A Tactile Windowing System for Blind Users

Denise Prescher, Gerhard Weber and Martin Spindler
Technische Universität Dresden
Human-Computer Interaction Research Group
Nöthnitzer Str. 46, 01187 Dresden, Germany
{denise.prescher, gerhard.weber, martin.spindler}@tu-dresden.de

ABSTRACT

Today's window systems present the information in a graphical and thereby a spatial manner making the text-only access of a standard Braille device insufficient to enable blind users an equivalent exploration of the data. In this paper we present the planar Braille Window System (BWS) designed for a tactile display consisting of a pin-matrix of 120 columns and 60 rows. The system is composed of six separate regions enabling the user to receive different types of information simultaneously. The content of the main region containing Braille windows can be shown in various manners (text- or graphics-based) through four different views. The interaction within our Braille Window System is implemented not only by keyboard shortcuts but also by the use of multitouch gestures. Therefore the user is able to interact directly on the touch-sensitive display. A study conducted with eight blind users has confirmed the concept of Braille windows, regions and views. Especially the gestural input for exploring details of the content offers new possibilities in interacting within a GUI.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Haptic I/O, Windowing systems*

General Terms

Human Factors, Design, Experimentation

Keywords

blind user, planar tactile display, screen reader, gesture interaction, Braille, tactile graphics

1. INTRODUCTION

Making the GUI talk [8] has broken the pixel barrier. Text shown in windowing systems is verbalized through speech synthesizers and gives blind users access to a plethora of applications. By and large, the same information as spoken is presented on Braille displays as most professional users such as blind programmers or scientists prefer the precision of Braille notation as well as the ability to 'click' on button labels (commonly called routing). But there is also considerable information of a GUI, such as graphical layout, that can neither be handled on a single line of Braille output nor can it be spoken.

Furthermore, the information related to a window frame is ignored in this respect as only one top-level window at a time may be active. Windows overlapped by the top-level window (physically or logically) are not dealt with by a screen reader. In particular, all windows are treated as modal. Modeless windows cannot be handled due to a lack of overview. In general, users find other ways of operating such a user interface element. But sudden and unexpected changes in a GUI, for example arising from pop-up windows in a browser, impede the accessibility considerably and are banned from accessible websites (compare WCAG 1.0 checkpoint 10.1, WCAG 2.0 guideline 3.2).

Still, several important applications make use of modeless windows to improve the usability of complex editing operations, for example Office applications with a ribbon listing current font name and font size. Similar, a word processor showing a modeless list of available style sheet names synchronizes the active list entry with the caret. There are many user interface elements built into the context of an application and sighted people seem to benefit from those self-explanatory features.

We investigate in this paper the effectiveness of a novel design of haptic interaction around a multitouch large tactile display to improve the ability of screen readers to be more self-explanatory. The following sections present the development process, the functionality and the evaluation of a tactile windowing system suitable for most desktop GUIs with unrestricted number of overlapping and framed windows.

2. RELATED WORK

The advent of compact two-line Braille displays (2x40 Braille modules) has promoted the idea of a tactile window system. Early DOS systems have allowed inspecting, for example, a table column header on one Braille line while entering data for a table cell on a second Braille line. Such Braille windows add another level of complexity to the non-visual user interface and have not survived in the GUI era.

Few large tactile displays such as the Stuttgart pin-matrix device exist. A tiling tactile window system has been developed for a Personal Information Manager application (PIM) and includes a calendar tool, an editor and a messaging ser-

ASSETS'10, October 25–27, 2010, Orlando, Florida, USA.

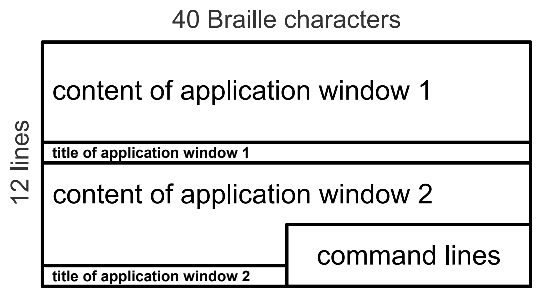


Figure 1: Layout of a Braille window system for a DOS application

Figure 2: Prototype of the planar tactile display

vice [4]. Space for text in this 12 line by 40 characters per line setup is a scarce resource. However, two application windows and also their titles can be displayed simultaneously while separated by a horizontal line of pins (see Figure 1), but without any scrollbar. Because of a small command line dialog included in the lower right corner, the lower application window is not rectangular.

Within the HyperBraille project[1] the planar tactile display 'BrailleDis9000' [11] is used as input and output device (see Figure 2). This tactile device is touch sensitive and consists of an equidistant pin-matrix of 120 columns and 60 rows. Therefore, the display not only allows a refreshable two-dimensional haptic output of information but also a gestural input [10]. These new possibilities require the development of a novel screen reader enabling bi-manual interaction with the information. A multimodal user interface was developed around this novel device, which is called 'HyperReader'. It is extending the capabilities of existing screen readers to deal with graphics.

3. THE BRAILLE WINDOW SYSTEM

The BWS described in this paper is a component of HyperReader, particularly managing the output of Braille windows in different regions and several view types on the tactile display. Thereby, each GUI window - which can be an application, a document or a dialog - is represented by a Braille window. The general layout concept consisting of regions (hereinafter also referred to as 'Braille areas') and views is described in detail in [7]. The advantage of the partition into separate regions (see paragraph 3.2.1) is as follows: the user can get not only several information simultaneously, but he also gets a special kind of data always on the same defined position which can shorten the time for locating.

3.1 Design Process

The BWS has been designed within an iterative and user-centered design process incorporating the concept of regions and views. Initially, a comprehensive analysis undertaken with blind collaborators identified the requirements specific for a two-dimensional tactile output. These include

- the need to orient the palm and finger position in respect to the context provided within a region,
- to locate the focused user interface element by a finger,
- to support navigation and exploration on the visual screen, and
- to support re-establishing the context when the user returns his or her hand after typing on a keyboard (referred to as homing).

Those requirements were applied in several tactile paper prototypes (see [5]) embossed on a Braille printer capable of producing equidistant dots. These early prototypes allowed us to get feedback on the tactile representation of specific features of the BWS and its interaction objects (e.g. scrollbars). Paper mock-ups do not easily allow an inspection of the interactive behavior of haptic user interface elements. But we conducted Wizard of Oz experiments [1] with three blind users to understand how updated information somewhere on the tactile display is located [5]. Thus, interaction within tactile pictures on BrailleDis9000 was reconstructed by a human activating the appropriate output on the planar tactile display. Video documentation allowed an analysis of errors and comments made by the three blind participants. In the following, we describe the tactile representation of Braille regions as identified at this stage of the design process and the evaluation of the implemented system.

3.2 Tactile Representation

In addition to the four regions described in [7] we added two other Braille areas to the HyperReader BWS, namely 'window title region' and 'view type region'. Each of the six rectangular regions is responsible for distinct types of information. The different regions are separated from each other by a line of dots. Because of the similarity to Braille letters and other tactile patterns on the interface, the use of broken lines for separation or marking should be avoided.

3.2.1 Braille Regions

In the following, we will give a brief description of each Braille area, especially on its functionality and the tactile representation of its interaction objects.

The actual content of application GUIs and open documents is displayed in the *body region* which takes up the biggest part of the display. Only this region can be shown in different views (see paragraph 3.2.2). The content of all the other regions is always displayed in Braille and depends on the active Braille window of the body region. If the active Braille window is switched, the content of the other regions also changes according to the new window. Furthermore,

[1]HyperBraille website: http://www.hyperbraille.com/

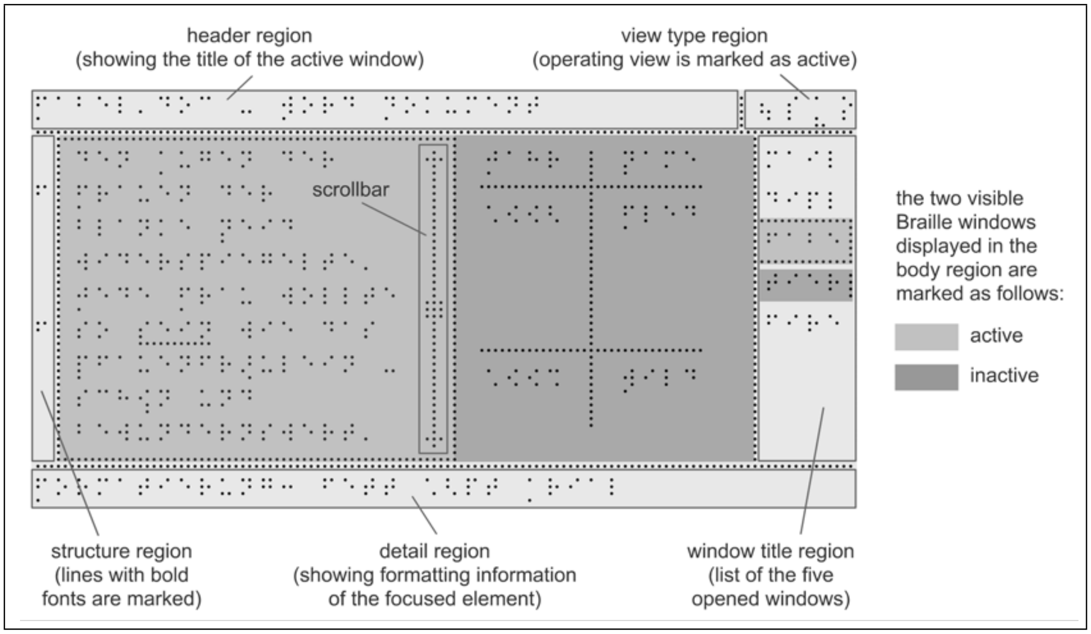


Figure 3: Tactile representation of our Braille Window System

the body region can show multiple Braille windows simultaneously and therefore enables the user to explore multiple documents or dialogs in parallel. An overlapping representation has been rejected by the three blind participants of our early workshop with mock-ups due to the much poorer tactile perceptibility, especially if the space between the objects is too small.

Multiple windows are handled in a tiled manner by dividing the body region into two parts[2]. These two parts can either be displayed below each other or side by side separated by a tactile borderline of pins. An additional borderline is drawn around the sub-body region containing the active window (see Figure 3), in order to allow the user to identify the focused document. Scrollbars (see paragraph 3.2.3) may only be shown in the focused Braille window.

In the *header region*, usually the window title information is presented. If an application menu is activated, the path of the menu is displayed. This Braille area enables the user to always be informed about the currently active document or application. By default the header region is allocated at the top taking one or two lines of Braille text.

The *view type region* is placed in the upper right corner, next to the header region separated by a small vertical line of dots. This Braille area provides an interactive list of all available view types of the body region. Each view type is represented by a single Braille character, the currently active view type is marked by an underline.

The purpose of the *structure region* is to provide users a fast overview of the document's horizontal structure. Thus, all text lines containing specific content elements, like headings or a special formatting, are flagged by a Braille character. This Braille area is allocated to the left of the body region providing space for only one or two Braille letters in one line.

[2]A division into more than two parts is not provided because the amount of space would be too small for a reasonable exploration of the content.

The *window title region* provides a list of all open Braille windows and implicitly all GUI windows. Taking into account the format of the planar tactile display, this area is vertically aligned to the right side of the body region listing the entries vertically. To save space, every window caption is only represented by its first four letters. The caption of the focused window is framed. In case of split body region, the title of the other visible window is marked as well.

The *detail region* is located under the body region taking one or two lines of text and providing the user with additional information. Depending on a switchable mode, it displays either detail information about the focused element or the content a non-graphical screen reader (e.g. Jaws[3]) would send to a standard Braille display (referred to as 'Braillex output'). The detail region can thus be regarded as a substitute for a conventional Braille display with 40 or 80 modules. Furthermore, this area can give the user temporary status messages from the HyperReader itself (e.g. what operation was executed after the user's input) hiding the previous content and then disappearing after a short period of time.

Figure 3 shows the tactile representation of the BWS and its Braille areas. In this example the body region is divided vertically showing two Braille windows next to each other. The active window is shown in operating view, the inactive one in symbol view.

3.2.2 View Types

As already mentioned, the body region can be displayed in one of four different views, namely outline, symbol, operating and layout view (see Figure 4, for detailed information see also [7]). Thus, the user can explore the information at different presentation modes and levels of detail according to his needs or current tasks.

The *outline view* allows for a quick overview by presenting the content of a document as abstract rectangles. In con-

[3]Jaws is a screen reader for Windows, see http://www.freedomsci.com/jaws-hq.asp

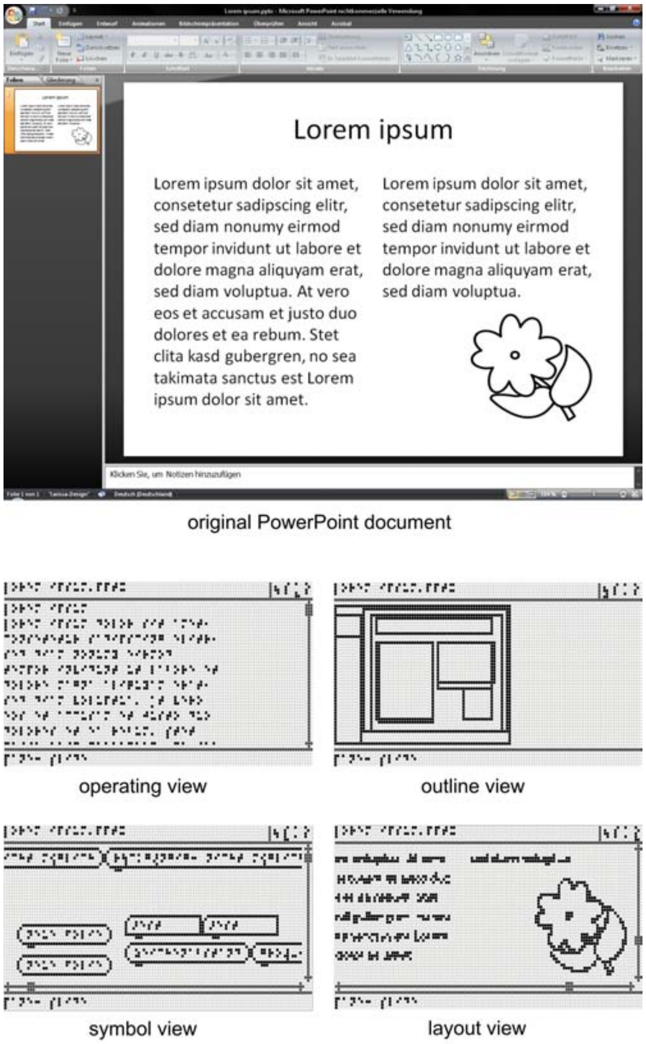
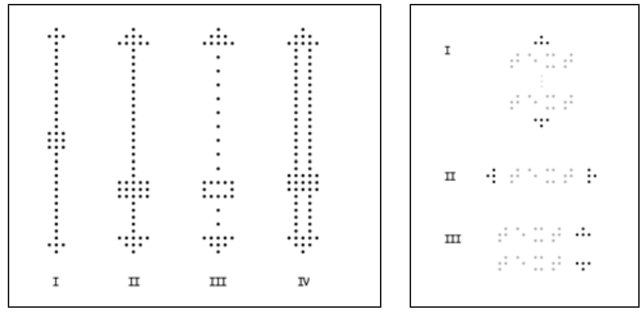


Figure 4: Document represented in the four different views of the HyperReader

trast, the output of the *operating view* is similar to this of conventional Braille displays as it is completely text-based enabling the user to read the content in Braille. In the *symbol view* spatial relationships in addition to Braille can also be explored. Direct access to the graphical representation of a window can be achieved in the *layout view*. Thus, this view type is a pixel based output showing text as tactile ink-print, offering users without any Braille skills new possibilities in tactile reading [6].

3.2.3 Scrollbars

If the content of a Braille area exceeds its dimension, a scrollbar is shown. Within the body region the scrollbar is a simplified tactile representation of a visual scrollbar. An informal evaluation with three blind subjects has shown that a single line of dots and a slider with a size of 3 x 3 pins is a good representation (see Figure 5a - I) [5]. In contrast, a broken line (III) was rejected because the fingers can follow such a line poorly, and a double line (IV) impaired the recognizability of the slider. The scrollbar is located right or below the content within the Braille area. The size of the



a) b)

Figure 5: Four design prototypes of a tactile scrollbar for the body region (a) and scroll arrows displayed in the other Braille areas (b)

thumb button is kept constant to simplify the recognition of this tactile symbol.

Most regions are small (only one or two lines or a few Braille letters next to each other), where a complete scrollbar would not be adequate. In these cases only scroll arrows are displayed. Depending on the number of lines and the orientation of the Braille area, the arrows are arranged in different directions (see Figure 5b). The scroll arrows of a vertical aligned area are at the top and the bottom (I), those of a horizontal area can be left and right of the single-lined content (II) or next to the content if it is two-lined (III). If it is not possible to scroll in one direction, the corresponding arrow is not shown.

3.3 Interaction

To interact with the system, the user can make his input in three different ways:

1. by keyboard commands
   (as usual with a standard screen reader)
2. with the aid of special hardware buttons placed next to the pin-matrix on the BrailleDis9000
3. by gestural input which is made possible by the touch-sensitive surface of the planar tactile display

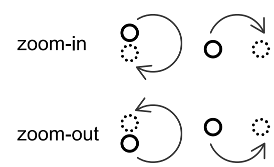
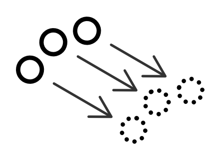
Because of the inability to distinguish between reading and entering a gesture, the user has to hold down a special button of the BrailleDis9000 while performing a gestural input [9]. The gestures proposed for our BWS were designed in cooperation with blind users within the early Wizard of Oz studies [5] mentioned in paragraph 3.1.

In the following, the most important possibilities of interaction with Braille windows and areas are described and, particularly, the gestures are summarized in Table 1.

3.3.1 Braille Area and Window Operations

Except for the body region, each Braille area can be hidden which allocates more space to the body region and therefore to the actual content of the Braille window. Furthermore, the areas can be changed in their size. This operation could not be executed in an efficient way by using a simple keyboard command, because the user has to define the region and also its new size. Therefore, we chose an intuitive line gesture being reminiscent of direct manipulation. However, this gesture triggers no continuous but a discrete

Table 1: Interaction within the Braille Window System

Operation	**Explanation**	**Gesture**
Resizing of a Braille area	*enlarging*: gesture begins at the border of the display where the chosen region is located and ends somewhere in the middle of the display *downsizing* (if no more downsizing is possible –> hiding): gesture from the middle to the border of the display	
Dividing the body region	two different manners: *horizontal* or *vertical*, each via button command dividing gesture with two hands would be intuitive, but such a gesture is not ergonomically feasible at this point because of the button holding while performing a gestural input	
Window operations	*minimizing*, *maximizing*, *restoring* and *closing* of a Braille window are implemented with button commands	
Switching the active window	*tabbing* through the window list by button command	
	activating a window with the aid of the window title region	double click on the corresponding entry
	showing the complete title of the window in the detail region	single click on the entry of the window title region
	changing the focused window within the divided body region	clicking somewhere into the inactive part of the body region
Zooming	user can specify the center for zooming (start point of the gesture) *zoom-in*: drawing the circle clockwise *zoom-out*: drawing the circle counterclockwise semi circle: zooming for a single step full circle: zooming for five steps	
Panning	user can specify the direction and the distance freely by grappling the content at the start point and dragging it to the end point two *scrolling modes* realized by different button commands: small step (one line of Braille text) and large step (overall size of the body region) into each direction	three finger gesture 
	jumping directly to the margin and edges of the document by single button commands	
	scrolling within the other Braille areas	click on the scroll arrows presented in Figure 5b
Panning inside the Minimap	changing the current viewport by moving the blinking frame	click at the new position within the minimap
Switching the view type	activating a view	single click on the corresponding letter within the view type region
	synchronizing the views	double click on the content (interaction object) that serves as reference

resizing and preserves Braille layout (no clipping). The body region can be enlarged to the size of the whole tactile display by a single operation hiding all other Braille areas at once. On the contrary, there is also a function to show all regions with a single command. Especially new users can benefit from this possibility because they easily can learn which Braille areas are available.

The window operations provided by MS Windows, namely maximize, minimize, restore and close, are implemented with a button command as these are simple operations without any parameter to consider. As an open Braille window usually fills the whole body region, the maximize operation of our BWS is only available when the body region is divided. Maximizing one part of this Braille area means that it expands to the whole size of the body region. The partitioning information is kept internally allowing the user to restore the divided presentation of the body region at any time. Furthermore, some options for switching the active window are implemented (see Table 1).

To allow the user cooperation with his sighted colleagues on the one hand, and to facilitate the direct input of GUI operations on the other hand, the output of HyperReader has to be synchronized with the GUI. Therefore some relevant window events of the GUI (especially when the foreground window has changed) are forwarded to the BWS refreshing the output on the planar tactile display. Vice versa, the BWS also triggers the corresponding operations in the GUI through synthesized input events.

3.3.2 Exploring the Content - Zooming and Panning

Compared to the graphical representation of a document on the screen, the output of BrailleDis9000 is very small-sized. Often, the document cannot be shown completely on the tactile display. Panning functions are enabling exploration of the whole document.

Besides, some of the view types demand the possibility of resizing the contents. Since Braille letters are not zoomable, the operating and the symbol view do not permit zooming. By contrast, the outline and layout view are depending on such zoom functionalities making not only overviews but also details of a document explorable.

The interaction possibilities for zooming and panning are shown in Table 1.

3.3.3 Helping with Orientation - Views and Minimap

Especially the layout view often requires a high zooming level. Thereby only a small part of the whole document is visible at once. If the user can establish no connection between the current part and the overall context, the so called 'desert fog' problem [3] can occur. This lack of orientation is prevented by providing a small map showing the whole document at once (therefore it equates to the document in the minimum zoom level) with a blinking border which highlights the current viewport (see Figure 6).

This *'minimap'* is realized as two-level-zoom approach (Gutwin and Fedak have shown that this is preferred for small screens [2]), i.e. within the body region either an overview (the minimap) or a zoomed-in view (the viewport in the actual zooming level) is shown. The minimap should help the user to easily get an overview of his current position within the Braille window. There is also the possibility to pan the current viewport within the minimap by moving the blinking border.

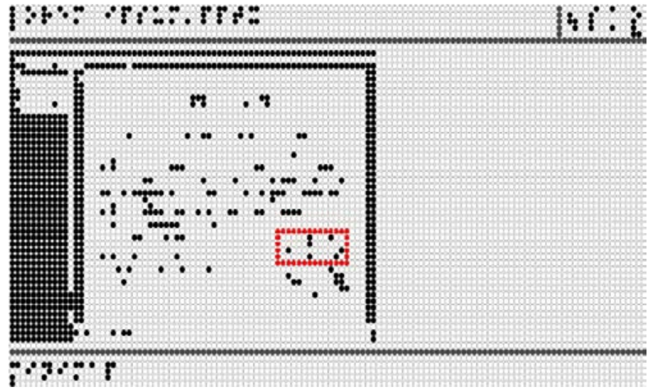


Figure 6: Minimap showing the current position within the Braille window

As mentioned above, the user can change the appearance of the body region's content by switching the view type. For maintaining the current position and thereby for retaining the orientation, the view types can be synchronized. For that purpose the user selects the object he wants to explore in another view and then changes the view type. The new viewport is then located around the position of the selected object.

4. EVALUATION

A study with eight blind subjects was conducted, testing the usability of the implementation of our BWS. In this way, the handling of the BWS, particularly by gesture input, could be observed. We were interested in the two-dimensional and bi-manual mode of operation in contrast to the habit of blind users to work with only one line of text on a standard Braille device.

In Table 2 some demographic data of the participants is summarized. All of them are daily screen reader users with Braille skills. Subject 2 and 3 have already participated in former studies within the HyperBraille project, the other ones had no experience with such a planar tactile display.

Table 2: Demographic data of the subjects

subject	age/ sex	level of visual impairment	occupation
1	35/m	early blind	advocate
2	27/f	early blind	social pedagogue
3	33/m	late blind	computer scientist
4	30/m	low vision	IT specialist
5	58/f	late blind	social worker
6	51/f	early blind	physiotherapist
7	29/f	low vision	office clerk
8	30/m	early blind	telephonist

4.1 Method

The two-hour test consisted of 21 single tasks and was grouped into the following parts:

1. familiarization phase: partial guided exploration of the

desktop (MS Windows Vista), learning the most important principles and input modalities of the BWS (explanation of the regions, views and gestures)

2. view types: autonomous exploration of a plain text document in the different view types, e.g. using minimap, zooming and panning

3. Braille areas: autonomous exploration of a complex text document using the different Braille areas, e.g. hiding, showing and resizing of the regions via gestures

4. divided body region: working with multiple windows displayed in the divided body region, e.g. dividing the body region, switching the active window and maximizing a Braille window

The tasks were given to each subject verbally and those for the familiarization phase were guided by the test conductor introducing the user to BWS and its concepts. But also in the following parts, some guidance was necessary, because the complex concepts could not be trained extensively within such a short testing period.

Throughout the whole test session, all the subjects have used both hands for interacting on the pin device. While performing the given tasks, the users should not concentrate on the displayed contents, i.e. it was not necessary to read the text of the presented documents. But rather, the participants were ask to focus on the handling of the BWS, e.g. the occurrence of information on several areas or the effect of different views or zoom levels on the document's appearance.

Our main purpose was to observe subjects while interacting with the Braille windows using gestures and the command buttons of the BrailleDis9000. This study is not analyzing the learnability of our concepts or that of the used gestures and commands. We rather aimed at examining the intuitiveness of operating our BWS. Therefore, we wanted to get answers to the following questions. How do users get along with the two-dimensional output? How is the interaction with different separate regions rated? Can users keep their orientation when exploring one or more Braille windows? How do users accept input by gestures?

For obtaining qualitative and quantitative data, each subject was asked some questions after each part of the study (e.g. rating of a special aspect by a given scale or predefined response options). Furthermore, the test was recorded with a video camera enabling a later analysis of the subjects' use of the system.

4.2 Results

The rating for the general handling of the planar tactile display is summarized in Figure 7. All the subjects have evaluated the different regions as expedient and helpful for getting specific types of information. For example, the structure region has helped all subjects in their task to quickly find text lines with bold words. The view type region facilitated the identification of the current view, and the header region the identification of the current window very fast. All subjects liked the detail region for receiving further information. In general, working with the regions was rated as efficient (5 subjects) and intuitive (3 subjects), but the users also need to get used to it (5 subjects). Furthermore, the view types were also considered to be expedient. So, the study could confirm the concept of regions and views.

Especially, the concept of 'clicking' the content (e.g. a desktop icon) for getting detailed information and audio output can open new dimensions for spatial exploring and, therefore, was well accepted by the subjects. For example, the receiving of an overview over the desktop icons was rated good (4.1 of 5 points) in the outline view combined with speech output. Particularly in respect of the layout view showed in a high zoom level, the minimap was very helpful for all subjects to get an overview of their current position.

Figure 8 summarizes the mean rating for the three main aspects of the BWS (navigation, interaction with Braille windows and regions). The possibility to split the body region into two parts for working with two documents next to each other pleased six of the subjects and was evaluated by the others as reasonable.

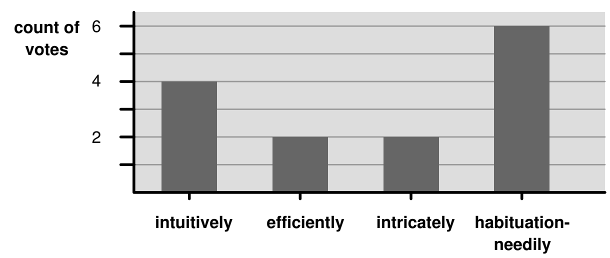


Figure 7: Appraisal of the general handling (multiple answers were permitted)

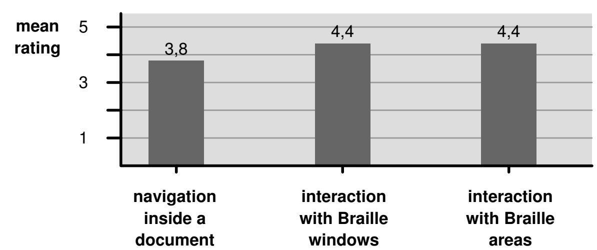


Figure 8: Mean rating of some interaction aspects (5 = very good, 1 = very bad)

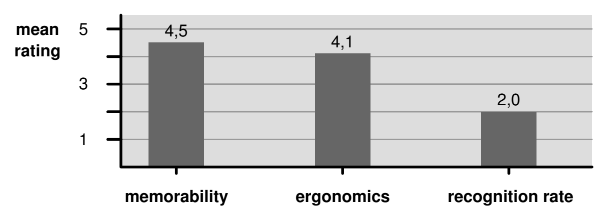


Figure 9: Mean rating of some aspects of the gestures (5 = very good, 1 = very bad)

Most of the subjects liked the interaction of gestures for zooming, panning and resizing of the regions, because of its intuitiveness. Three users even would prefer it over the input by keyboard commands, but the combination holding a button while performing gestures was criticized because it lowers their performance. The used gestures were rated as shown in Figure 9.

4.3 Discussion

In general, all the subjects could handle the two-dimensionality of the output. However, it becomes clear that blind users have to get used to it to utilize an efficient way of interaction. And, apart from the operating view, users also should possess a good spatial imagination. In our study each Braille window was opened in the operating view, except the desktop which was opened in the smallest zoom level of the outline view. Therefore, no suggestion can yet be given in which view type a new window should be opened and which zooming level has to be chosen by default.

Within the short time of testing, the subjects saw the necessity of the views, but most of them could not yet imagine how they would work with the different view types, i.e. which view should be chosen for which task. Without synchronizing among the views, users may have difficulties to keep their orientation. Especially, such a large-area display requires this synchronization for an efficient working. Furthermore, the layout and outline view make a multimodal output of Braille and additional auditive information necessary.

5. CONCLUSION AND OUTLOOK

The Braille Window System designed for a novel planar tactile display consists of six regions and therefore enables the user to get different information about a document at the same time. Especially, gestural input can open new dimensions in spatial exploring and interacting. The four view types allow the user to perceive information in several representation modes. Synchronization makes it possible not only to keep, but also to understand the context.

A further study will be necessary for making concrete statements about the homing time needed within our BWS, especially in comparison to standard Braille devices. Thereby, we have to measure the time a user needs for finding the desired information in a Braille area after making an input (by gesture, button or keyboard command) depending on the number of presented regions. Furthermore, an analysis is necessary how efficiently the localization of the caret and cursor can be facilitated on the two-dimensional display.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] N. O. Bernsen, H. Dybkjær, and L. Dybkjær. Wizard of oz prototyping: How and when. In *CCI Working Papers in Cognitive Science and HCI*, 1993.

[2] C. Gutwin and C. Fedak. Interacting with big interfaces on small screens: a comparison of fisheye, zoom, and panning techniques. In *GI '04: Proceedings of Graphics Interface 2004*, pages 145–152, School of Computer Science, University of Waterloo, Waterloo, Ontario, Canada, 2004. Canadian Human-Computer Communications Society.

[3] S. Jul and G. W. Furnas. Critical zones in desert fog: aids to multiscale navigation. In *UIST '98: Proceedings of the 11th annual ACM symposium on User interface software and technology*, pages 97–106, New York, NY, USA, 1998. ACM.

[4] K. Klöpfer. *Ein multifunktionaler Büroarbeitsplatz für Blinde (A Multifunctional Work Place for the Blind).* PhD thesis, Universität Stuttgart, Institut für Informatik, 1987.

[5] D. Prescher. Ein taktiles Fenstersystem mit Multitouch-Bedienung (A tactile window system for multitouch operation). Diploma thesis, Dept. Computer Science, TU Dresden (unpublished), 2009.

[6] D. Prescher, O. Nadig, and G. Weber. Reading braille and tactile ink-print on a planar tactile display. In *ICCHP '10: Proceedings of the 12th international conference on Computers Helping People with Special Needs*, pages 482–489, Berlin, Heidelberg, 2010. Springer-Verlag.

[7] M. Schiewe, W. Köhlmann, O. Nadig, and G. Weber. What you feel is what you get: Mapping guis on planar tactile displays. In *UAHCI '09: Proceedings of the 5th International on ConferenceUniversal Access in Human-Computer Interaction. Part II*, pages 564–573, Berlin, Heidelberg, 2009. Springer-Verlag.

[8] R. S. Schwerdtfeger. Making the GUI talk. *BYTE*, pages 118–128, Dec 1991.

[9] M. Spindler, M. Kraus, and G. Weber. A graphical tactile screen-explorer. In *ICCHP '10: Proceedings of the 12th international conference on Computers Helping People with Special Needs*, pages 474–481, Berlin, Heidelberg, 2010. Springer-Verlag.

[10] I. Sturm, M. Schiewe, W. Köhlmann, and H. Jürgensen. Communicating through gestures without visual feedback. In *PETRA '09: Proceedings of the 2nd International Conference on PErvsive Technologies Related to Assistive Environments*, pages 1–8, New York, NY, USA, 2009. ACM.

[11] T. Völkel, G. Weber, and U. Baumann. Tactile graphics revised: The novel brailledis 9000 pin-matrix device with multitouch input. In *ICCHP '08: Proceedings of the 11th international conference on Computers Helping People with Special Needs*, pages 835–842, Berlin, Heidelberg, 2008. Springer-Verlag.