinery. “”ACM Code of Ethics and Professional Conduct”.” (2018), [Online]. Available: https://www.acm.org/code-of-ethics (visited on 09/15/2022).