Enhancing eBook Accessibility: Exploring 2D Tactile Displays for Blind and Low-Vision Readers

Sara Alzalabny
NeptunLab
University of Freiburg
Freiburg im Breisgau, Germany
sara.zalabny@partner.kit.edu

Hans Mees
ACCESS@KIT Karlsruhe Institute of Technology
Karlsruhe, Germany
hansmees01@gmail.com

Karin Müller
ACCESS@KIT Karlsruhe Institute of Technology
Karlsruhe, Germany
karin.e.mueller@kit.edu

Thorsten Schwarz
ACCESS@KIT Karlsruhe Institute of Technology
Karlsruhe, Germany
thorsten.schwarz@kit.edu

Bastian Rapp
Freiburg Center of Interactive Materials and Bioinspired Technologies University of Freiburg
Freiburg im Breisgau, Germany
bastian.rapp@neptunlab.org

Rainer Stiefelhagen
CVHCI@KIT Karlsruhe Institute of Technology
Karlsruhe, Germany
rainer.stiefelhagen@kit.edu

Abstract

Ensuring that electronic books (eBooks) are inclusive and accessible to all readers, including people who are blind or have low-vision, is crucial for promoting equal opportunities in education and information access. In this paper, we explore the potential use of 2D refreshable tactile displays to convey eBooks for people who are blind or have low-vision. Therefore, we introduce a design of an eBook reader that incorporates interaction concepts derived from suggestions in the existing literature on how eBook readers can be customized for this target group. In addition, we followed a participatory design approach by involving blind users in a preliminary study. We integrated their feedback along with their suggestions for improving the interactions and the representation methods implemented in the reader. This paper discusses the design decisions and presents users' suggestions and feedback gathered during our preliminary study. It also highlights our insights for future work in developing user interfaces and interaction concepts for 2D refreshable tactile displays.

CCS Concepts

• **Human-centered computing** → **Interaction devices**; **Haptic devices**; *Graphical user interfaces*; **Accessibility systems and tools**; **Accessibility technologies**; Accessibility design and evaluation methods.

Keywords

Accessibility, 2D Tactile Displays, EPUB, User Interfaces, Interaction Concepts

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1 Introduction

EBooks are becoming more important with the increasing demand for digital information, as they enable the readers to access books with reduced effort, compared to the traditional paper format [22]. However, numerous eBook applications fail to provide blind users the same benefits as sighted users, resulting in restricted and inequitable access to digital resources [4]. One of the widely used formats for eBooks is the Electronic Publication (EPUB) format [27]. EPUB is used for representing newspaper articles, educational materials, and scientific publications. The format is designed to be easily readable on a variety of devices, such as mobile devices, and computers. In comparison to other formats like Word and PDF, this format offers a distinct advantage by supporting dynamic content, reflowable text, and adaptability to various screen sizes. Moreover, it can include text, images, links, and other multimedia elements, enhancing the overall reading experience.

Numerous studies have investigated how eBooks can be made accessible to blind people. Some of the approaches discussed the possibility of making EPUB accessible via traditional methods used by blind individuals, such as one-line Braille displays and screen readers. These methods depend on converting the information into one-dimensional data that can be accessed solely by audio or a combination of audio-Braille feedback. However, screen readers often fail to deliver the structural information such as text size, spacing information, and relative positions that may contribute to the overall understanding of the document and the overall reading experience [9]. Additionally, some investigations showed that this knowledge about the spatial layout could enable blind and low-vision people to collaborate and co-author effectively with sighted individuals [13].

2D refreshable tactile displays [5, 8, 26] represent a significant advancement in assistive technology, offering the capability to present data in a 2D format while enabling interactive experiences for blind individuals. With the advent of devices that incorporate

touch functionality, such as HyperBraille [18] and DotPad [21], there is an opportunity to implement more sophisticated interaction concepts to enhance access to 2D data. Several researchers have investigated the use of these displays for conveying both graphical and textual content to blind users [1, 2, 6, 7, 16, 19, 23]. However, the development of tailored user interfaces and interaction concepts for these displays, particularly in reading contexts and eBooks, remains largely underexplored.

In this paper, we introduce a new eBook reader for EPUB format that runs on 2D refreshable tactile displays. Our contributions include:

- A design of an EPUB reader designed to facilitate eBook reading for blind users using 2D refreshable tactile displays.
- Interaction concepts incorporating both touch- and button-based inputs, developed through insights from existing literature and feedback from two blind persons.
- Findings from a preliminary study, involving two blind participants, that evaluated the proposed reader and provided feedback for future refinement.

2 Related Work

In this section, we review prior research focused on enhancing the accessibility of eBooks and proposed solutions for developing eBook readers specifically designed for blind users. Furthermore, we examine existing literature on the design of user interfaces tailored for 2D refreshable tactile displays.

Improving the accessibility of EPUB files has been a focus of many researchers aiming to enhance the reading experience for blind users. Bartalesi et al. [3] addressed this challenge by identifying key limitations in how screen readers convey information about images and tables, particularly how screen readers read alternative text seamlessly within the main text. Therefore, they proposed a solution to this issue, by adding hidden tags preceding various elements such as titles, tables, and lists within the EPUB format. This approach enhances accessibility by providing the user with the element-type information before it is read out by the screen reader. The results of evaluating this enriched EPUB format in a survey with 18 blind participants showed improvement considering the detection of images and tables, however, some improvements were noted for future eBook readers to further improve the accessibility. One recommendation is the incorporation of a navigation structure that enables users to navigate through content section by section. Additional features include easier and quicker access to the table of contents, the option to toggle the visibility of complex data elements such as tables and images upon user request, and the use of the content structure for navigation through the table of contents and headings. Further suggestions encompass the ability to semantically detect element types from tags and attributes.

In a survey by Leporini et al. [12] involving 75 blind participants, their preferences for studying with different types of books were explored. The results showed that 56 participants preferred eBooks over audiobooks for studying, and 92 expressed interest in a new eBook reader with improved reading capabilities. The survey also highlighted significant usability challenges, such as difficulties in managing notes and navigating sections efficiently. While mobile devices are valued for their portability, they often lack accessible editing features, making tasks like annotation and searching cumbersome. Participants emphasized the need for functionalities such as efficient navigation through pages, chapters, and paragraphs, alternative text for images, and features like bookmarking, text highlighting, and exporting content to files or email.

Kim et al. [10] presented another approach of which blind users can read EPUB and Digital Accessible Information System (DAISY) documents using 2D tactile displays. The system consisted of an application that ran on a smartphone, which processed the eBook file and also handled the user interactions. By using this application, the user could navigate in the file using their phone and accordingly, the displayed data on the smartphone is converted into tactile format and can be displayed on the connected tactile display. By relying solely on the smartphone for user interaction, the researchers did not explore opportunities to utilize some of the currently available tactile display capabilities for direct touch-based navigation or interaction, which could enhance usability and accessibility. Furthermore, the approach was not evaluated with blind users to gather insights into the system's practicality and effectiveness.

Several studies have explored the design of user interfaces for 2D refreshable tactile displays, particularly their potential for presenting graphical information to blind and low-vision individuals [6, 24, 25]. Leo et al. [11] demonstrated that using 2D tactile displays improved blind and low-vision participants' performance in spatial problem-solving tasks compared to traditional raised paper methods. Loitsch et al. Loitsch et al. [16] developed an interface for rendering UML sequence diagrams on 2D tactile displays, incorporating scrolling interactions to enhance navigation. However, their study also highlighted the challenges posed by the limited resolution of tactile displays, emphasizing the need for alternative interaction techniques to overcome these limitations. Prescher et al. [23] addressed the issue of disorientation often caused by midpoint zoom techniques on larger tactile displays by proposing two innovative zooming approaches. Their focus zoom method centers on the selected element, offering a more intuitive and targeted zooming experience, while mitigating navigation challenges.

Some other research approaches explored the potential use of 2D refreshable tactile displays for reading digital documents. An example of this is the work of Melfi et al. [17], where they introduced an approach for presenting PDF documents on a 2D refreshable tactile display. The authors mentioned one challenge associated with 2D tactile displays which is the limited available space to represent full text. For this purpose, Melfi et al. proposed a solution by substituting the text in the original document with symbols. By selecting the symbols through touch interactions, the screen reader can read the corresponding text. However, this method mainly concentrated on PDF documents.

3 Design of an EBook Reader for EPUB Format on 2D Tactile Displays

In this section, we present our suggested eBook reader for EPUB format. In our case, we used a HyperBraille 2D refreshable tactile display [18] for testing the concept. The display has a resolution of 104 * 60 pins and supports touch functionality. The new eBook

reader combines audio feedback and haptic interactions. The interactions we have implemented cover some of the recommendations of Bartalesi et al. [3] and Leporini et al. [12], including the implementation of different schemes for navigation, such as navigating by chapters or sections.

3.1 EPUB Format Preparation

In an initial step, the EPUB reader program, implemented in C++, processes three file formats embedded within the EPUB file, as depicted in Figure 1: (a) The first file format is an eXtensible HyperText Markup Language (XHTML) document, which contains the primary book content. (b) The second file format is a Cascading Style Sheet (CSS) file that defines the layout and formatting of the content, specifying the sizes and positions of text, images, and other elements. Both file formats are parsed using the litehtml library [15]. (c) The third file format for graphics is the Portable Network Graphics (PNG) format which is parsed using OpenCV library [20].

After parsing, some adjustments are made to the files for a better tactile representation. For example, all images are resized to fit the dimensions of the 2D refreshable tactile display, with the colors reduced to black and white. Additionally, the distances between all elements are modified to ensure adequate spacing, preventing overlap or elements being too close to each other.

For the XHTML file, an additional hidden tag is added to mathematical equations written in LaTeX format to distinguish them from standard text to enhance accessibility. Afterward, text elements from each page are translated into six-dot Braille on a word-by-word basis using the Liblouis library [14]. Words are evaluated if they fit within the current line to avoid splitting, ensuring clarity. If a Braille word exceeds the available space, it is hyphenated after the first syllable. Other file formats in the EPUB, such as video or audio files, are not processed since they are not used for tactile representation. The final tactile format is then displayed on the 2D tactile display, which is connected through TCP/IP connection.

3.2 View Modes

The interface provides three viewing options for presenting EPUB document pages: structure view, reduced structure view, and content view. Users can choose to display these views either horizontally or vertically on the screen.

3.2.1 Structure View. The structure view displays bounding boxes corresponding to the elements on the page with the original position and size of each element, as shown in Figure 2 (a). An identifying letter of the corresponding XHTML tag is added on the upper left corner, as shown in Figure 2 (a) the highlighted corners of the bounding boxes, of each rectangle to identify the type of the element, as shown in Table 1, e.g. the Braille letter 'h' represents a header and 'p' represents a paragraph to inform the reader of the type of content.

3.2.2 Reduced Structure View. The reduced structure mode omits paragraph and section elements, leaving only headings, images, and equations. This mode aims to simplify the search for key elements by removing text elements that occupy significant space. This view mode is based on the recommendations of Bartalesi et al.[3] of toggling the visibility of complex data elements.

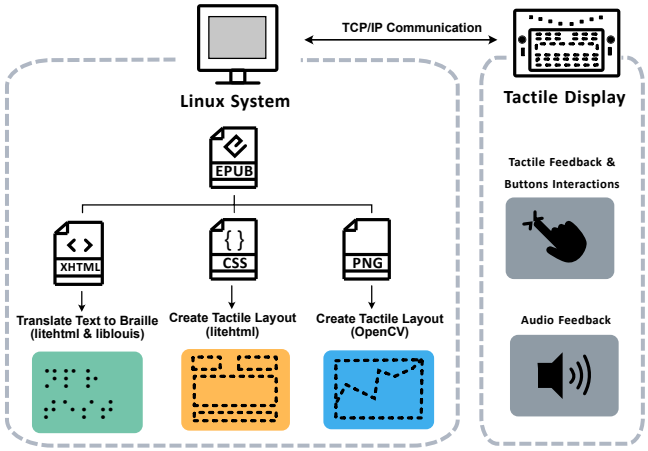

Figure 1: Adjustments to EPUB files for tactile display representation: XHTML files are parsed, with additional tags added to equations and text translated into Braille. CSS files are modified to resize elements and ensure minimum spacing between them. PNG images are adjusted to fit the resolution of the 2D refreshable tactile display, with colors converted to black and white.

Table 1: Element identifier symbol for each element type in the EPUB document.

Element Type	Element Identifier (Braille)
Header (h)	⠓
Paragraph (p)	⠏
Section (s)	⠎
Image (i)	⠊
Hyperlink (a)	⠁
Equation in Latex format (l)	⠇

3.2.3 Content View. The content view presents all elements in a sequential manner according to their arrangement in the XHTML file. Images are depicted either by their alternative text or if no text is provided, an empty text placeholder is shown to indicate the presence of an image to the user. Each element is accompanied by an indicator letter on its left, similar to the structure view, as depicted in Figure 2 (a).

3.3 Interaction Concepts

The interface includes 11 interaction concepts, and the button layout was designed based on previous work with blind participants [1, 2]. In that study, users expressed a preference for functionalities that would allow them to keep their hand on the display without needing to remove it to press a button. The interactions, as shown in Figure 3, are as follows:

Change Orientation: Button 1 rotates the current view by 90 degrees.

Scroll Pages: Buttons 2-right and 2-left enable the user to navigate

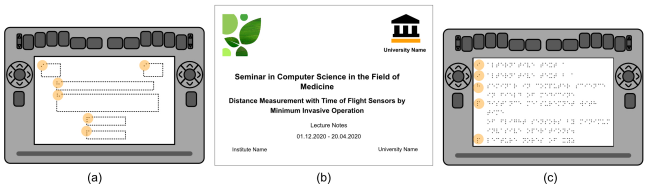

Figure 2: Available views in the EPUB reader. Highlighted areas in both views display the Braille letter serving as the element identifier. (a) The structure view, showcasing the layout of the first page of the EPUB document shown in (b). (b) The original format of the first page of an EPUB document. (c) The content view representation of the same page, where all elements are arranged in a linear, stacked format.

to the next or previous page, respectively.
Element Scrolling: Buttons 2-up and 2-down scroll by element.
Switch View Mode: Button 3 enables the user to switch between structure and content view.
Navigation Page: Button 4 displays the navigation page (table of content). By pressing the same button again, the user can return to the last page that was displayed before moving to the navigation page.
Default Mode: Button 5 switches to the default mode in the structure view.
Reduced Mode: Button 6 activates the reduced mode in the structure view, where all text paragraphs are filtered.
Page Information: Button 7 reads the current page number by the Text-to-Speech Synthesizer (TTS).
Audio Feedback: Pressing Button 8 in the content view mode triggers audio feedback, reading aloud the displayed text.
Move to Section: By double tapping inside the boundary box of any paragraph in the structure view, the content of the section is displayed in the content view.
Line Scrolling: Button 10 scrolls line by line (4 Braille rows at a time).

3.4 Preliminary Study

We conducted a preliminary study with two blind users to evaluate and refine the design of the reader and the interaction concepts. The study had two main objectives: to evaluate how easily blind users can read and interact with EPUB documents using 2D tactile displays, and whether they can easily and quickly search for specific elements.

3.4.1 Participants. Two blind male participants (P1, P2), aged between 50–60 and 20–30, respectively, were recruited via university mailing lists to test the EPUB reader and provide their feedback. Both participants had experience with various 2D tactile displays and eBooks in EPUB format, and both were proficient Braille readers.

3.4.2 Procedure. Each test lasted one hour and comprised three sessions:

- **Session 1 (10 min) :** we gathered demographic information, including the participant's age and their experience with both tactile displays and eBooks.

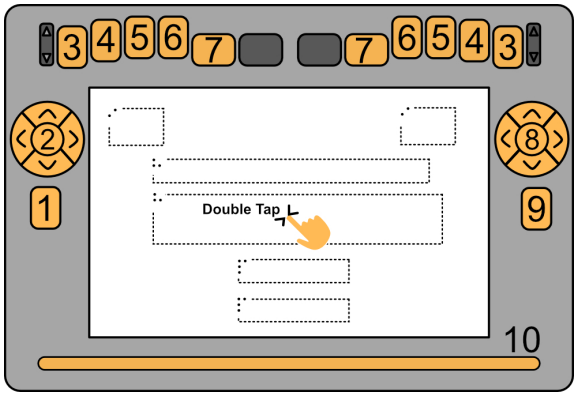

Figure 3: Available interactions in the EPUB reader on the HyperbBaille display (marked in yellow). Dark grey indicates buttons not currently in use. 1) Horizontal / vertical orientation switch, 2-right) page forward, 2-left) page backward, 2-up) element scroll upward, 2-down) element scroll downward, 3) structure / content view switch, 4) navigation page, 5) default mode in structure view, 6) reduced mode in structure view, 7) current page and line number, 8) stop TTS, 9) touch enable interaction 10) element scroll.

- **Session 2 (20 min) :** we introduced participants to the different view modes and navigation techniques using an example document. During this session, participants navigated a short document, shown in Figure 4 (a), and were tasked with locating a mathematical equation on the second page.
- **Session 3 (30 min) :** participants interacted with another document, shown in Figure 4 (b), and completed two tasks: 1) finding specific information on the currently viewed page, and 2) navigating to specific information in a particular chapter.

All sessions were audio recorded, and notes were taken on participants' comments.

3.4.3 Results. Both participants were able to read the document and solve the given tasks. Both used their index finger for selection, and it was observed that using a double-tap for selection could sometimes cause issues, particularly when the user prefers to keep one hand on the text while reading. This was confirmed by the feedback we received from participant P1 who suggested implementing a toggle button for enabling and disabling the touch functionality to prevent inadvertent clicks during screen exploration. Alternatively, the participant proposed a method for executing touch functions by placing a finger on an element and simultaneously pressing a touch button. Additionally, it was noticed that the participant often needed to interrupt the audio feedback after listening to the first few sentences. Moreover, the user reported confusion caused by closely placed boxes in the structure view, especially when the distance between them is one pin or less. They recommended specifying a minimum fixed distance between the boxes to resolve this issue.

P2 shared his impressions of the new presentation format for EPUB documents, stating:
"That is really interesting because I have never had, for example,

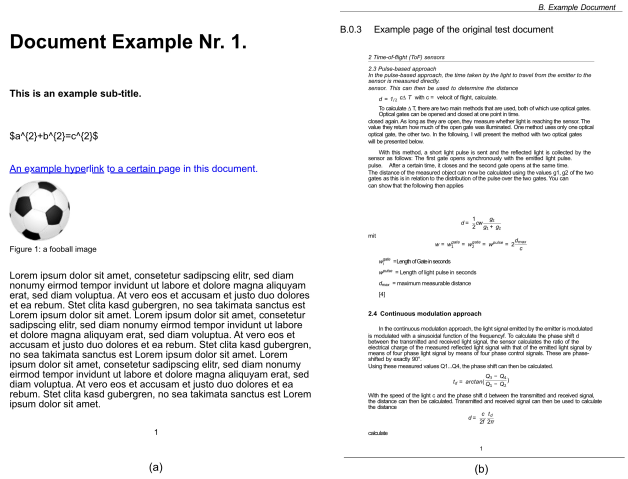

Figure 4: First pages of the two EPUB documents used during our preliminary study: (A) The first page of a document consisting of four pages, used in the second session as a demonstration to show the participant how the reader works. (B) The first page of a document consisting of nine pages, used in the third session of the study.

multi-column format under my fingers, because as a blind person, everything is always displayed vertically."

The participant also reported a preference for the structure view over the other two view modes and he answered when asked about the reason for this:
"I found it great that you have a bit of an overview of what the document really looks like."

Regarding the reduced structure view, P2 mentioned that this view mode was not intuitive for him. The participant commented that this view no longer corresponded to the original structure of the document which he identified mentally using the structure view mode. Compared to P1, he did not use the reduced structure view mode during the test.

The element identifier was shown to help distinguish between various elements in the document, however, it was observed that closely situated elements sharing the same identifier could occasionally lead to confusion. This occurred when one of the elements was pressed, and it became challenging to discern which specific element was clicked on, especially when displayed in content mode. To address this issue, the P2 recommended appending numbers to element identifiers to differentiate closely positioned elements sharing the same identifier. For example, if three paragraphs are aligned on the same line, their identifiers should be designated as p1, p2, and p3. Alternatively, the participant also proposed incorporating an option to audibly access either the content or the summary of an element without the need to switch to content view mode.

3.4.4 Improvements to the Design and Interactions Based on the Feedback. Based on the feedback provided by participants, several modifications were made to refine the design and interactions in the EPUB reader:

Touch Enable Button In response to P1's suggestion, we implemented a touch enable button (Figure 3, Button 9). This allows the user to interact with any document element by simultaneously placing a finger on the element and pressing the touch button to avoid inadvertent clicks.
Interrupting Audio Feedback To address usability concerns, we introduced an option to interrupt the audio feedback. Users can now toggle the audio button (Figure 3, Button 8) at any time to stop or start the audio feedback anytime, enhancing control over auditory interactions.
Enhanced Audio Functionality Following P2's recommendation, the audio feedback feature was modified to provide immediate access to content. Users can now place a finger on an element identifier in the structure view and listen to the corresponding content without needing to switch to the content view mode.
Improved View Mode Differentiation Adjustments were made to the spacing between adjacent bounding boxes in the view modes to improve tactile differentiation. A minimum gap of 2 pins was added between all elements displayed, ensuring clearer boundaries between boxes.

4 Discussion

Both participants in our study were able to read an EPUB document and navigate to the different chapters and search certain elements within it. However, regarding the different views in the EPUB reader, we noticed that the structure view and content view were the most frequently used modes during the tests. In contrast, the reduced mode was not used by the first participant, while the second participant found it unclear and unnecessary to locate specific information within the document. This may be attributed to the altered document structure in the reduced mode, which differs from the familiar behavior of reading documents on computers or mobile phones. However, it would be valuable to analyze whether offering the reduced mode in the content view would benefit users. Additionally, it was important to define a minimum distance between the different bounding boxes in the structure view to avoid confusing closely placed elements.

Regarding searching for certain information, we noticed that one participant was faster using the content view in comparison to using the structure view. One reason for this can be that in the content view, it is possible to scroll by element. This has the advantage that large elements can be quickly skipped, which in comparison to the structure view, would require more scrolling. Another explanation for this is, as the participant mentioned, is due to the following advantage in the content view: by simply locating their finger on the element symbol of the first element and scrolling element by element, the element symbol of the next element appears in the exact same position, which was helpful for the participant to quickly locate the element with the symbol he was looking for. The reduced mode's limited adoption highlights the influence of familiarity on users' preferences. Representing data in formats that deviate significantly from common paradigms may require additional training or redesign to align with blind users' expectations.

Regarding the implemented interaction concepts, our observations underscored the importance of maintaining an overview of

the content during interaction. For example, users appreciated the ability to listen to audio feedback for a specific element while simultaneously keeping one hand on the tactile text. This highlights that multimodal interaction concepts that combine audio feedback with concurrent Braille translation are important for user interfaces that run on 2D refreshable tactile displays. These findings align with those of Denise et al. [23], who emphasized that interaction concepts for 2D refreshable tactile displays must prioritize minimizing disorientation and maintaining constant tactile engagement with the data.

Some additional interactions were suggested by the participants. For example, they recommended the ability to access a summary of an element by placing a finger on it and pressing a specific button, which would trigger an audio summary without requiring a switch to the content view. The need for a toggle to stop the audio feedback at any point, as requested by one of the participants, further emphasizes this desire for a summary feature, as users may want to listen to only a portion of the text to quickly gather the key information. However, further analysis would be required to explore this. Additionally, one participant expressed interest in the ability to edit the document and add comments while reading, which was also a common request in the survey by Leporini et al. [12].

Both participants found the navigation page option highly useful, though they utilized it differently. The first participant used it primarily for reading, switching between chapters as needed, while the second participant relied on it mainly to locate specific information. For this participant, the ability to quickly navigate between chapters was particularly advantageous. This aligns with the findings of Bartalesi et al. [3], where survey participants emphasized the need for a quick navigation structure, such as a table of contents, to efficiently jump to specific sections.

5 Limitation

While our study provides valuable insights into the usability of different views and interaction concepts for 2D tactile displays, some limitations must be acknowledged. Broader testing with a more diverse group of users, including those with varying levels of familiarity with EPUB documents and tactile displays, would provide a more comprehensive understanding of user preferences and challenges. Additionally, our preliminary study primarily focused on qualitative data related to user preferences and usability concerns. Future work could benefit from incorporating objective performance metrics, such as reading speed, task completion time, and error rates, to better quantify the effectiveness of the system and interaction modes. Further research could also explore how the system could be adapted to other 2D tactile displays with different resolutions or interaction capabilities. Understanding how the system performs across various display technologies would enhance its broader applicability. Additionally, investigating how to accommodate both Braille and non-Braille readers—possibly through alternative interaction paradigms or adjustable modes tailored to varying literacy levels—would be valuable in expanding the system's usability.

6 Conclusion

In this paper, we explored the potential of 2D refreshable tactile displays for making eBooks in EPUB format accessible to blind and low-vision users. We presented a novel EPUB reader tailored for these displays, incorporating three distinct views and 11 interaction concepts designed to support navigation and interaction through buttons and touch gestures. Key features included cross-page and section navigation, a dedicated navigation page for chapter transitions, and audio feedback for content exploration.

A preliminary study with two blind users demonstrated the effectiveness of the structure and content views, as well as the navigation page, in facilitating reading and locating information. Participants appreciated the system's usability and provided valuable suggestions, such as adding editing capabilities. Our findings suggest that future 2D refreshable tactile displays hold significant potential for delivering accessible, multimodal eBook experiences.

This work highlights the importance of aligning interaction paradigms with user needs and existing mental models to ensure accessibility and usability. Future research will build on these findings by refining the design, implementing the suggested features by the participants, and conducting larger-scale evaluations to explore how such systems can be integrated into daily reading practices and extended to other content types, such as technical documents or academic materials.

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