VibraSense: Empowering Accessibility for the Blind & Deaf

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Abstract- **Access to information for the deaf-blind community remains a significant challenge, particularly in developing nations where the high cost of printing braille books limits availability. This paper presents a novel, cost-effective solution enabling deaf blind users to access online resources through vibrational braille. Deaf-blind users can input questions, which are answered by a large language model (such as Gemini API) and transmitted character-by-character to gloves equipped with vibrational motors, providing tactile braille feedback.**

By integrating affordable hardware and intuitive software, this system bridges the gap between technology and accessibility, offering a scalable alternative to traditional braille materials. The solution has the potential to democratize information access for the deaf-blind, fostering inclusivity and empowerment through education and technology

***Index Terms*—Deaf-blind accessibility, vibrational braille, ESP32 microcontrollers, Gemini API, assistive technology, inclusive education, tactile feedback systems.**

I. INTRODUCTION

Globally, approximately 160 million individuals live with deaf-blindness, including half a million in India. These individuals face immense challenges in accessing information, education, and digital resources, limiting their ability to participate fully in societal, economic, and educational activities. While assistive technologies exist for the visually impaired, the needs of the deaf-blind community remain largely unmet, creating a significant gap in inclusivity and access. Braille, a tactile writing system invented by Louis Braille in 1821, transformed the lives of visually impaired individuals by enabling literacy through raised-dot patterns. Braille encoding is organized into three grades: Grade 1 for basic transcription, Grade 2 for contractions and abbreviations, and Grade 3 for personal stenography. Despite its importance, the lack of cost-effective, scalable braille solutions continues to hinder the deaf-blind community's access to digital information and learning tools. By integrating affordable hardware and intuitive software, this system bridges the gap between technology and accessibility, offering a scalable alternative to traditional braille materials. The solution has the potential to democratize information access for the deaf-blind, fostering inclusivity and empowerment through education and technology.

This paper introduces a novel system designed to bridge this gap by leveraging vibrational braille technology. The solution translates text responses from a large language model (such as Gemini API) into tactile feedback using gloves equipped with vibration motors, allowing deaf-blind users to interact with digital content character by character.

The paper is organized as follows: Section II reviews related literature and existing assistive technologies. Section III details the system design, including its hardware and software components. Section IV discusses the results of initial testing, and Section V evaluates the system's potential impact, limitations, and future scope. The conclusion highlights the significance of this work for empowering the deaf-blind community.

II.RELATED WORK

Recent advancements in assistive technologies have significantly contributed to improving accessibility for visually impaired individuals.

A. The paper "Communication Device for Converting Text to Braille" (ICICT 2023, IEEE Xplore) introduces a Braille display system that utilizes electromagnetic principles to address challenges like high costs and low flexibility in traditional devices. This system, comprising a Braille pad, keypad, microcontroller, and GSM module, converts text to Braille with minimal delay, enhancing usability. However, the reliance on electromagnetic mechanisms may limit portability, which VibraSense addresses through its compact, glove-based vibrational system.

B. The work "Development of Communication System for Deaf & Blind Persons Using Text to Braille Conversion" (IIHC-2022, IEEE) focuses on converting SMS messages into Braille characters using a Renesas microcontroller. Tactile feedback is provided via a vibrating wristband, enabling real time message interpretation. While effective, this system is limited in functionality compared to VibraSense, which integrates text-based communication with learning and practice modules for broader applications.

C. Another innovative approach is presented in the paper "DRISHYAM: Real-Time Text to Braille Conversion and Re alisation" (INDICON 2020), which describes a mobile app connected to an Arduino Uno and a Braille cell to convert images into tactile Braille feedback. While this system allows visually impaired users to access visual information through touch, its dependency on image-based input and external hardware contrasts with VibraSense's focus on versatile text based vibrational feedback.

D. Further advancements are seen in the study "A Novel Braille Pad with Dual Text-to-Braille and Braille-to-Text Capabilities" (ICICICT 2017), which introduces a Braille pad equipped with a keyboard for input and a display for output in both Braille and English. By integrating an LCD and optional laptop connectivity, this device facilitates communication between visually impaired and sighted individuals. VibraSense differentiates itself by emphasizing portability and real-time text-to-Braille conversion through a wearable design.

E. The survey "Designing of English Text to Braille Conversion System" (ICIIECS 2015) explores methods for converting English text to Braille using an automated value thresholding algorithm. While highlighting the potential for accurate con version, the survey lacks emphasis on real-time applications, which VibraSense achieves through its wireless and tactile vibrational feedback system.

F. Lastly, the paper "Vibrotactile Alphabets: Time and Frequency Patterns to Encode Information" (IEEE Transactions on Haptics 2021) presents a system that delivers text messages through patterns of vibrations using varying frequencies and durations. This method generates multiple combinations to encode messages effectively. VibraSense builds upon similar vibrational techniques but extends its application to Braille based tactile feedback and incorporates interactive learning modules to empower users.

These studies collectively contribute to the development of assistive technologies for visually impaired individuals. However, limitations such as dependency on external devices, lack of portability, and restricted real-time applications per sist. VibraSense bridges these gaps by providing a compact, wireless, and versatile system that combines real-time text-to-Braille conversion with integrated learning and practice features, promoting independence and accessibility.

III. SYSTEM DESIGN

A. Hardware Part

• Braille Representation:

– Braille is a tactile writing system used by individuals who are visually impaired or blind. It represents characters through raised dots arranged in a rectangular cell of up to six dots, conventionally referred to as a "Braille cell."

– Each Braille cell typically consists of two columns of three dots, and the specific pattern of raised dots corresponds to a particular character or symbol.

– It enables tactile reading by allowing users to feel the patterns of dots with their fingertips, offering an accessible medium for communication, education, and independent living

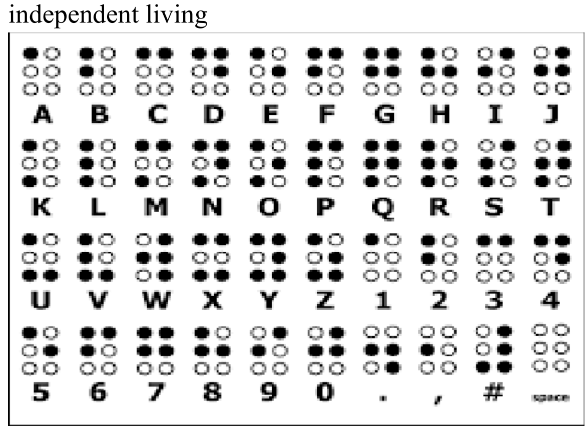

Fig. 1. Braille Notation

• Glove design:
– We have developed an innovative glove embedded with vibration motors that transmit Braille notations through tactile vibrations, providing users with a hands-on learning experience. This design enables individuals to perceive Braille characters directly on their fingertips, simulating the tactile sensation of traditional Braille.
– By delivering characters through vibrations, the glove facilitates faster and more intuitive learning, helping users quickly adapt to the system. Additionally, the customizable vibration intensity and timing make the design adaptable to individual user preferences, enhancing comfort and usability.

• Motors: X-Y axis Coin Vibrator Motor ERM type

Fig. 2. X-Y Axis Coin Vibrator Motor

– This motor generates vibrations in the X and Y planes, producing a multidirectional feedback effect.
– The motor operates at low voltages, is energy efficient, and provides a reliable and consistent vibration pattern.

• ESP32 master slave architecture:
– We have implemented this using three ESP32 boards, where one board acts as the master and the other two act as slaves

Fig. 2. Master-Slave Architecture

– Master ESP32 Board: It hosts the logic for receiving user inputs, processing data, and determining the commands to be sent to the slave boards.
– Slave ESP32 Board: Each slave board is responsible for controlling the vibration motors for a specific side of the Braille cell. Upon receiving commands from the master board, the slave boards activate the respective motors for the specified duration and intensity.

B. Software Part
The software component of VibraSense is designed to provide an intuitive and accessible interface for deaf-blind users. Given the unique needs of the target audience, the system includes robust features to ensure seamless navigation, data privacy, and effective learning. We have created the website using Java Spring Boot, WebSocket, JavaScript, and other technologies to deliver a responsive and interactive user experience. The following subsections detail the development and implementation of key functionalities.

Search Module: Users can search for queries via the /search page. The query is sent to the Gemini API, which processes it and returns a response
.– *Ctrl + Shift + S* : Focuses on the search bar.
– *Ctrl + Shift + Space* : Highlights and iter ates over response characters.

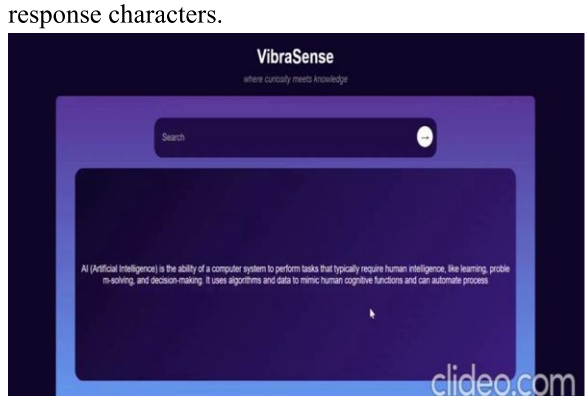

Fig. 4. Website UI for Search Module

Learning Module: Accessible via the /learn page, this module teaches users vibration-based Braille. Users can type characters and experience corresponding vibrations.
– *Ctrl + Shift + Left Arrow:* Rewind to the start of the sentence
.– *Ctrl + Shift + R:* Restart text iteration.

Practice Module: This module helps users reinforce learning via exercises on the */practice* page.
– Five categories: Home Row, Top Row, Bottom Row, Numbers, Combined Test
– Users input test numbers, and random exercises from the database are presented.

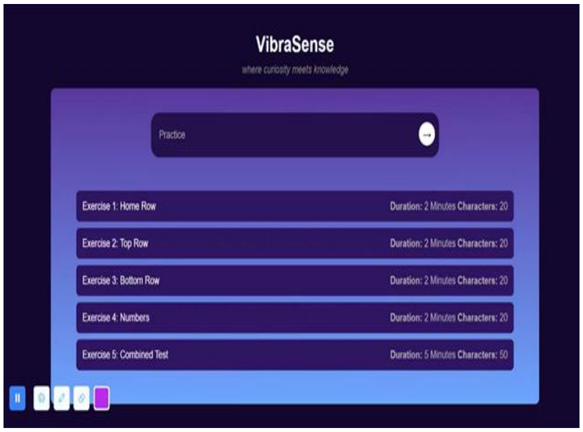

Fig. 5. Website UI for Practice Module

Privacy and Encryption: Ensures user queries and responses remain private.
– *Ctrl + Shift + H: Toggles encryption.*
Adjustable Response Features: Users can customize response speed and size for a better experience.
– Response Speed:
∗ *Ctrl + 1: Slow (600ms per character).*
∗ *Ctrl + 2: Normal (350ms per character).*
∗ *Ctrl + 3: Fast (150ms per character).*
– Response Size:
∗ *Ctrl + 8: 50 words.*
∗ *Ctrl + 9: 75 words.*
∗ *Ctrl + 0: 100 words.*
Enhanced Accessibility Features: Additional shortcuts improve user navigation:
Ctrl + Shift + S: Focuses on input fields
Ctrl + Shift + Space: Starts, pauses, or resumes text iteration with visual highlights

C. Project Operations
Web Socket & ESPnow Connection Establishment
WebSockets: Communication protocol designed to enable persistent, bidirectional, full-duplex communication between a client and a server over a single TCP connection. Unlike traditional HTTP, which is unidirectional and requires a new connection for each request-response cycle, WebSockets maintain an open connection that allows for real-time data exchange with minimal overhead.

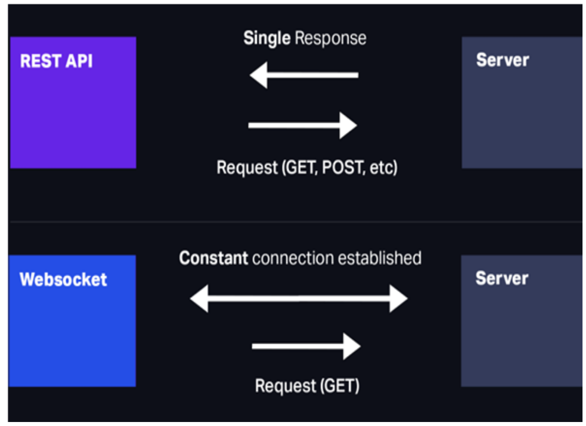

Fig. 6. Web Socket vs REST API

ESP-NOW: A communication protocol that allows for fast, low-power, and efficient data exchange between ESP32 devices. In our case it enables direct communication of the master board with other esp32 boards in its proximity.

Choice of Module: First, the User chooses his or her choice of module from the three available that are search, learn and practice.
- In case of Search Module, the user gives a query or question as input via the Braille Keyboard Cover. This question is passed on to the Gemini API which then fetches the answer for the corresponding question. The answer is then displayed on the website.
- In the case of the Learning Module, the user gives some text as input via Braille Keyboard Cover. This input is read later and transmitted to the user again. This module helps the user to improve upon the weaknesses in recognizing braille of some characters.
- In the case of the Practice Module, the user chooses one of the rows of the keyboard or a random combination. Based on the choice, the characters from that row are then transmitted to the user. This lets the user practice the specific vibration braille of certain characters from a particular row or even a random combination to test his or her skills.

Data Transmission from website to Master ESP32 board: The text is transmitted one character at a time in JSON format from the website to WebSocket server. In our master board code, we have specified the reference or IP address of the WebSocket server, thus enabling the master board to seamlessly retrieve text from the website through this connection.

Data Transmission from Master to Slave: The master board retrieves the text character by character and sends it to the two slave ESP32 boards. These slave boards represent the left and right dots in standard Braille Notations, and in our case they represent the motors on the left and right hand respectively. Based on the character read, the corresponding vibration motors are set.

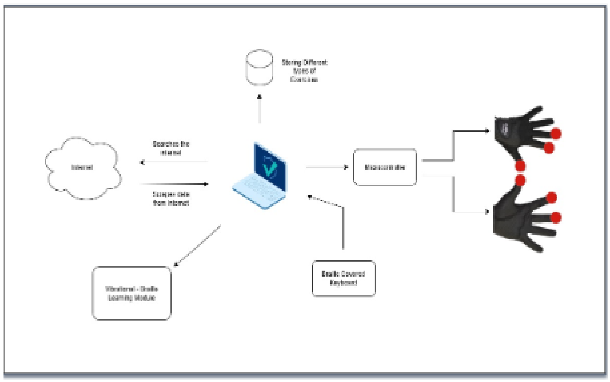

Fig. 7. Block Diagram

Braille Vibrations: The Slave boards set the corresponding vibration motors attached to our glove based on the character read, which in turn gives the user tactile feedback leading to a faster learning curve.

IV. RESULTS

The VibraSense system successfully converted text into Braille patterns, providing accurate and real-time tactile feedback via vibration motors embedded in the gloves. The system exhibited minimal delay in converting text, ensuring smooth communication.

A. Adjustable Response Features

The VibraSense system offers adjustable response speed and size, allowing users to customize their experience based on personal preferences. The response speed can be set to three levels: slow, normal, fast. These settings enable users to tailor the feedback speed for optimal interaction.

B. Real-Time Feedback

One of the key features of the VibraSense system is its real time feedback capability. There is no noticeable delay between text appearing on the screen and the corresponding vibrations being felt on the glove. As soon as the word is displayed on the screen, the user can feel the vibration feedback instantly, ensuring smooth and synchronous communication.
This shows the design of our gloves. We have attached the vibration motors to the pointer, middle and ring finger to make it visually similar to standard braille notation. This design will also indirectly help users to read Braille from hard copies as well.

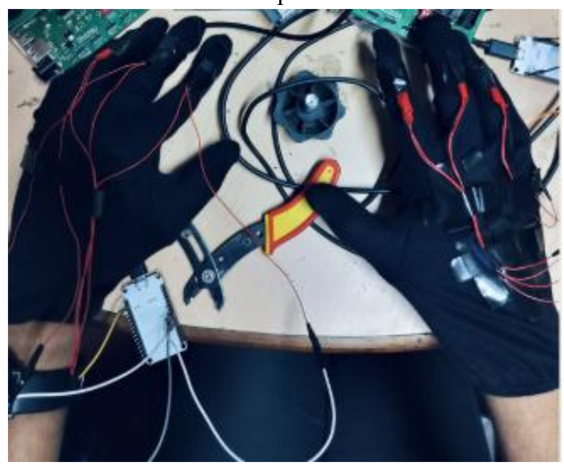

Fig. 8. Glove Design

C. Limitations and Future Work

While the system performed well, there are areas for future improvement. One key enhancement would be integrating the battery directly into the gloves for improved portability and convenience. This would eliminate the need for external power sources and make the system more practical for everyday use. Other improvements will focus on processing complex language structures, enhancing glove comfort, and reducing weight for longer usage periods. Additionally, further refinements in vibration feedback precision and the inclusion of more advanced Braille symbols could enhance the system's capabilities.

V. CONCLUSION

This paper presents an innovative approach to leveraging tactile feedback for delivering Braille notations of online text to deaf-blind individuals. The proposed solution includes a website featuring interactive learning modules for vibrational Braille and a chatbot that responds to user queries. The responses are transmitted as vibrations onto a specially designed glove, enabling users to interpret them effectively. Customizability options allow users to adjust the reading time gap between characters to suit their individual comfort levels, enhancing the user experience.

The tactile feedback mechanism not only provides a hands-on learning experience but also facilitates faster skill acquisition. Moreover, the product significantly improves efficiency by transmitting all Braille notations in parallel, allowing users to perceive an entire character simultaneously rather than sequentially. This parallel transmission approach ensures a quicker and more seamless reading experience, making the solution highly effective and user-friendly.

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