A Real-Time Biofeedback Device for Individuals with Neuro Vocal Intensity Disorder

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***Abstract*— Parkinson's disease is a Neurodegenerative disorder that affects motor, cognitive, and psychological functions. It is caused by the reduction in dopamine production in the Substantia Nigra region of the brain, which results in symptoms such as tremors, sluggish movement, and muscular stiffness. Research indicates that 89 percent of people with Parkinson's disease (PD) experience speech and vocal impairments, including hoarseness, breathiness, and a quiet, monotonous voice. Existing devices for providing feedback to individuals with Neuro vocal intensity disorder use headsets, which can reduce the physical sensations of speech. However, these devices may provide feedback in the form of user's voice in an altered version or as white noise, which can increase mental stress. Furthermore, ambient noise is not considered for providing feedback, making them unsuitable for use in both low and high-noise environments. Additionally, these devices can be uncomfortable for the user. To address these limitations, this paper proposes an innovative device that uses vibro-tactile feedback to provide accurate feedback for the users. The proposed approach allows the user to experience physical sensations and environmental noise while receiving feedback, providing a more realistic and effective feedback. Though there are many factors in vocal disorder such as muscle weakness which requires regular exercise, this paper focusses only on a feedback device for speech modulation.**

***Clinical Relevance*— People with Neuro vocal disorders seem to modulate their voice better during speech exercise under the supervision of a therapist. This shows that people with such disorder can response well to feedback which could be provided with an assistive device that will serve as a substitute for the therapist, enabling individuals to modulate voice on their own.**

I. Introduction

Parkinson's disease is a debilitating Neurodegenerative disorder that affects millions worldwide. The most common symptoms of Parkinson's include tremors, rigidity, and bradykinesia. However, individuals with Parkinson's disease also experience impairments in their speech and vocal abilities, which can have a significant impact on their emotional well-being. Research shows that 89 percent of people with Parkinson's disease have speech and vocal impairments, such as hoarseness, breathiness, and a quiet, monotonous voice. These impairments can lead to social isolation and a reduced ability to communicate effectively. Speech therapy and a baseline speech examination can help individuals with Parkinson's disease maintain their speech ability as their condition worsens [1]. However, several factors contribute to speech and voice impairment in Parkinson's disease, including dysfunction in the motor system, sensory processing, and difficulties in cueing oneself to speak loudly enough. The impact of Parkinson's disease extends beyond speech impairments. People with Parkinson's are also more susceptible to bone fractures, strokes, and diabetes, and the disease can cause major depression. In the United States, it is estimated that one million people have Parkinson's disease, and 90,000 individuals are diagnosed with the disease every year [2].

This paper explores the impact of Parkinson's disease on speech and vocal abilities and discuss strategies for maintaining communication abilities in individuals with Parkinson's disease and examine the factors contributing to speech and voice impairment in Parkinson's disease and discuss potential interventions to improve communication outcomes for individuals with Parkinson's disease. Gaining knowledge on speech impairments associated with Parkinson's disease provides a clear understanding of the need to provide a better solution improving the quality of life of people with this debilitating condition [3]. The aim of this paper is to focus on the prototype developed for providing vibro-tactile feedback to modulate speech intensity.

II. Background Report

Speech and language therapists play a crucial role in helping Parkinson's patients maintain their communication abilities and improve the necessary muscle strength and movements for speech. The chapter will delve into the available treatment options and functional limitations that Parkinson's patients face, as well as the broader impacts of vocal disorders.

A. *Improving Communication in Parkinson’s Disease:*

1. *The course of Therapy/Treatment*

The Lee Silverman Voice Treatment is an evidence-based intensive treatment that teaches people with Parkinson’s how to speak at optimal volume. Another option is the Parkinson’s Voice Project SPEAK OUT! a less-intensive speech therapy program that combines speech, voice, and cognitive exercises [4]. After individual treatment, group therapy called The LOUD Crowd® is the next step.

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Additionally, alternative communication devices such as Expiratory muscle strength training (EMST), Speech Vive, and Hi-VOLT® 4 PD can assist with speech improvement [5].

2. Problems, Challenges, and Implications

One of the biggest challenges in designing communication devices for Parkinson's patients is accommodating the variability in vocal loudness and intensity. Devices also need to be easy to use, calibrate automatically in a dynamic environment, and be small and water-resistant. If these problems can be solved, approximately 10 million people worldwide could benefit from using these devices [6].

Improving communication abilities can greatly enhance the quality of life for individuals with Parkinson's disease. Speech and language therapists, along with alternative communication devices, provide treatment options that can help individuals maintain their communication skills and improve their muscle strength and movements needed for speech. By addressing the challenges in designing communication devices, more individuals can have access to these tools to enhance their communication abilities [7].

B. Speech Disorders in Parkinson's Disease: Functional Limitations and Broader Impacts:

1. Broader Impacts

Individuals affected by vocal disorders, such as loudness, shakiness, hoarseness, and monotone, may hesitate to engage in social activities. Addressing this issue can increase their confidence in speaking and socializing, leading to improved well-being [8].

2. Functional Limitations

PD patients face various functional limitations that can impact their speech abilities. Firstly, they can perceive their voice, but are unaware of its loudness, pitch, and intensity [9]. Secondly, they are unable to control the loudness and rate of their speech, and an external stimulus encouraging them to adjust these factors could improve speech clarity. Additionally, the speech disorder can make communication with family and friends difficult, affecting the emotional well-being. The primary cause of Hypokinetic Dysarthria is the decreased range of motion in the speech mechanism [10].

III. Related Work

This chapter provides an overview of the different types of technology related to Parkinson's disease that are commercially available, as well as research prototypes presented in conference, journal papers, patents and technologies described on websites. The chapter aims to give readers an understanding of the various types of technology available for individuals with Parkinson's disease and their potential benefits [11].

A. Commercially Available Products

Speech Vive is a device designed for individuals with Parkinson's disease to improve speech and voice production. The device is worn behind the ear and plays background noise in the user's ear, making them to speak louder. The device does not require training to use, making it functional for people with mild cognitive impairment or reduced memory. Clinical trials indicate that hypophonic patients respond well to the device, improving speech clarity and increasing vocal loudness. *Hi-VOLT* is a calibrated, voice-activated light bracelet that helps patients gauge the level of loudness required to be understood by others. These products are cost-effective and allow patients to practice from home [12].

B. Research Prototypes Presented in Conference and Journal Papers

Several studies have been conducted on various technologies that assist individuals with speech and voice impairments. One of these studies looked at using tactile feedback through haptic devices, such as a vocoder, to help those with hearing impairments improve their vocal intensity. Another study tested the feasibility of using mobile health technology for at-home vocal training for older adults with cognitive and chronic conditions that affect speech. A third study focused on synthesizing personalized voices for individuals using text-to-speech synthesis technology. [13] Another device called "EchoWear" works in conjunction with a mobile device to provide speech therapy for patients with Parkinson's by analyzing speech quality metrics. A mobile-assisted voice condition analysis system was also developed using machine learning models to filter out patients' voices in an unsupervised acoustic environment, which can improve speech therapy. Various studies conducted in [14] aim to fill the market gap and help individuals regain normalcy in their lives.

C. The Design of Devices Presented in Patents and Journal Papers

1. The Device for Self-monitoring of Vocal Intensity is a throat microphone that monitors the user's vocal volume and provides feedback through tactile, audible, temporal or visual means. However, the threshold level is fixed, and the device only works for low or high-volume indication, not both simultaneously. Additionally, the threshold level does not change based on environmental conditions [15].

2. The Biofeedback system for speech disorders is an auditory biofeedback device that detects disfluencies in speech and provides feedback for immediate and carryover fluency. The device uses an Electromyograph (EMG) to detect muscle tension and provide feedback. However, the user must wear headphones to receive feedback, which can isolate them from their surroundings, also the feedback provided does not adapt to the varying environmental conditions [16].

3. The Voice Feedback Device for Voice Loudness Control is designed based on the Lombard effect, where feedback is given to users through the white noise to adjust their vocal loudness based on the ambient noise. The device compares the signal from two microphones and determines the level of

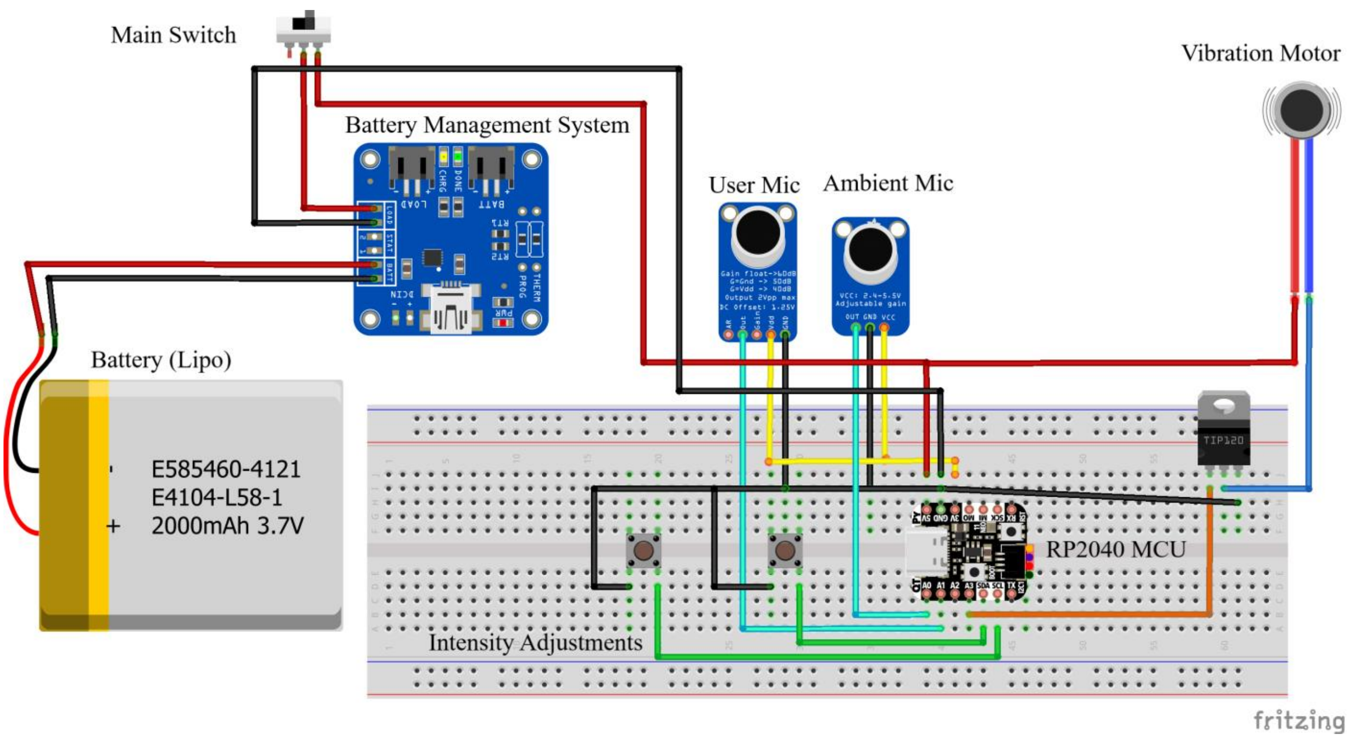

Figure 1 Circuit diagram

loudness of the user. However, this device can only be used in specific situations, and cannot be calibrated based on user needs and capability [17].

4. The Ambulatory Feedback on Vocal Loudness is a biofeedback device that determines the optimal configuration and threshold levels for individuals with Parkinson's disease. The device measures the user's voice sound level during baseline and defines three threshold levels. The activation time has two settings, 500ms, and 1000ms, which are tested using six semi-structured conversations of 10-15 minutes each. However, this device is specific to individuals with Parkinson's disease, and the threshold level is fixed.

All these devices are designed to provide feedback to individuals concerning their vocal intensity or speech disorders. However, they have fixed threshold levels and may not work in every environment [18], [22].

D. Technologies Described on Websites

1. The LSVT Coach: Clinician Edition helps individuals with Parkinson's disease track their progress while practicing vocal exercises from home. The device records and analyzes the user's voice in real time and displays the data as graphs for tracking progress. While it provides at-home vocal exercises and real-time feedback, it requires a computer and internet connection and may be challenging for some users to use [19].

2. Lingraphica AAC Devices are tablet-like devices with text-to-speech, drawing, and pre-determined answer functions designed to cater to individual communication needs. The device has a Parkinson's-specific app for speech recovery exercises with real-time feedback and progress tracking. Insurance covers the device, but it may encourage users to rely on the provided functions instead of their voice, and its size may make it challenging for some users to use. Three models with varying features are available, and the more expensive version offers a better display and LTE capabilities [20], [21].

IV. Proposed Approach

The proposed shoulder brace is designed to incorporate the device onto the interior surface of the brace, ensuring that it remains hidden from view. Additionally, the device is removable, allowing users to detach it during washing, and the shoulder brace in lightweight and flexible to make the user comfortable. The box containing the vibration motor, battery management system, battery, ambient microphone, and the controller will be placed inside the shoulder brace and the brace can be worn on either of the shoulders. The user microphone placed on top of the collarbone will pick up the user's vocal intensity. Signals from both the microphones are filtered using low pass filter to avoid spikes. Both these signals are used in determining the user and ambient sound levels for providing feedback.

The intensity of vibration motor can be adjusted using the buttons provided based on the user's convenience. The device comes with a rechargeable battery and battery life of 12 hours on a single charge. The primary aim of designing the device is to ensure user-friendliness and accessibility with minimal effort and disturbance to the wearer. The shoulder brace is adjustable to accommodate for all body types comfortably.

V. Implementation

The device consists of two microphones, one for capturing the user's voice and another for ambient noise. A Qt Py RP 2040 microcontroller is used. Two buttons are provided in the

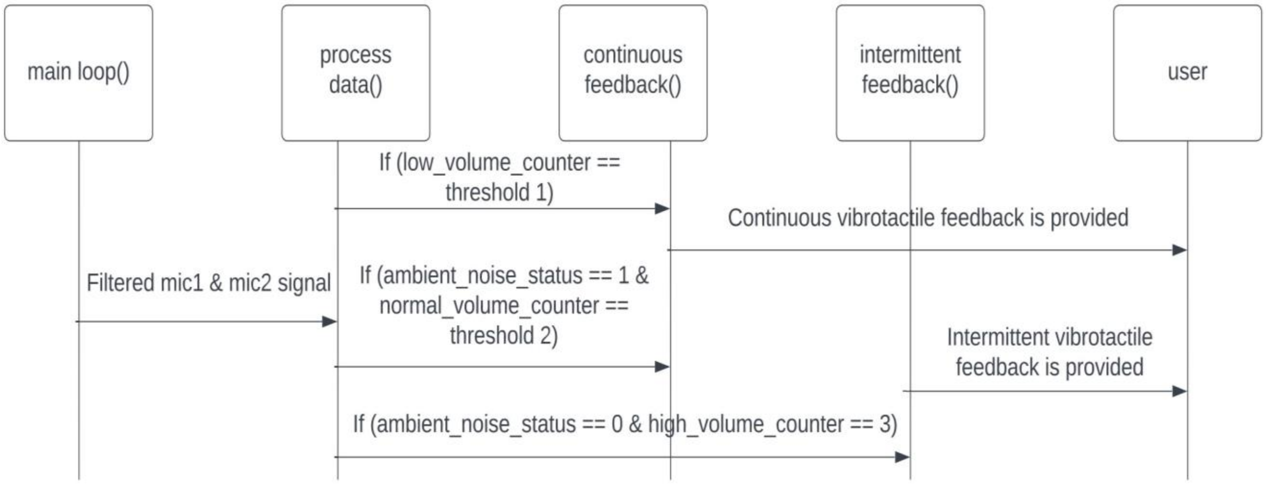

Figure 2 Sequence Flow Diagram

device to increase and decrease the intensity of the vibration motor based on the user's needs. Fig. 1 shows the circuit diagram.

An adjustable-gain microphone is used as a user microphone. The gain of the user microphone is optimized so that it will only capture user's voice and eliminates ambient noise. Though the gain is optimized, the user microphone will capture some background noise, but it is negligible. A bone conduction microphone with better sensitivity can help overcome this problem. The bone conduction microphone can be placed on top of the collarbone, where the sensitivity is better. Auto-gain microphone is used as ambient microphone. The gain of this microphone adjusts automatically and is directly proportional to the distance of the sound source. Hence, this microphone is effective at capturing background noise that is far away.

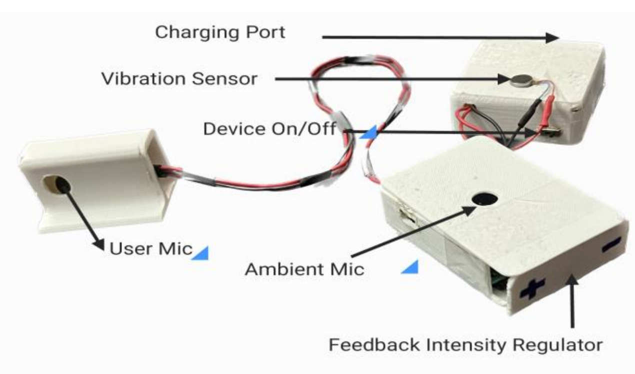

Figure 3 Final Prototype

Once the device is turned on, the ambient mic will capture background noise. When the user starts speaking, the captured background noise will be used to compare with the user's voice level and provide feedback. The sequence flow diagram in Fig. 2 illustrates the feedback logic of the device.

The logic has three different states: high, normal, and low for the user's voice level, and two discrete states: noise and no noise for background noise. When the user speaks at a low volume, irrespective of ambient noise, continuous vibrotactile feedback will be generated. When there is no background noise and the user converses in a normal voice, no feedback is provided. But if the user is conversing in a normal voice in the presence of background noise, continuous feedback will be provided. If the user speaks at a high volume in the absence of ambient sound, intermittent vibrotactile feedback will be provided, prompting the user to reduce their volume. But if ambient noise is present and the user speaks at a high volume, feedback is not provided.

The microphone signals are sampled for a fixed timeframe and filtered using a low-pass filter. A low-pass first-order filter is used to avoid spikes in the signals and filters out high-frequency sounds, which can lead to false triggers. A few examples of day-to-day life scenarios involving sudden microphone signal changes are opening or closing a door, clicking a button, etc.

Even if the user is speaking in a normal voice, the voice level sometimes reaches the lower band level during the conversation. This is because of the ups and downs in the phonation of words. Eventually, the controller gives feedback that the user is soft. To avoid this problem, a counter is used, and only if the counter exceeds the threshold level, feedback will be provided. The counter is also used for the other two stages but with different threshold values. Though the counter will increase the delay in feedback, it will help prevent false feedback. Feedback delay is in the range of 1-3 seconds and can be reduced by employing better filtering techniques and microphones.

The user's voice range for high, normal, and low is determined from limited speech data. With more data, the scale factor for all threshold values can be found which can be used for calibrating the device based on an individual's voice need and capability. Fig. 3 shows the final prototype.

The components are housed inside a box, and the box with the components is positioned inside a pouch attached to the shoulder brace.

Figure 4 Shoulder Brace Setup

Figure 5 Normal Attire Over the Device

The battery management system, battery, and vibration motor are placed in a separate box and stacked on top of the components box. The vibration motor is placed in a different box so that the microphone in the component box is not affected by vibrations. The user's mic is situated on top of the collarbone and facing upwards, closer to the mouth. All the components can be removed easily if the shoulder brace needs to be cleaned. Fig. 4 shows the shoulder brace setup with the prototype. and Fig. 5 shows the proof that the device is concealed under regular attire.

VI. Conclusion

The device has been tested under different ambient noise conditions and is found to perform well with no false feedback. However, if the ambient noise is too high the user microphone captures some background noise and affects the feedback. With a highly sensitive bone conduction microphone for the user mic and a high gain mic for the ambient noise, the accuracy of the feedback can be improved. More than being an assistive device, this device promotes a sense of being supervised and helps users modulate their voice according to their needs. Hence, the number of feedback stages is limited to three rather than more feedback stages, which makes the user feel independent and not rely completely on the device.

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