Background Research Summary

In recent years, significant progress has been made in the development of technologies and resources for people with disabilities. However, accessibility still remains unequal, with those affected facing daily challenges and restrictions that often go unnoticed by others without disabilities. Vision is a primary means of absorbing information and understanding the world around us, yet millions cannot rely on sight alone. The World Health Organization (WHO) estimates that around 40 million people are blind, and another 250 million live with some form of visual impairment (Mfamobani, 2023). For Visually Impaired People (VIPs), these challenges demand creative solutions, enabling them to navigate and thrive in a society that frequently overlooks their needs. In particular, Braille-focused assistive technologies designed for VIPs foster learning and autonomy but often can be limited in functionality and expensive to purchase. Data shows that 90% of employed VIPs are Braille literate (BrailleWorks, 2022); however, achieving this level is challenging for individuals who often lose phonemic awareness and phonics early on due to a lack of resources (Swenson, 2013). Such facts are why this team has chosen to devote its efforts to a Braille-centered invention, aware of its necessity and importance in the education of younger VIPs.

What is Braille?

As a tactile writing system, Braille enables many VIPs to read and write by using their sense of touch. Braille is a modification of the standard alphabet composed of raised dots arranged in specific patterns within cells to represent letters, numbers, and punctuation (Library of Congress, 2023).

The Braille alphabet is based on a three-by-two-cell configuration. Each Braille letter of the alphabet is formed using one or more dots in the Braille cell. Braille has two versions: Grade One and Grade Two. Grade One Braille is more commonly used for reading signs and brief notes, as it is a straightforward letter-for-letter transcription of the alphabet. Grade Two Braille is quicker to read and takes up less space due to its use of contractions and abbreviations, and is therefore used in most novels and magazines (ConnectCenter, 2017). Braille is read by passing one's fingertips over the characters on a Braille Cell, allowing VIPs to translate letters in an accessible format.

Significance of Braille

By using Braille, blind and visually impaired people can interpret the written word without relying on sighted readers. While Braille provides VIPs with a wide range of reading materials, these materials are often very bulky, costly, and limited (Library of Congress, 2023). Apart from reading materials, existing technologies are costly, averaging $3,500 (*Refreshable Braille Displays*, n.d.).

Moreover, the outside world contains a lot of visual information conveyed through text, such as signage. Advertisements, signs, and menus often do not have a Braille translation, which leaves VIPs reliant on audio or sighted individuals to assist them.

While fewer than 10% of 1.3 million people who are legally blind are Braille readers, access to Braille enhances knowledge accessibility and autonomy (National Federation of the Blind, 2009). Therefore, it is critical to cater to the development of accessible technology to reduce the barriers to Braille literacy.

Braille Literacy

Adolescents comprise a large number of the visually impaired community. WHO estimates that 1.4 million children worldwide are blind, and 36.4 million have some level of visual impairment (American Foundation for the Blind, 2024). For visually impaired adolescents who often begin their literacy education on par with sighted colleagues, learning Braille from a young age aids with literacy, as Braille is a better way to understand punctuation, grammar, and spelling than audio (Braille Works, 2023; Swenson, 2013). Braille literacy also has major implications on future life outcomes for a VIP as literacy affects an individual's health, lifespan, wellness, and socioeconomic status. According to Braille Works, the unemployment rate of VIP adults is around 70%, while 90% of employed VIPs can read and write (Braille Works, 2023). Evidently, Braille literacy has a direct correlation to employment and greater financial independence for VIPs.

Despite the well-documented importance of Braille literacy, the Braille literacy of students with visual impairments stands at around 10% (Braille Works, 2023). This discrepancy is correlated to a decline in qualified teachers who can educate students in Braille literacy. Early exposure to Braille is crucial to master Braille, where ample, daily practice is critical for success. They also need individualized feedback, which is difficult for teachers with heavy workloads (Hoskin et al., 2022).

While addressing the teacher shortage is a complex problem, an immediate impact can be made by focusing on enhancing the availability of cost-effective assistive Braille devices for VIP adolescents. In a study investigating the effectiveness of technology for Braille literacy education for children, it was found that technology for Braille literacy education should provide real-time auditory and tactile feedback and be easy to use, motivational, and engaging (Hoskin et al., 2022). Individualized, real-time feedback will help alleviate the discrepancy in qualified Braille educators and ultimately increase Braille literacy in adolescents.

Current Braille Translation Technologies

While there are existing assistive devices for helping VIPs with learning Braille, devices aimed at increasing accessibility for text-to-Braille remain limited and costly. The most common Braille translation technologies are centered on translating computer documents into Braille files that can later be printed on a Braille printer or sent to a Braille display. While it is useful for accessibility purposes, the obvious limitation is the medium, as such translations are only compatible with a computer interface. Costs also become a limiting factor of the technology, as Braille translation software is priced at around $895, and Braille printers are among the thousands range (American Foundation for the Blind, 2024). The high unemployment rate among VIPs makes these devices even more financially inaccessible.

Our focus is a portable device that can translate text-to-Braille, in real-time, from any surface, such as from a sign, book, computer screen, etc., and then provide the user a way of physically reading that translation on a Braille surface. Through extensive market research, we have found four competitors whose products meet some of our major criteria but have some significant drawbacks.

Competitive Technology

The following are four designs and proposed systems addressing Braille accessibility. These competitors are all protected under patents or are considered intellectual property. These patents are current and non-expired. The team chose to explore these four competitors because each shared an aspect relating to the team's invention, either with physical design or objective.

Competitor 1: Tactile

(Intellectual Property) US Patent No.: 11033187 B2
Li, G., Wang, C., Doshi, C., Yu, T., Shi, J., & Xia, C. (2021). *Text to Braille Converter*.

Tactile is a device designed by MIT undergraduates in 2017 but is currently not for sale (Petronzio, 2017). This device never went to a market testing stage, but an analysis of its components is important, as it has a similar function to the proposed device.

Tactile is a text-to-Braille translation device that contains 30 Braille cells attached to the top of a roughly brick-sized block with a camera on the underside. The device takes pictures of flat, written text, scans on the bottom of the device, sends them to a microcontroller that converts the image to text, and ultimately displays the translated Grade 1 Braille on the tablets.

Despite the device being touted as being smaller and more cost-effective than current Braille machines, modifying the device to make it smaller could make it more accessible and portable. For example, designing a device with fewer Braille tablets would make it more portable and responsive. Furthermore, adding the ability to adjust the position of the camera would allow users to take more versatile pictures of text in their surroundings. Adding a mechanism for the device to automatically know if the user is done with the line, as well as a text-to-audio feature would not only make the device easier to use on a daily basis, but it would also expand the device's audience. Even though this project has not been updated since 2017, no other competitors currently perform the basic function of translating text from a camera to Braille.

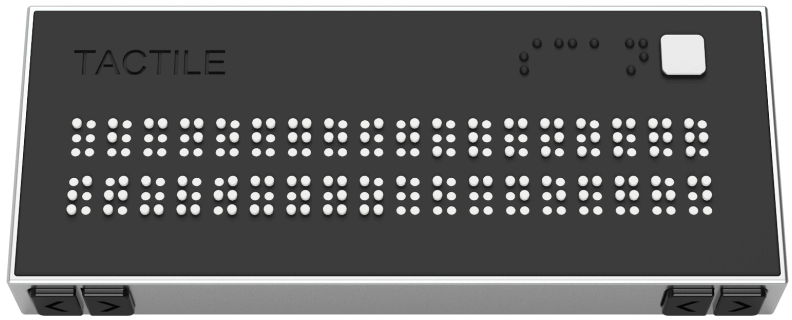

Figure 1: Top view of the Tactile Device. The white pegs move up and down to display Braille characters for users to move their fingers across the board and read the Braille (Petronzio, 2017).

Competitor 2: Smart Interactive System for Braille Learning

(Intellectual Property) US Patent No.: 11514817 B2
SHAIKH, S. A. S. A., RAMESH, D., DAWLE, S. A., & SRIVASTAVA, A. K. (2022). *Smart interactive system for Braille learning*.

The Smart Interactive System for Braille Learning combines a Braille keyboard, digital slate, large displays, and a proximity touch sensor to deliver immediate audio, tactile, and haptic feedback. Controlled by a microcontroller, it facilitates Braille typing, embossing, and reading. The system includes an audio amplifier, and actuator feedback for accuracy, and supports wired and wireless connectivity (USB, Wi-Fi, Bluetooth). In addition, the patented system offers multilingual educational content structured as lessons of increasing difficulty, enhancing Braille literacy with real-time feedback, game-based practice, and classroom leaderboards for an engaging learning experience.

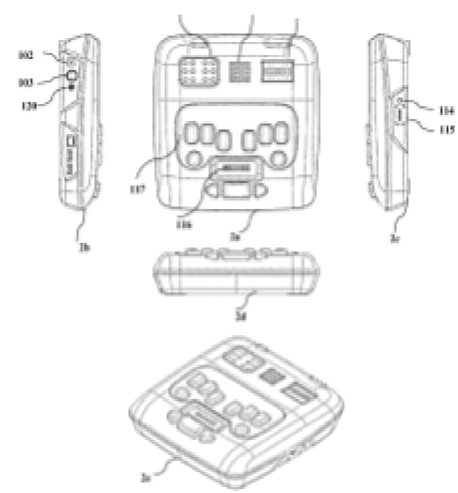

Figure 2: Diagram and design of Smart interactive system for braille learning (SHAIKH et al., 2022)

This patent addresses the same need this team's invention wishes to tackle. The inventors and this team share the belief that more resources need to be developed to increase Braille literacy. The way these inventors designed their system, however, significantly differs from this team's proposed design outcome. While focusing on the physical Braille medium, the patented system does not include an optical component central to the translation service this team's device will complete. This team's Braille display will be of standard size and feature 16 cells, as it is ideal for larger sentences. Further research on this patent shows that it may not have been developed to the extent proposed.

Competitor 3: Portable Braille Printing System for the Visually Impaired.

(Intellectual Property) European Patent No.: WO2022132100A1
Dal, D., & Çakir, M. (2022). *Portable Braille Printer System for the Visually Impaired People*

The patented portable braille printing system for the Visually Impaired aims to be a cost-effective, portable braille printer that translates text from computer files into Braille and embosses the translated Braille to produce tactile documents (Dal & Çakir, 2022). A microcontroller is used to control a Braille pen which moves across the paper to emboss Braille characters. This device addresses the high cost and size of current Braille printers and aims to tackle similar problems as our second device design.

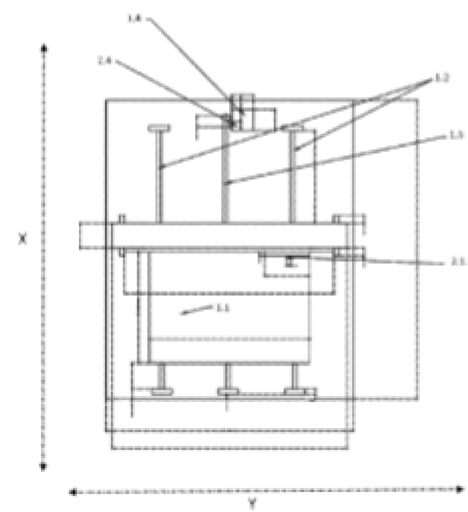

Figure 5: Top view of invention system and enlarged view of Braille tip and Braille plate (Dal & Çakir, 2022)

Due to its simple design, the patented Braille printer is the size of a Braille typewriter and is portable for VIPs to carry in and outside of the home. The device uses a single Braille pen that embosses the cut sheet or tractor media based on the translated Braille. After printing, VIPs can touch the raised characters to interpret the text and potentially save the embossed paper for future reference.

While the device is portable, it is unable to translate text that is not digitally saved. There is a significant amount of physical text VIPs encounter daily in their environment, whether it is on menus, signs, etc. As such, this device has limited applications as it can only translate computer files into Braille. Additionally, having a single Braille pen to emboss the paper can make the printing task extremely tedious, especially for longer documents.

Adding a camera to automatically read text and convert it to Braille will allow the device to be used on numerous different types and formats of text, increasing the utility and practicality of carrying the device outside the home to perceive the surroundings. Furthermore, incorporating multiple Braille pens could significantly speed up the embossing process, making the device more efficient. By improving both speed and versatility, these additions would make the device a more valuable tool for everyday use, promoting greater independence and accessibility.

Our Inventions

Throughout this process, our team has identified two solutions to this problem: creating a text-to-Braille translation device, as well as creating a low-cost Braille printer.

Solution One: Refreshable Braille Display

Our first solution, a text-to-Braille translation device, aims to create a novel and affordable alternative to typical refreshable Braille display technologies by incorporating rotating electromagnets and 3D-printed Braille cells connected to custom PCB boards (Varada, 2023).

This design concept employs electromechanical refreshable Braille modules. The key component of this design is a cam actuator, which consists of an eccentric cam with a magnet embedded in it. This complex is rotated to two stable positions by an electromagnet that can change its polarity. The rotation of the cam causes a Braille dot to be lifted or taken down. The frame of this device has been designed by the team in Onshape CAD and 3D printed using an SLA 3D printer. All electrical design was constructed upon a PCB board and a Raspberry Pi. Text-to-speech will be implemented using a speech application program interface (SAPI) allowing given text to be converted into audio. Batteries will be added to ensure the device can sustain power whilst being portable.

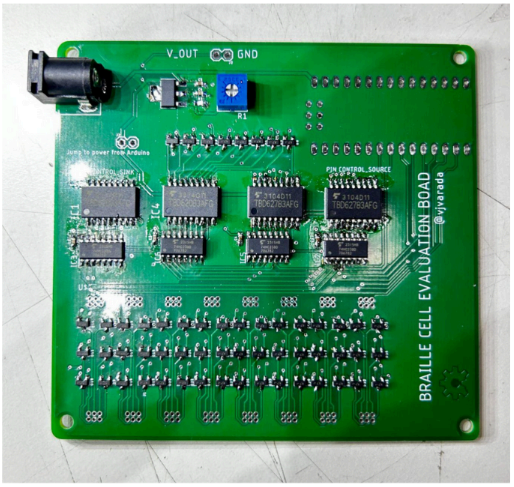

Figure 6: Custom PCB Board

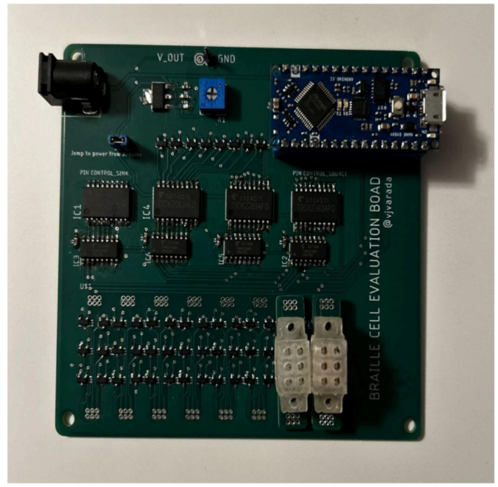

Figure 7: PCB with Samples Braille Cells

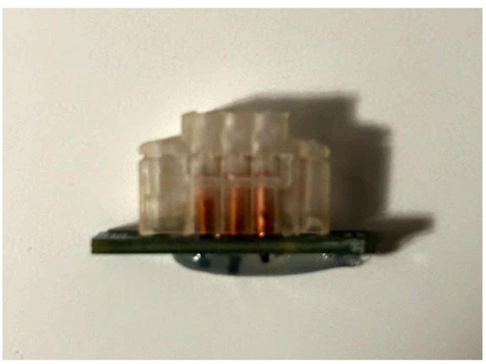

Figure 8: Assembled Braille Cell

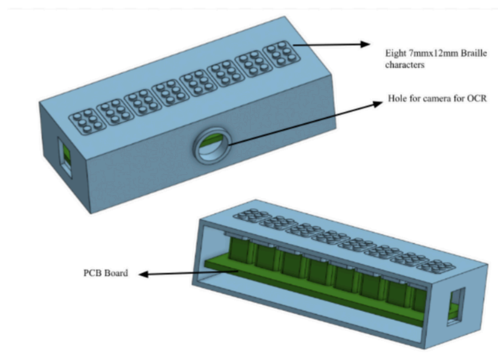

Figure 9: CAD of the Complete Device

The team has created prototypes of this model previously, which are shown in the pictures above. Our team decided to pursue this design because it promised both portability and affordability, qualities that increase the Braille characters that could be displayed. Not only that, the materials needed were accessible to procure and overall, had straightforward assembly. We did encounter some problems while producing this device, such as issues with printer quality, that prompted us to re-evaluate our design and think of alternative methods of using the same technology in a different design. In the future, our team hopes to implement this device into an educational setting, making it robust for young children to use repeatedly and adding a speech component (altering the design to include a speaker) to aid in the Braille education process. This specific implementation and device are both urgently needed in the VIP community, as there is limited educational hardware available to schools to be able to teach students Braille in a way that parents would be able to assist in the learning process, as much of this learning would be done outside of the classroom.

Solution Two: Portable Braille Printer

Our second solution is to create a portable Braille printer that embosses Braille characters onto paper to allow VIPs to independently access printed materials and produce their own tactile documents wherever they are.

Similar to solution one, the portable Braille printer would use camera input to produce a tactile medium to allow VIPs to understand and interpret text in their surroundings. However, this design would allow users to preserve the Braille output for later reference, creating a physical record of the information they encounter, which could be particularly useful for repeated use or study. Inspired by commonly used Braille embossers and craft machines, the device would use a pen-like arm to emboss the paper while it moves along a paper roll. The paper roll would be a roll of cut sheet media or tractor paper as their thickness allows the pen to indent the paper without tearing and is commonly used in industry-standard braille printers. However, an important consideration is the speed of printing. Having a single arm to emboss each individual Braille dot can be inefficient and tedious for the user. Therefore, the printer will have two rows of six Braille cells, with each cell having six Braille pens in a 3x2 matrix configuration. This way, multiple characters can be embossed at once, accelerating the printing process. If the text from the camera input requires more than 12 Braille characters to represent, the device will shift the paper and continue printing the rest of the text. After the device has finished printing, the device will have a serrated edge to allow users to tear the printed paper and save it for future reference.

After the user takes a picture of text in their environment, the device will perform OCR to extract the text and initiate the printing process. The device will print in Grade 1 Braille and will use a set of six Braille pens to represent one English letter. The device will translate the extracted text into Braille and use a similar electromechanical approach as our first solution. Based on our research, we found that this method is the most cost-effective and straightforward technique to convert printed text into Braille, making the device both affordable and easy to use for VIPs. The roll of paper will be above the Braille pens. The Braille pens will rise using a cam actuator, which consists of a rotating cam with a magnet embedded in it. The rotation of the cam causes a Braille pen to be lifted up, imprinting the paper. As all twelve Braille pen matrixes will emboss the paper at the same time, we estimate that the printing process should take no longer than 10 seconds after the picture is taken. After the printing is complete, the pens will retract down, allowing the paper to move along the device without interference. If necessary, the device will repeat the printing process if the extracted text requires more characters.

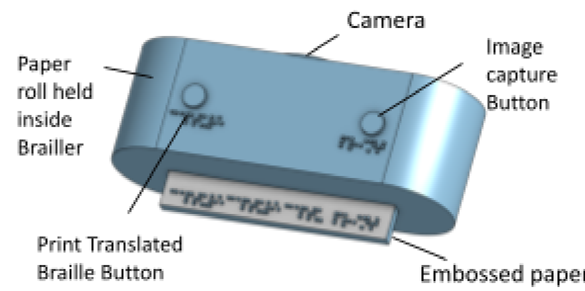

Figure 10: Portable Braille Printer CAD

The user can tear the printed page and run their finger along the paper to interpret the translated Braille. Because users can save the paper, they can revisit the text as often as needed. For users who are interested in being more fluent in reading and interpreting Braille, saving the page can help them reinforce their learning and familiarize themselves with Braille characters. Additionally, the portability of the device makes it a valuable and functional resource for new learners and VIPs who want to interpret and access text in their surroundings.

Preliminary Performance Specifications:

The context for these inventions lies in the daily challenges VIPs face due to the lack of accessible written information. The proposed solutions—a text-to-Braille translation device and a portable Braille printer—are technically feasible due to their reliance on proven technologies. The text-to-Braille device employs electromechanical refreshable Braille modules, using rotating electromagnets and 3D-printed Braille cells connected to custom-printed PCB boards, ensuring both portability and cost-effectiveness. The Braille printer uses a similar electromechanical approach to emboss Braille on paper, allowing users to create a physical record of information they encounter. Both models leverage established technologies, such as optical character recognition (OCR), cam actuators, and Braille printing mechanisms, making these solutions realistic with further development. Furthermore, our team has already tested prototyped versions of the OCR software as well as aspects of the Braille module and Braille cells, which further proved the technology's potential.

To determine which proposed invention is most useful and unique, our team conducted three key steps. First, we analyzed existing technologies to identify market gaps our device could fulfill. We also consulted VIPs and organizations serving this community to design our device as we believe the development of our idea and invention must be done alongside those we aim to benefit (as explained in Community Engagement documents). Finally, we established and ranked requirements for the ideal invention using an engineering decision matrix. We assigned points based on how well each device met factors like effectiveness, price, and portability and the importance of those factors. The refreshable Braille display earned more points than the portable Braille printer, making it the objectively better option (Figure 12).

However, to maintain the iterative and explorative approach of inventing, our team will continue to work with both ideas till we can not only objectively, but technically and practically reduce our two proposals to one. We will continue to present our ideas to individuals in the community to determine which idea is more effective and unique.

Requirement	Level	1	2		Key
The device shall be able to record text from a surface	3	Y	Y		Functional
The device shall be able to convert the text into braille characters	3	Y	Y		Physical
The device shall be able to present the braille characters to the users, at least 6 characters at a time	3	Y	Y		Cost
The device shall be able to help the user properly position the device in front of the text	3	Y	Y		
The device is portable, and can be operated outside of the home	3	Y	Y		
The device shall weight less than 400 grams	3	Y	N		
The device shall be less than 8 cm tall, 15 cm wide, and 8 cm deep	3	Y	N		
The device shall cost less than $125	3	Y	N		
The device shall be able to convert the text into speech	2	Y	N		
The device shall be able to present the speech to the user	2	Y	N		
The device shall have buttons to control the device physically	2	Y	Y		
The device shall be made of durable material	2	Y	Y		
The device will connect to an app which can help the user customize their experience	1	Y	Y		
Totals		33	20		

Figure 11: Engineering Decision Matrix of both proposed Braille devices. Column 1 is the refreshable Braille display, and column 2 is the portable Braille printer.

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