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HaptX DK2 Tactile Smart Gloves as Refreshable Braille Displays*

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I. Introduction

The World Health Organization estimates that 2.2 billion people are visually impaired. Despite recent progress in assistive technologies for blind and low vision people (BLVP), a gap exists in physically unrestricted Braille reading solutions. One hardware option supporting such boundaryless digital text accessibility is wearable haptic gloves, which offer the greatest ease of use for BLVP as they enable users to experience motor control, intention, and tactile interaction in virtual and mixed-reality environments. This work introduces novel, next-generation smart gloves, adapting HaptX DK2 tactile gloves into refreshable Braille displays to meet the 8-dot Braille Authority of North America (BANA) standard. Our proposed system leverages user's hand orientation and position to dynamically modulate Braille character flow across the gloves fingertips' tactile actuators. The current study focuses on Braille representation utilizing the Liblouis translation library to stream digital content as physical Braille.

II. Methods

A. Overview

HaptX DK2 smart gloves were custom built as a dynamic refreshable Braille display by activating laser-cut 8-dot Braille compatible tactile actuators positioned on each of the gloves' fingertips. Custom software utilizes the Liblouis translation framework to convert digital text into Braille cell mappings and control the dynamic inflation of the glove's tactile actuators to simulate digital text in tactile Braille format. Real-time software adapts the activation behavior of tactile actuator grid inflation to match the speed and directionality of users' hand movements, supporting an intuitive tactile Braille experience.

B. Liblouis – Braille Transcription Framework

Liblouis is an open-source tool that enables seamless translation and formatting of Braille content across various digital document formats. Liblouis' Braille translation is driven by translation tables, which define rules in an intuitive, text-based syntax. These tables support uncontracted Braille, mapping print characters to Braille symbols, as well as contracted Braille, which replaces common words and letter sequences with specific Braille contractions.

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C. HaptX Custom DK2 Tactile Smart Glove

The HaptX DK2 tactile smart glove system was customized to support its use as a refreshable Braille display [1]. First, we ensured the glove adhered to size and spacing standards defined by the BANA, with slight deviations to maintain some original motion capture functionality. The tactor grid, shown in Fig. 1, was spaced based on Braille dimensions but is slightly narrowed to support continuity of Braille letter movement across fingers. Equal spacing was employed between dots in adjacent cells. The tactile panels were fabricated by a laser-cutting process, in an effort to balance precision with scalability. Due to variations in finger sizes, critical design decisions for individual fingers included prioritization of index and middle finger tactile actuator grids for efficient Braille reading. The smaller ring and pinky fingers' tactile actuator grids had less surface area and reduced tactile sensitivity. A modified DK2 thumb panel (not shown) supported tactile actuators near the distal joint.

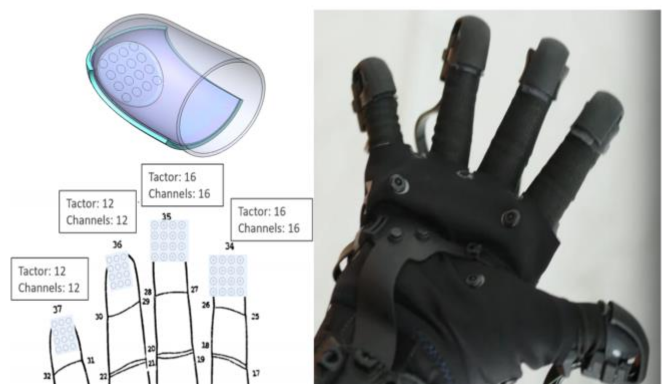

Fig. 1. Left top: CAD image of the fingertip tactile grid for a pointer/middle finger, gray shows glove fabric. Left, bottom: The distribution of the tactile actuator (tactor) grids for each fingertip in the HaptX DK2 smart glove. Grids on the index and middle fingers are prioritized with higher resolution as these fingers serve the primary role in tactile perception for BVIP. Right: The right hand of the HaptX DK2 smart glove. Tactile actuators are beneath the black thimble-like structures on the fingertips.

To utilize the HaptX DK2 Tactile Smart gloves as a refreshable Braille display, real-time translation of digital text-to-Braille is converted to Braille cell position information and streamed to the HaptX tactile actuator system, as in Fig. 2.

First our software intakes a text or other file and harnesses Liblouis translation framework to convert the digital content into 8-dot Braille [2]. Braille is generated using Liblouis' translation tables, while semantic mappings from Liblouis enables advanced formatting for structured documents. The Liblouis translation process produces Braille equivalent content. The Braille characters themselves are parsed by our custom software into 8-dot Braille cell components, labeled 1 through 8. For example, the letter 'b' is comprised of cells 1 and 2. To efficiently process large streams of text, each

Liblouis Braille character is converted into a numeric list, represented as an array, which corresponds to specific positional Braille values (e.g., [1, 2] for 'b').

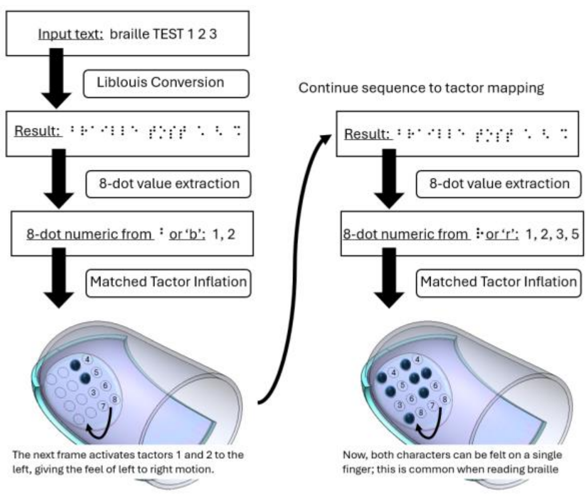

Fig. 2. A visual representation of the tactor activation given input text. The input text 'Braille TEST 1 2 3' is first converted to standard 8 dot Braille by Liblouis. Then corresponding Braille cells for each letter are extracted and mapped to tactors, which inflate at a user-controlled speed and amplitude.

The entire Braille word is then represented as an array, with the Braille letters nested within (e.g., [[1, 2], [1], [1, 2, 4, 5]] for 'bag'). While grouping letters within words serves a purpose for effective streaming and user determined stream-speed, there is no benefit to grouping sentences; therefore, each Braille word is converted to an array in real time, allowing the user to feel the tactile Braille stream on a letter-by-letter basis. Following Braille-to-array conversion, the positional Braille values (e.g., cells 1 or 2) are mapped to specific tactor IDs of the 8-dot Braille tactor grid. Fig. 2 shows the process of mapping a letter to the tactor grid, which is inflated in the appropriate fingertip of the glove as described below and as seen in Fig 3.

HaptX's haptic feedback system uses pneumatic actuators to control the inflation of tactors, creating tactile sensations on the user's fingers through its native Software Development Kit [3]. We ensure the software controls the pressure and timing of these actuations consistent tactile output of Braille characters. Tactile actuator intensity and timing are precisely controlled to enhance the readability and usability of the system. By default, the software inflates tactors dynamically by streaming the Braille sequence across the user's gloves at a constant rate, starting from the right-hand pinky and ending at the left hand. This default behavior simulates the movement of Braille cells across the user's fingertips in a manner that mimics the experience of traditional Braille reading. However, we further designed the system to consider users' hand movements by querying acceleration information from the motion capture data collection system built into the HaptX DK2 tactile smart gloves. The motion data allows us to adapt users' reading speed based on their hand movements. For example, sliding the hand right increases Braille streaming speed to be faster than the preset default; sliding left reverses the direction of the Braille cell stream, effectively allowing the user to re-read a previously streamed Braille sequence when the hand returns to rest.

III. Results

The Haptx DK2 tactile smart gloves were customized with BANA standard 8-dot Braille tactors, as shown in Fig. 1, to form a refreshable Braille display device. All tactors were fabricated using laser-cutting, as mentioned, ensuring precise dimensions for tactile feedback. Initial tests showed variability in tactor diameters due to laser drift, with a median diameter of 1.84 mm, slightly exceeding the standard 1.44 mm set by BANA. Through empirical studies, an optimal tactile actuator inflation pressure was determined to be 25 psi (172 kPa), balancing tactile responsiveness and user comfort. The system consistently achieved the required inflation height of 0.48 mm, critical for accurate Braille perception. Tactor failure only occurred after tactors withstood at least 10,000 inflation cycles, with primary failure modes being tactor delamination and bursting. Future iterations will utilize silicone-molded tactors for enhanced uniformity and durability. An example of an inflated tactor and the prototype grid is shown in Fig. 3.

After DK2 glove development and prototyping, we conducted a pilot user study with three participants (2 female, 1 male), aged 34±6 years, including one sighted, one low-vision, and one fully blind user. Participants achieved an average letter recognition accuracy of 68% and sentence recognition accuracy of 54%. They rated the gloves with 4.67/5 comfort, 3.33/5 usability, and 3.66/5 intuitiveness.

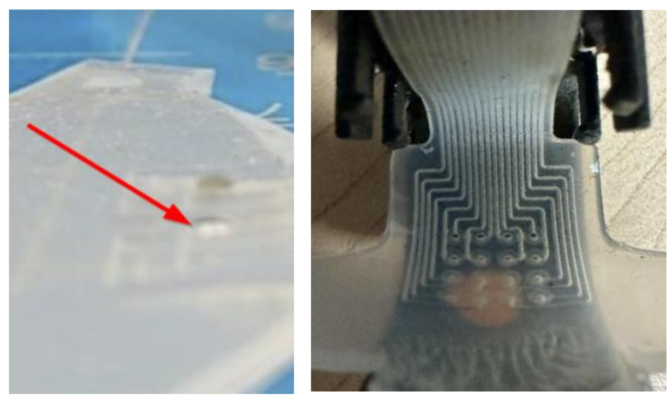

Fig. 3. Left, an inflated tactor. Right: the index fingertip of DK2 glove as a refreshable Braille display using BANA standardized Braille tactor layouts.

IV. Conclusion

This study demonstrates HaptX DK2 tactile smart gloves can be customized into a novel, high-fidelity, refreshable Braille display to make accessible digital content for BLVP. Integration of pneumatic tactile grids, real-time text-to-braille translation, and motion-adaptive streaming enables a flexible and spatially dynamic reading experience, unlike traditional Braille displays with fixed cell limitations. While the current system is a prototype, initial results confirm feasibility and user acceptability. Future work will expand the user study and refine glove and actuator design for richer haptic interaction.

References

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