AR-Based Haptic Whiteboard User Interface for Blind People

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Abstract

In a professional as well as an educational context, visual two-dimensional information spaces, like whiteboards, are frequently used to explain complex relations of the topic at hand, highlight important thoughts during discussion or structure ideas. During meetings facilitating this kind of aids, blind people can participate in the actual verbal discussion, and, if the tool used is digital and accessible, can access the textual information via screen readers. However, the spatial arrangement of pieces of information, which is usually crucial information as well, is not accessible. This work presents an AR-based user interface approach and prototype, which allows blind people to haptically access spatial information on two-dimensional information spaces, like whiteboards.

Keywords

Blind/Low Vision, Mobile Technology, Augmented Reality (AR), Employment & Workplace, Education

Introduction

Two-dimensional shared information spaces, like whiteboards and similar means are commonly used in numerous contexts. Business meetings often use whiteboards to gather thoughts and structure complex relationships. In education, blackboards are widely used for similar purposes. These tools offer crucial benefits to sighted people during lecture, discussions and meetings, while blind people miss out on this source of information in multiple ways. Firstly, textual information on traditional paper-based whiteboards is not accessible to this group of people. However, text alone is only one part of the information usually stored. Most of the time the position and spatial arrangement of chunks of information is valuable knowledge as well. Pieces of information placed next to each other are often related. Pieces of information above one another can act as headings. Additionally, not only the consumption of information is sufficient, but also the manipulation and creation are normally necessary for inclusion. Taking whiteboards with notes on them in brainstorming meeting as example: While sighted people can write notes and stick them to the whiteboard at the position they like, blind people cannot do that on traditional whiteboards. Furthermore, during discussions in these kinds of meetings, whiteboards get included in the conversation. People point at them to emphasize on an argument, which again is not possible for blind people.

In summary, whiteboards and similar tools are commonly used in many contexts, but they are not accessible to blind people for several reasons. This work proposes a cost-effective and flexible user interface approach that aims at overcoming these issues and allowing blind people to access spatial as well as other information and participate as equals in these kinds of scenarios.

State of the Art

Making spatial information accessible to blind people is a research field that has been investigated for many years and in numerous contexts. Navigation and world exploration are two popular research topics, which manifested in countless different user interface approaches (Brock and Kristensson; Geronazzo et al.; Guo et al.; Willis and Helal). One important issue to highlight in this context is that it is of utmost importance to avoid overloading the auditory channel of a blind person. This is safety critical for outdoor navigation, but also crucial for other scenarios. In a meeting or lecture setting, a user interface that heavily relies on the auditory channel forces the user to decide to either operate the user interface or pay attention and contribute to conversations happening simultaneously. Braille displays are an established approach within the community, but are best suited for linear text. There are variations to this, like the HyperBraille pad offering a two-dimensional array that can be used to display 2D information (Stephan Pölzer and K. Miesenberger). However, it comes with several disadvantages like a high price, a relatively low resolution, limited market penetration and relatively large enclosure, which makes it less than ideal for transportation.

Alternatively, augmented reality has shown that user interfaces involving spatial concepts can be used to successfully assist people in work environments (Lahlou; Büttner et al.). This technology opens up the possibility for flexible and cost-effective user interface concepts (Wacker et al.), also tailored to blind people (Verma Aashish, Miesenberger Klaus, Pertl Gregor, Reithmayr Kerstin). This work presents a user interface approach based on Google's ARcore Framework (Google Developers) utilizing off-the-shelf smartphones to allow blind people to haptically access and understand a 2D information space.

Conceptual Solution

Our user interface approach aims to provide an alternative to traditional paper-based whiteboards, which allows blind people to not only retrieve textual information, but also access and understand the spatial arrangement of pieces of information (notes) on a whiteboard, which implicitly holds crucial information about cohesion and hierarchy. Moreover, users are not only able to consume spatial information, but also modify it and highlight notes or areas on the whiteboard to others, which allows them to direct the attention of sighted people to specific parts of the whiteboard, which allows for a much more effective communication.

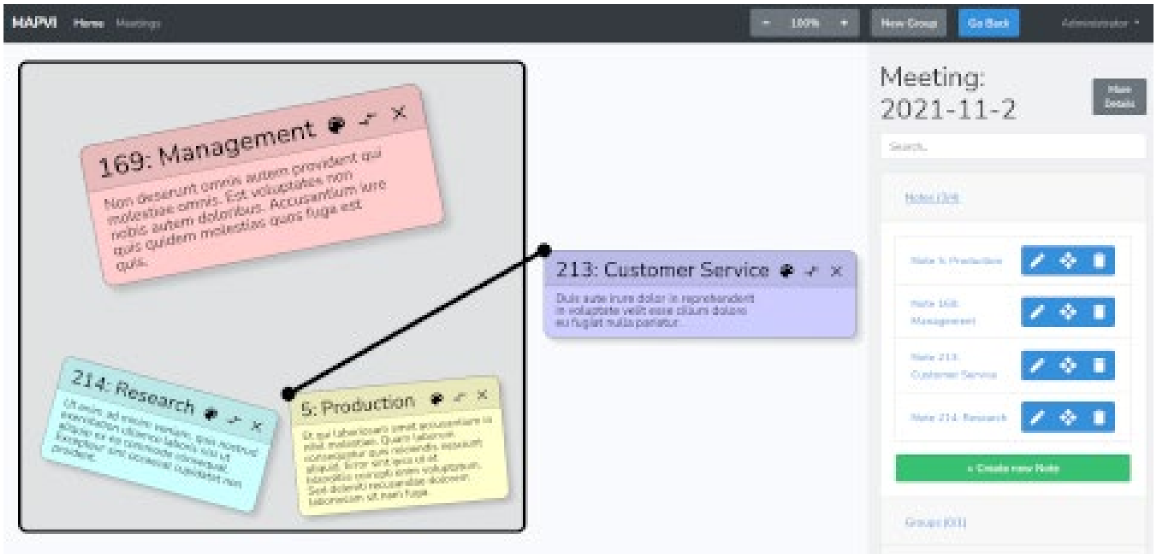

Fig. 1. Web Interface of the Whiteboard Application.

For this purpose, an Android app was implemented which connects to a digital whiteboard application (Miesenberger et al.; Gunther et al.) (see figure 1). The app is based on ARcore (Google Developers) and Unity (Technologies) to create a virtual representation of the whiteboard, in particular the notes of the whiteboard in front of the user. During operation, the users hold the smartphone in their hand and haptically explore or manipulate items on this virtual plane erected in front of them (see figure 2). The visual user interface on the right-hand side of figure 2 is only an addition for testing and debugging. The main output channel is of haptic nature. Only minimal acoustic output to convey textual information and give short cues is used to ensure that the auditory channel does not get overloaded. At the moment five modes of operation are implemented and working:

- Explore spatial arrangement of notes: The user holds the smartphone in the hand and without pressing any button moves the hand to explore the virtual plane erected in front of him or her. If the smartphone and the user's hand approach a note, the phone starts vibrating, getting stronger the closer the device is. If the phone touches a note, it starts to vibrate continuously. Text-to-speech (TTS) announces the title of the note. This lets the user explore the whiteboard haptically and understand the spatial arrangement of notes.

- Retrieve detailed information of note: If the user virtually touches a note, the user can click the volume up button to retrieve additional information, including the body text and the name of the person who created the note.
- Move and rotate note: The user can not only retrieve spatial information of the whiteboard but can also manipulate the position and rotation of the note. When the user touches a note, he or she has to press and hold the volume up button and move the phone in the desired position and orientation. The position and the rotation of the note on the whiteboard changes in real time, also visually in the digital whiteboard application.
- Highlight note: Additionally, the user can highlight parts on the whiteboard in two different ways. Firstly, the user can, when touching a note, visually highlight a note to sighted people by clicking the volume down button.
- Show cursor: Secondly, the user can activate a visual cursor on the whiteboard to draw attention to a whole region on the whiteboard by just pressing and holding the volume down button.

System Feedback for User Actions

User involvement showed that for every action, which the user performs and the system recognizes, some form of system feedback is highly desirable. Even though physical buttons are used for all actions, which already provide tactile feedback when being clicked, a confirmation via either vibration, sound or even voice proved to be highly beneficial to make users feel more secure when navigating the application.

In particular, the following feedback mechanisms where implemented:

- Every successfully initiated action activates a chime as confirmation. This applies to: moving and rotating a note, showing the cursor, highlighting a note. Retrieving additional information already triggers text to speech. Therefore, no additional feedback is required in this case.
- Every unsuccessful initiation of an action triggers a warning/fail sound. This can happen if the user tries to trigger an action that requires a note, but the user's hand and the smartphone are not in range of a note. This applies to: moving and rotating a note, highlighting a note and retrieving additional feedback of notes.
- If the user decides to rotate a note, the current angle of the note is communicated via vibration. The closer the angle is to 0 degrees, the stronger the vibration gets. At 180 degrees, meaning the note is upside-down, the vibration is at its lowest level.

Technical Implementation/Prototype

A fully functional prototype (see figure 2) of the Android app as well as the digital whiteboard application has been implemented. From a technical perspective, it relies on a server infrastructure, which holds all information on the whiteboard. A web interfaces allows a traditional visual view on this information during meetings or lectures (see figure 1). This web interface, and any other user interfaces, communicate with the server with a standardized interface, namely a REST-Service for data exchange supporting all CRUD operations and a web socket services for real-time events (e.g. when notes get changed and other views need to be updated). The AR-based smartphone app also uses the same interface to retrieve and modify data. It furthermore relies on Google ARcore Framework (Google Developers). This framework uses the smartphones camera and inertial sensors to provide positioning data of the device. Unity (Technologies), usually a game engine, is used to create virtual objects in space in front of the user, each object corresponding to a note on the whiteboard. The positions and the distances between these objects correspond to the positions and distances of the notes on the whiteboard. Colliders attached to these objects trigger haptic events. If the smartphone is close to a note it starts vibrating; the closer the smartphone gets to the object, the stronger the vibration gets. If the smartphone touches the object, the vibration becomes continuous. The volume buttons are used to activate different modes, either by clicking, or pressing and holding the button (see chapter Conceptual Solution).

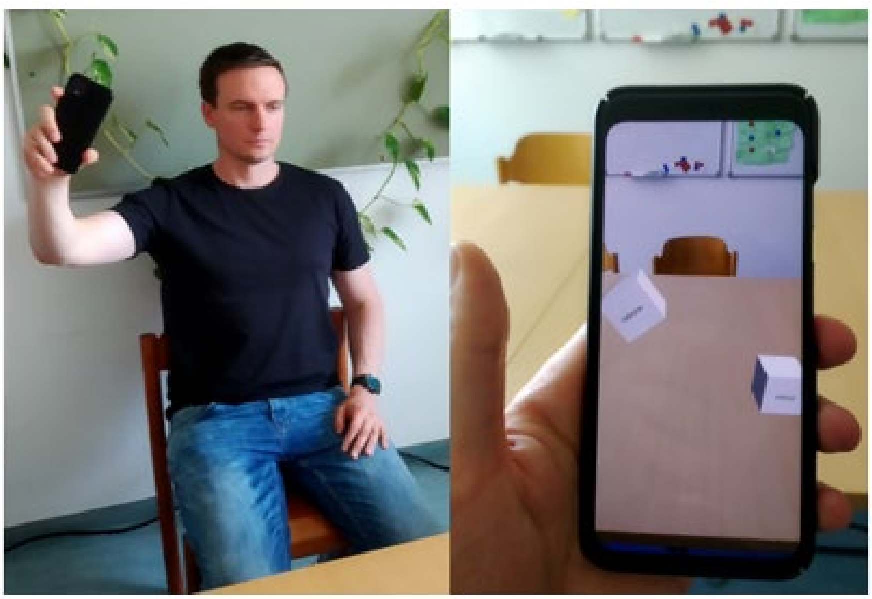

Fig. 2. Left Image: Person Using the Smartphone to Explore the Virtual Whiteboard Haptically. Right Image: Note Surrogates Displayed in AR Smartphone App.

User Feedback and Requirements for the Next Iteration of the Prototype:

Recent user feedback has highlighted following user requirements and features based upon them, which will be added in a next iteration of prototype:

- **Configure Motion Range:** Depending on the user, his or her preferences, the setting and the surrounding environment, the dimensions of the virtual surface erected in front of the user and therefore the range of motion needs to be made user-adjustable. In some instances, users want to use less space and narrower motions to explore the whiteboard. In other instances, especially with more spare physical space and a larger number of notes, a larger range of motion might be preferable. This feature will be implemented by allowing the user to configure the range of motion during an initialization phase at the first run of the application or manually triggered during subsequent runs.
- **Search function:** Users expressed the need for a search function to locate single notes on the whiteboard. This user interface feature will be implemented using a combination of the web interface and the smartphone app. Blind users can choose a note, which they want to search on the whiteboard. Afterwards the mobile app switches into a different mode, which shows only the desired note on the virtual plane and increases the range from where the vibration feedback starts. This will allow the user to comfortably locate single notes on the whiteboard.
- **Sequential guided walkthrough:** Users expressed the desire for a guided walkthrough for sequential traversal of all notes on the whiteboards. Normally, users, who open an unknown whiteboard for the first time, pick a random position on the whiteboard and start exploring the rest of the whiteboard from there. Usually, the starting position is around the center, which leads to a free but relatively unstructured exploration process. While some people prefer this method, other users stated that they are worried that they might miss a note and they additionally want a guided walkthrough, which guarantees that they traverse all notes from start to finish.

Conclusion and Further Work

In this paper, we presented a user interface approach and fully working prototype, which aims at making 2D information spaces, like whiteboards, accessible to blind people. It uses affordable off-the-shelf hardware to make this spatial information haptically understandable. TTS and sound cues assist the user and grant access to additional information. Current user testing shows promising results. Users describe the exploration of the whiteboard using vibrations as intuitive and valid alternative to sound. While blind people were involved from the beginning and throughout the development, it has not been tested at a broader scale. Therefore, the next major step are evaluations to study the benefit for blind people as well as highlight areas where the concept or the prototype can be improved.

Future Applications

User feedback has shown that there is interest in bringing this kind of haptic user interface to other scenarios. Especially the educational context seems to offer promising scenarios where this approach might be able to support blind and severely visually impaired students in understanding spatial information. Examples where this approach could be applied are geographic maps, mathematic and chemical formulas but also content like the solar system or the structure of molecules.

Geographic maps are an obvious scenario. However, mathematic and chemical formulas might not necessarily be, since they can be serialized and displayed on braille displays. While this is certainly true, a spatial presentation accessible to blind students could still offer benefits, especially in mixed classroom settings, where the teacher and other students are sighted. During conversations, sighted students might refer to spatial aspects of a formula, which excludes blind people. E.g. “I don’t understand the top-right part of the equation. Could you please explain it again?" If blind students are able to understand the spatial layout of the subject of discussion, they might be able to participate and contribute regardless.

In contrast to geographic maps and whiteboards, which hold two-dimensional spatial information, the user interface concept might even be extendible to three-dimensional information spaces like the structure of molecules, geometric figures, maps of multi-storey buildings etc. These use cases will offer additional challenges, probably in terms of orientation to ensure that the blind user does not get lost. In addition, more physical space around the user is required. For 2D information spaces a virtual "wall" erected in front of the user is sufficient. However, to display the third-dimension actual physical space around the user is necessary.

Acknowledgments

This project (MAPVI) including this publication was funded by the Austrian Science Fund (FWF): I 3741-N31.

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