ECE 445 Senior Design Laboratory

Project Proposal

Voice Dosimeter

Team 79

David Gong (dsgong3)

Michael Rizk (rizk2)

Jaden Li (sizhel2)

TA: Chi Zhang
Professor: Michael Oelze

I. Introduction

Problem

Professional voice users – teachers, singers, actors, actresses, broadcasters, clergy, salespeople, courtroom attorneys, telemarketers, and health care specialists – constitute about 30% of the working population [1]. Many of these people will commonly experience voice disorders associated with high voice usage that can negatively affect productivity. The US societal costs of voice-related teacher absenteeism and treatment expenses alone have been estimated to be as high as 2.5 billion dollars annually [2]. Such absenteeism could be prevented for teachers and other voice professionals if they were able to measure how much they were using their voices every day through the use of a voice dosimeter. Measurement of voice usage can also be used in recovery of voice disorders as vocal rest is often recommended. Despite the apparent utility of voice dosimeters, there are currently none that are commercially available. Some devices were available in the past, but they cost thousands of dollars. A low-cost and widely available voice dosimeter would allow for clinical and research use of voice-related problems and voice therapy options.

This project will be conducted in collaboration with graduate student Charlie Nudelman and Professor Pasquale Bottalico at the College of Applied Health Sciences. Their group had previously developed a DIY voice dosimeter using a contact microphone and a portable audio recorder. They are still using this device today, but there are a few improvements they would like to see.

Solution

The device that Charlie and Pasquale are using is bulky and requires a wired connection. It is impractical for patients to wear daily and collect data for a long period of time. We aim to create a cheaper and more comfortable voice dosimeter that is capable of recording data for long periods of time without recharging while the data can be uploaded to another device wirelessly.

To achieve this goal, we will be using an accelerometer instead of a contact microphone that Charlie and Pasquale's initial design used. This will allow us to record the vibrations from the vocal cord with a smaller form factor. Afterward, this data can either be transmitted via Bluetooth onto an external computer or be stored on-board if a computer is not nearby. Finally, this data will be processed to extract critical information about vocal usage and strain, which researchers can then analyze to improve voice therapy options.

Visual Aid

As shown in Figure 1, the voice dosimeter will be a small device that can comfortably be attached to the vocal cord above the collarbone. It will record the user's vocal vibrations as they speak.

Figure 1: Visual aid of voice dosimeter system

High-level Requirements list

1. The device shall accurately measure voice features including sound pressure level within 2dB, fundamental frequency within 5Hz, and cepstral peak prominence within 2dB.
2. The receiver phone or computer shall have an app or website for viewing voice features in real time with less than 1 second of latency.
3. The device shall have 8 hours of battery life to last through a full workday.

High-level Verification

1. To verify requirement one, our device shall be worn by a user in a quiet room. A measurement microphone will be placed one meter from the user's voice. The user will read the first ten Harvard sentences at three different volumes [3]. The three voice features will be compared from our voice dosimeter to the features using the measurement microphone and the same algorithms. Average error will be computed for each voice feature.
2. To verify requirement two, our device shall be worn by a user in a quiet room. A camera will be set up that can view the computer/phone screen of the receiver. The user will record a video of the screen while making a vocalization. Afterwards, the video will be viewed in a video editing software to measure latency.
3. To verify requirement three, a user shall wear the device for a full eight hours starting with full battery. For this verification, the SOC shall read the voltage of the battery every ten minutes and store the voltage value. At the end of the eight hours, functionality will be verified on the receiver.

II. Design

Block Diagram

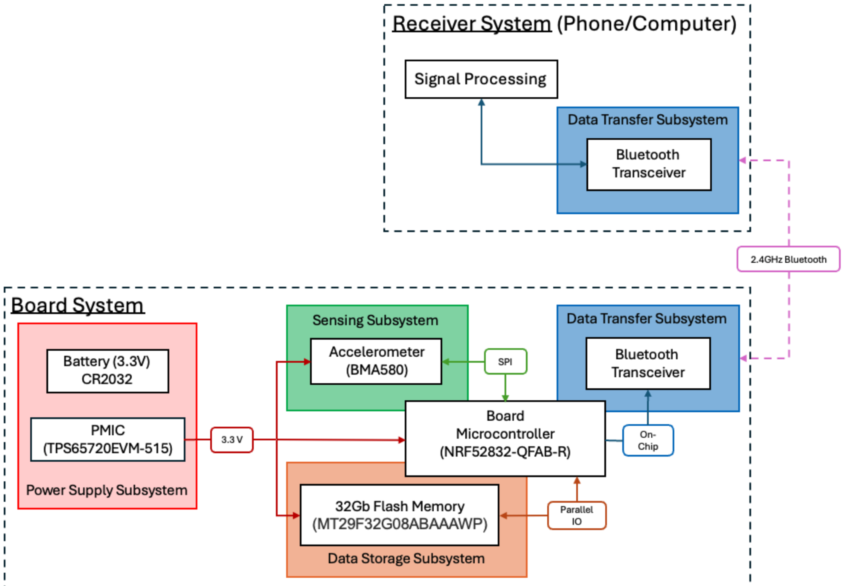

Figure 2: Block diagram of overall system

Subsystem Overview and Requirements:

Power

One of the most critical subsystems of the device will be power management. As this is a wearable device, we want to ensure that even with a small battery, our device is able to run continuously for at least 8 hours. Thus, in addition to a 3.3V button battery, this subsystem will also include a PMIC for voltage and current regulation. Not only is a PMIC a good way to prevent overcurrent, but the PMIC we have chosen has been designed for Bluetooth and wearable devices.

Requirement: The power subsystem is able to supply enough power for at least 8 hours of continuous usage (total power to be calculated).

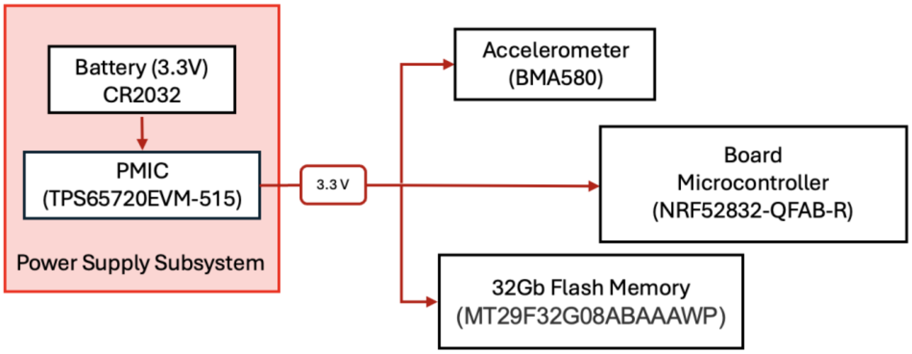

Figure 3: Block diagram of the power subsystem. The battery is connected to the PMIC which then distributes power to the accelerometer sensor, the MCU, and the flash memory IC.

Sensing

The sensing subsystem is the primary driver of this device. Without this, there would be no purpose to wearing this device. We will be using an accelerometer to measure the vibration of the user's throat as they speak. Furthermore, as the accelerometer will be placed close to the user's neck, external sounds and vocalizations will be isolated. The data collected from the accelerometer will be sent to the microcontroller via SPI protocol.

Requirement 1: The sensing subsystem should be accurate enough to determine the fundamental frequency of the user's voice to within 5Hz.

Requirement 2: The sensing subsystem should isolate external noise by 20 dB.

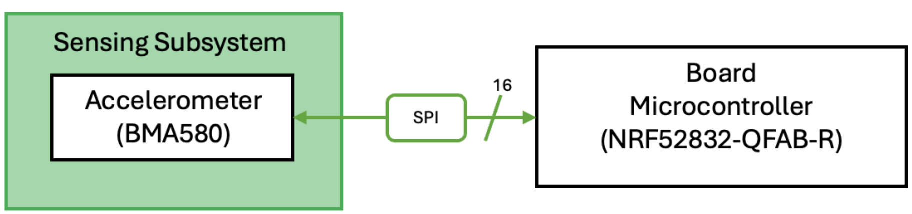

Figure 4: Block diagram of the sensing subsystem. The accelerometer transfers 16 bits of data at a time to the microcontroller through an SPI interface.

MCU/Bluetooth

The MCU chosen for this device is the NRF52832-QFAB-R, which has an onboard Bluetooth transceiver. In this system, the Bluetooth low-energy stack on the SOC functions as the peripheral device, whereas the Bluetooth module on a phone or computer functions as the central device. When data from the accelerometer is received, the MCU either stores the data on a memory IC or sends the raw accelerometer/vibration data to the phone or computer when the two devices are bonded.

Requirement 1: The Bluetooth subsystem should be able to transmit real-time accelerometer data with less than 20ms latency.

Requirement 2: The Bluetooth subsystem should be able to transmit at a range of at least 5 meters.

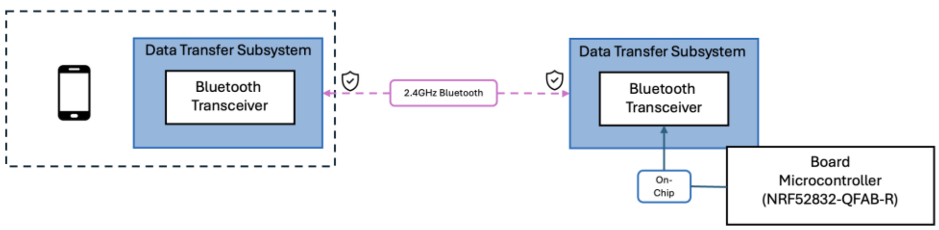

Figure 5: Block diagram of the Bluetooth communication subsystem. The data will be routed to the microcontroller before transmitted through Bluetooth to a central phone or computer to perform the necessary data processing.

Storage

The storage subsystem consists of a 32 Gb flash memory IC. The flash memory has enough storage for at least eight hours of raw accelerometer data. When the central Bluetooth transceiver is not connected, the data is stored on this flash memory IC. Then, when the voice dosimeter is close enough to connect to the central transceiver, the MCU proceeds to read and transmit the stored data. The NAND flash memory IC that has been chosen interacts with the MCU through a parallel interface.

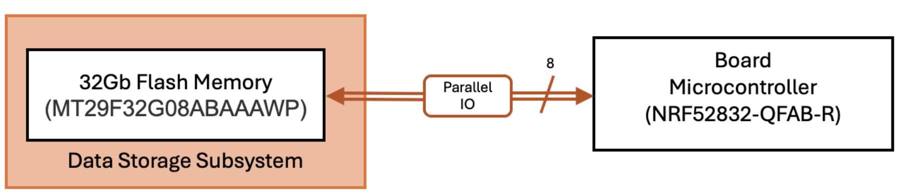

Figure 6: The 32Gb flash memory uses 8-bit addressable memory and a parallel interface. This means that the memory IC will be connected to the MCU with an 8-bit wide bus.

Processing

The processing subsystem will estimate four features of the user's voice in real time: sound pressure level (SPL), fundamental frequency (f0), cepstral peak prominence (CPP), and vocal dose. These features are extracted from the raw accelerometer data. SPL is calculated using total energy, F0 is estimated using the Praat algorithm, and CPP is calculated following the algorithm in Hillenbrand et al [4]. Vocal dose is calculated using a weighted sum of the three other values.

Tolerance Analysis:

Accuracy

There is some risk that the voice features calculated from the measurements of our accelerometer won't match with the voice features calculated from a microphone due to the lower sample rate. The BMA580 accelerometer has a sample rate of 6 kHz while high quality digital microphones typically have sample rates of 44.1 kHz or higher. However, most of the energy of an average human voice will be below 3000 Hz [5]. Also, we can calibrate the accelerometer to a measurement microphone for more accuracy.

Latency

All three of our voice feature algorithms will run on blocks of 50ms. Bluetooth low energy on our SOC has a minimum latency of 7.5ms [6]. We can increase the BLE latency to decrease power consumption. This gives us a minimum latency of 57.5ms.

Power

We can estimate power consumption of the SOC BLE module using the power profiler from the Nordic Semiconductor website [6]. We will send 96 Kilobit per second of vibration data. If we use a connection interval of 15 ms and a payload of 189 bytes at a power of -20 dBm, we will use an average current of 735 uA according to the power profiler.

Flash memory uses 30 mA for 900 us for each 4-kilobyte page write [7]. We generate and store 12 kilobytes of vibration data per second. This gives us an average current draw of 81 uA.

The accelerometer uses 125 uA when in high performance continuous operation [8].

The total average current is 941 uA at 3.3 V. With our battery capacity of 230 mAh, this gives us an estimate of 222 hours of battery life.

III. Ethics and Safety

As we go forth with this project, we want to mention relevant ethical and safety issues mentioned in the IEEE and ACM codes of ethics, and our consequent solutions to them.

Privacy: Our device will record the vocal data of the user, and that data will be transmitted over Bluetooth. This is private data that we only want accessible to the appropriate groups. Furthermore, there is a chance that we record other people's vocal data by accident if they are near the user, and we don't want to intelligibly record other people without their consent. As per ACM Code of Ethics 1.6, everyone is entitled to their privacy, and we must respect that.

For our data transmission, we will follow Bluetooth security protocol to ensure a secure Bluetooth connection. Also, our design choice of using an accelerometer would ensure that our device is only able to measure the user's vocal data because an accelerometer just senses the mechanical vibrations of the surface it is attached to.

Wearable Electronics Potential Risk: Our project is a wearable device that requires enough power to function for at least eight hours. Adhering to IEEE code 7.8.9, we deliberately chose a low-voltage battery to minimize the risk. Furthermore, our wearable device will have key components encased in silicone for comfort, but this also doubles as an insulator layer of protection.

References

[1] R. W. Chan, I. R. Titze, and M. R. Titze, ‘Further studies of phonation threshold pressure in a physical model of the vocal fold mucosa’, *The Journal of the Acoustical Society of America*, vol. 101, no. 6, pp. 3722–3727, 06 1997.

[2] Verdolini, K., & Ramig, L. O. (2001). Review: Occupational risks for voice problems. Logopedics Phoniatrics Vocology, 26(1), 37–46. https://doi.org/10.1080/14015430119969

[3] "IEEE Recommended Practice for Speech Quality Measurements," in IEEE No 297-1969 , vol., no., pp.1-24, 11 June 1969, doi: 10.1109/IEEESTD.1969.7405210.

[4] Hillenbrand, James & Cleveland, Ronald & Erickson, Robert. (1994). Acoustic Correlates of Breathy Vocal Quality. Journal of Speech, Language, and Hearing Research. 37. 769-778. 10.1044/jshr.3704.769.

[5] Crandall, I. B., & MacKenzie, D. (1922). Analysis of the energy distribution in speech 1. Bell System Technical Journal, 1(1), 116-128.

[6] “Online Power Profiler for Bluetooth LE - opp - Online Power Profiler - Nordic DevZone,” *Nordicsemi.com*, 2025. https://devzone.nordicsemi.com/power/w/opp/2/online-power-profiler-for-bluetooth-le (accessed Feb. 14, 2025).

[7] “NAND Flash Memory.” Accessed: Feb. 14, 2025. [Online]. Available: http://datasheet.elcodis.com/pdf2/90/57/905705/mt29f128g08waac6.pdf

[8] “BMA580 Advanced, ultra-small, triaxial high performance low-g accelerometer with digital interfaces BMA580 Datasheet,” 2024. Available: https://www.bosch-sensortec.com/media/boschsensortec/downloads/datasheets/bst-bma580-ds000.pdf

[9] Association for Computing Machinery, “ACM code of ethics and professional conduct,” *Association for Computing Machinery*, 2018. https://www.acm.org/code-of-ethics

[10] IEEE, “IEEE Code of Ethics,” *ieee.org*, Jun. 2020. https://www.ieee.org/about/corporate/governance/p7-8.html