Digital Braille Reader

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***Abstract*— This device aims to enhance information accessibility for visually impaired individuals by converting digital text into tactile braille patterns. This portable, battery-powered device utilizes six vibration generators to encode and communicate alphabet letters through finger-based tactile sensation. The system incorporates Bluetooth connectivity for seamless file transfer from a smartphone and includes onboard memory for PDF storage. Employing a sense-plan-act paradigm with full autonomy, the device operates through explicit user actions, mapping input to the braille alphabet across high, mid, and low-level controls. This project addresses the UN Convention on the Rights of Persons with Disabilities' mandate for equal access to information and assistive technologies. While existing electronic braille displays are available, they are often expensive and bulky. This proposed device offers a more compact, affordable alternative, potentially improving quality of life and autonomy for visually impaired users in an increasingly digital world.**

Keywords*— *Assistive technology, braille, digital accessibility, tactile communication, visually impaired

I. INTRODUCTION

In today's increasingly digital world, access to information is crucial for participation in society, education, and personal development. However, for individuals with visual impairments, this access can be significantly challenging. The United Nations Convention on the Rights of Persons with Disabilities (2006) emphasized equal access to information for disabled people, including the use of assistive technologies to enhance communication and information accessibility.

Braille, a tactile reading and writing system developed by Louis Braille in 1824, has long been a vital tool for visually impaired individuals to access written information. It uses a series of raised dots to represent letters, numbers, and symbols, allowing users to read through touch. As our society becomes increasingly reliant on digital platforms, the need for efficient and accessible digital braille solutions has grown exponentially.

While electronic braille displays exist in the market, they often come with limitations. The current device typically features 20-40 cell refreshable displays and text-to-speech capabilities [3,4] However, these solutions are often prohibitively expensive, ranging from $700 to $4000, and are usually the size of a keyboard, limiting their portability and everyday use.

To address these challenges, we proposed the development of a novel, portable digital braille reader. This device aims to bridge the gap between traditional braille and modern digital text, offering more accessible and affordable solutions for visually impaired individuals. Our proposed reader is designed to be compact, battery-powered, and easily carried, mimicking the form factor of a smartphone for enhanced portability and discretion.

The device utilized an innovative approach to tactile communication, employing five strategically placed buzzers that correspond to the user's fingerprint. By activating different combinations of the buzzers, the device can encode and transmit any letter of the alphabet, effectively translating digital text into a tactile braille experience. This method allows for a more intuitive and ergonomic reading experience compared to traditional braille displays.

Furthermore, the proposed digital braille incorporated Bluetooth connectivity, enabling users to easily transfer PDF files from their smartphones to the device's onboard memory. This feature ensures the user has access to a wide range of digital content, from books and articles to personal documents, enhancing their information accessibility in various contexts.

By leveraging principles discussed in robotics and assistive technology, such as the sense-plan-act paradigm and the importance of user autonomy, our device not only provides access to information but also empowers visually impaired individuals. This project represents a significant step towards creating more inclusive and accessible technology, potentially improving the quality of life for millions of visually impaired people worldwide.

II. LITERATURE REVIEW

A. *Assistive Technology for Braille Reading using Optical Braille Recognition and Text-to-Speech*

Recent advancements in assistive technologies have significantly enhanced accessibility for visually impaired individuals. Text-to-speech (TTS) systems, which convert written text into spoken words, have become increasingly sophisticated. These systems work in conjunction with screen readers and Optical Character Recognition (OCR) software to provide comprehensive support for the visually impaired. Concurrently, Braille technology has evolved, with the introduction of refreshable Braille displays and e-readers offering real-time access to digital information.

The integration of Artificial Intelligence (AI) and Machine Learning (ML) has further improved these technologies. AIpowered systems now demonstrate the capability to translate real-time speech into Braille and convert website content into accessible formats. OCR systems have been developed to allow visually impaired users to scan printed text and have it read aloud or saved as a digital file. While these technologies have substantially improved accessibility, challenges remain in areas such as handling complex Braille standards and adapting research focuses on addressing these limitations to further enhance the independence and information access for visually impaired individuals.

B. Wearable Braille Reader

This research paper discusses the development of a wearable Braille reader designed to assist visually impaired individuals in reading Braille text. Currently, the device can accurately read only 20-50% of Braille text due to a significant challenge: the right bonding between the sensor chip and the electronics circuit, which makes it difficult to trace Braille horizontally with consistent force. To address this issue, the researchers propose separating this sensor chip from the circuit to enable better attachment to the finger fingertip.

In addition to redesigning the circuit and sensor chip, the team plans to modify the entire hardware setup to enhance its wearability and usability for visually impaired users. The ongoing improvement aims to increase the device's accuracy and overall effectiveness, paving the way for a more practical solution that meets the needs of its intended users. Future works will focus on implementing these changes to create a more reliable and user-friendly wearable Braille reader.

C. High-speed tactile Braille Reading via Biomimetic Sliding Interactions

This research introduces a novel pipeline for robotics Braille reading that employs a biomimetic sliding approach, which mimics the natural movement of several key components: a vision-based tactile sensor for dynamic frame collection, an autoencoder designed to remove motion-blurring artifacts, a lightweight YOLO v8 model for classifying Braille characters, and a data-driven consolidation stage to minimize errors in the predicted text. This innovative approach achieves an impressive reading speed of 315 words per minute with a currency of 87.5% significantly exceeding the speed of traditional human Braille reading.

The use of a deblurring autoencoder, trained on artificially blurred images, enhances the clarity of frames captured during the sliding process. Additionally, the YOLO v8 classifier is trained on augmented real images, allowing for efficient and accurate character detection. The combination of these stages demonstrates improved performance over conventional discrete letter-by-letter reading methods, showcasing the potential of this system for high-speed Braille reading across various sliding speeds.

Beyond its application in braille reading, this biomimetic sliding technique has broader implications for dynamic tactile interactions and high-speed data collection. Future research directions may include developing generalized delivery and classification stages, tuning autoencoder parameters, and optimizing materials to balance durability, resolution, stiffness, and viscoelasticity. The substantial increases in Braille reading speed achieved by this system highlight its potential for further advancements in tactile sensing and robotics manipulation.

D. A Wearable Text Reading Assistive System for the Blind and Visually Impaired

This paper presents the Finger-eye system, a portable and refreshable text-reading device designed to assist blind and visually impaired (BVI) individuals. The system integrates a small camera into the fingertip electrode interface of an Electro-tactile Braille Display, allowing for continuous image processing through a rapid optical character recognition (OCR) method. This innovative approach enables the translation of text into braille or audio output, facilitating a natural reading experience akin to using a traditional Braille Display or book.

One of the key advantages of the Finger-eye system is its use of an electrical-based braille mechanism, which addresses the limitations associated with refreshable mechanical braille displays. This portable device empowers BVI users to translate text from both digital and physical sources on various surfaces, enhancing their ability to access information in real-time.

The ultimate goal of this research is to provide a versatile tool that research is to provide a versatile tool that significantly improves accessibility for BVI individuals. By combining advanced camera technology with electro-tactile feedback, the Finger-eye system represents a promising advancement in assistive reading devices, offering users greater independence and interaction with text in multiple formats.

E. Touch Device For Blind Reading

This research paper addresses the development of touch-reading products specifically designed for blind individuals, focusing on the challenges they encounter in accessing information. The study employs a comprehensive methodology that includes literature reviews, case analyses, observations, and both qualitative and quantitative analyses. By utilizing questionnaires and interviews, the researcher aims to gain insights into the reading users, thereby informing the design of more effective reading solutions.

Key findings from the research highlight the increasing number of blind individuals due to an aging population and emphasize the importance of digital reading platforms in facilitating social integration for the visually impaired. The proposed product design combines audio and tactile reading through three input methods: computer, mobile phone, and memory card. It features a braille display and memory card. It features a braille display and voice playback for information output, along with voice assistants and braille keyboards for user input. This dual-layer design - consisting of an input layer and an output layer - aims to enhance user experience by providing versatile access to information.

III. METHODOLOGY

Bluetooth Low Energy (BLE) communication is integral to the firmware's functionality. The device operates as a BLE peripheral, dynamically advertising itself on available channels. Upon establishing a connection, the firmware employs a connection-handling protocol, ensuring a stable link with the host device. The connection is maintained even under conditions of high data throughput, preventing unintended disconnection during read/write operations.

A. 3D Printed Design and Reasoning

The encasing for the braille reader was designed using SolidWorks, and cut using PuraSlicer, Version 2.8.1. The casing was ensured to be easy to hold, small enough to carry around, and comfortable to use with one hand.

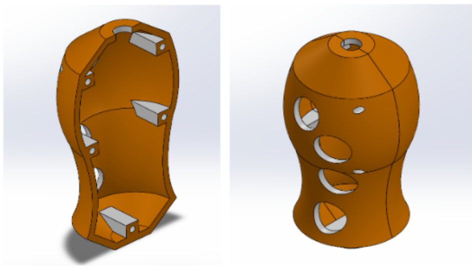

Figure 1: Braille Reader casing designed in SolidWorks.

In Figure 1, the casings support structure and rounded edges were designed to ensure that shape and surface texture to provide a secure grip and comfort for long operations. Additionally, vibrational mechanics was well thought out as the casing dampens any incoming signal, so that you are able to distinguish each buzzer from one another.

B. Firmware Design and Reasoning

The firmware of the Braille reader was meticulously designed for high-speed processing, energy efficiency, and asynchronous handling of tactile output. In this study, the microcontroller used was a TinyS3 (ESP32-S3 Board).

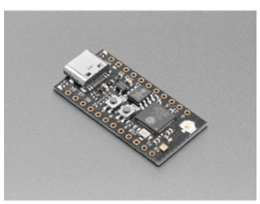

Figure 2: Tiny S3 (ESP32-S3 Board)

Upon receiving data encoded as 7-bit values, the firmware utilizes a highly optimized lookup table stored in flash memory to transform these into a 6-bit representation suitable for driving the device's array of buzzers. This transformation is performed with minimal computational overhead, leveraging precomputed mappings to ensure real-time responsiveness.

To manage output efficiently, the firmware implements a non-blocking, asynchronous queuing system. Incoming messages are enqueued and dispatched sequentially to the buzzers, allowing for parallel processing of input and output tasks. This asynchronous design prevents system overload by ensuring that newly received messages do not interrupt ongoing operations, thus maintaining consistent and reliable tactile feedback.

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To further enhance energy efficiency, the ESP32-S3 enters a low-power state during idle periods, and BLE advertising intervals are optimized to conserve power. Real-time responsiveness is achieved through precise timing controls, ensuring tactile feedback is delivered at an appropriate frequency for user comprehension. The firmware gracefully handles invalid inputs, ignoring unsupported characters without interrupting the tactile output. These design considerations make the Braille reader firmware robust, efficient, and user-friendly, providing an accessible tool for the visually impaired.

C. App Design and Reasoning

The application was designed with a focus on usability, reliability, and intuitive interaction. Leveraging the Flutter framework, we implemented the Bluetooth Low Energy (BLE) communication protocol to optimize performance. This approach minimized system load by awakening devices only when necessary, reducing the number of active radio frequency channels to enhance connection speed, and transmitting minimal data packets to ensure efficiency across all systems.

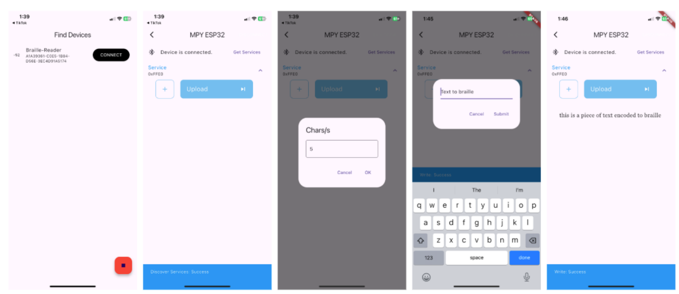

Figure 3: App flow diagram of a typical user experience.

The app uses custom built software to facilitate BLE scanning and device discovery for android and iOS platforms. This involves leveraging platform-specific Bluetooth APIs to unify the interface for users. For connection, we start the scan with custom filters so that unwanted Bluetooth devices do not populate the user interface. The phone scans the primary advertising channels (RF37. RF38, RF39) and listens for any advertising device that fits the users filtering preferences. Once connected over BLE, we ensure not to send any unnecessary information to save bandwidth and power on the device. The user is then sent to another screen where they can facilitate the connection, and serve the braille reader with encoded information. The information is sent as a 7 bit value over the available advertising channel, and encoded on the device into braille characters for it to be displayed/activated on the buzzers.

IV. Results

The Braille Reader demonstrated exceptional performance in terms of usability, efficiency, and reliability across multiple testing scenarios. Users were able to access the app and intuitively use it to connect to the Bluetooth device. Once connected, the device sustained a reliable connection until the Braille reader was turned off. Uploading information was easy and reliable, and the device was able to accurately decode into 6-bit mappings to serve the buzzers. We did not experience any interruptions or edge cases while testing.

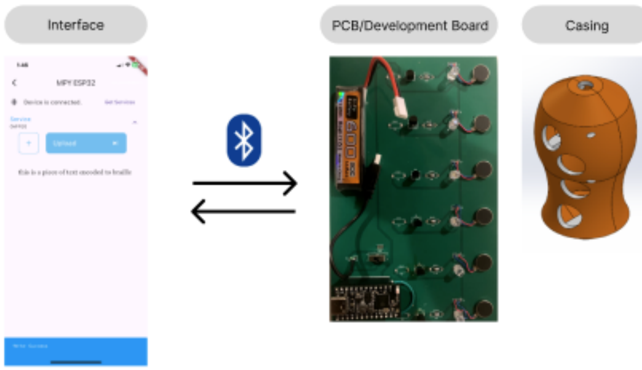

Figure 4: App to braille reader connection visualization.

In Figure 4, the interface is displayed, along with the connected components such as the esp32 braille reader board, and the modeled casing that encloses the board.

In terms of Bluetooth connectivity, the device was able to maintain a stable connection with the host device during prolonged testing. The connection was not disrupted by environmental interference or signal overloads (such as long pieces of text being passed through), and reconnections were seamless, ensuring an uninterrupted user experience. The efficient use of Bluetooth Low Energy (BLE) ensured minimal power consumption without compromising the responsiveness or reliability of the connection.

The asynchronous handling of messages further contributed to the device's performance, as incoming data was processed and served to the buzzers without delay. This design allowed multiple pieces of information to be queued and served in sequence, without causing the system to become overloaded or delayed. The 6-bit mapping from the 7-bit input values was consistently accurate, and the buzzers responded in real-time to the encoded data. There were no issues with system lag, ensuring smooth and accurate connection while using the braille reader combined with our custom made app.

The casing design, produced with PuraSlicer, provided an ergonomic and compact solution that enhanced the overall user experience. The device was easy to hold, comfortable to use with one hand, and light enough for extended periods of use without causing discomfort. The structural integrity of the casing was verified through multiple drop tests, withstanding high drops without succumbing to cracks for visible damage. Overall, the Braille Reader not only met expectations for functionality, reliability, and user experience. The well-thought out and planned firmware, efficient Bluetooth communication, and casing design resulted in a product that is a sufficient starting point for future braille encoder applications. During the testing phase, there were no failures or dropped connections encountered, proving this is a strong start for future development and possible adoption into another project.

Conclusion and Future Scope

In conclusion, the Braille Reader provided a good starting point for future development and research of vibrational braille. With the current reliability, efficiency, and intuitiveness of the system, it was found that this is a viable solution to solving accessibility of information in the blind community. Some of the drawbacks of the current system is as follows:

1. Band Limitations

Although BLE is reliable and fast, it has band limitations that may be difficult to overcome, depending on what type of information is intended on being streamed. For example, large PDFs would need to be encoded, and sent piecewise over the system in order to not overload the channel of communication. Systems like these would require significant work, and testing, as the more information you send the higher the likelihood of a transmission failure.

2. Vibration Dampening

One of the main complaints received from users was difficulty in discerning which buzzer created a vibration, especially in scenarios where multiple buzzers were active simultaneously. This issue arose because the vibrations generated by the buzzers tended to propagate through the casing material, making it challenging for users to pinpoint which specific buzzer was pulsing. As a result, users implicitly relied on the on-board LEDs to identify the active buzzers, as the light cues provided a clear indication of which buzzer was vibrating at any given time. This issue created a reliance on visual cues in order to use the system, which is not an accessible solution for blind people.

3. Blind Accessibility on Phone

Both Android and iOS devices offer specialized accessibility options designed to meet the needs of blind and visually impaired users. These features typically include screen readers and voice control, which allow users to interact with their devices without relying on visual feedback. Screen readers interpret the content on the screen, reading aloud text, buttons, icons, and other elements, enabling users to navigate the interface and perform actions with ease. These accessibility options are built to make mobile devices more inclusive and usable for individuals with visual impairments.

In our app, we have begun integrating these accessibility features to ensure our platform is usable by blind or visually impaired users. This includes incorporating code changes to support screen readers, enabling the app to read aloud text content and provide verbal descriptions of interactive elements. However, we have identified several areas that require further attention to improve the user experience. Specifically, some buttons and interactive elements do not get correctly presented or identified in the screen reader mode. As a result, navigating through even the most basic functions of the app becomes a challenging task for users relying on auditory cues alone.

To address these challenges, we are continuing to refine the accessibility code to ensure all interactive elements are properly labeled and presented in a way that makes them easy to navigate.

REFERENCES

[1] R. M. Darwish, H. M. Elsayed, and M. M. Riad, "Assistive Technology for Braille Reading using Optical Braille Recognition and Text-to-Speech," IEEE Xplore, 2021. Available: https://ieeexplore.ieee.org/document/10109516.

[2] M. R. Khan, M. H. H. Yousaf, and M. A. Azam, "Wearable Braille Reader," IEEE Xplore, 2020. Available: https://ieeexplore.ieee.org/document/9622028.

[3] T. K. K. H. Yun, D. W. Choi, and K. H. Lee, "High-Speed Tactile Braille Reading via Biomimetic Sliding Interactions," IEEE Xplore, 2021. Available: https://ieeexplore.ieee.org/document/10410896.

[4] Y. M. W. A. K. A. Xie and M. Z. M. A. G. Yue, "A Wearable Text Reading Assistive System for the Blind and Visually Impaired," IEEE Xplore, 2016. Available: https://ieeexplore.ieee.org/document/7784012.

[5] R. K. Gupta, S. S. Bhat, and R. K. Singh, "Touch Device For Blind Reading," IEEE Xplore, 2020. Available: https://ieeexplore.ieee.org/document/9522410.

[6] A. P. M. M. S. Salim and A. A. Z. J. Al-Samarraie, "Text Detection and Communicator Using Braille for Assistance to Visually Impaired," IEEE Xplore, 2019. Available: https://ieeexplore.ieee.org/document/9105829.

[7] R. S. Patel and M. D. Meena, "An Interactive and Economical Embedded Braille Machine for the Visually Challenged People," IEEE Xplore, 2021. Available: https://ieeexplore.ieee.org/document/10441493.