Human-Computer Interaction for Visually Impaired Users

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Abstract

Human-Computer Interaction (HCI) deals with methodologies for building design solutions. HCI focuses on developing a deep understanding of users and their needs. It is important to design products for everyone that includes people with disabilities. The purpose of this paper is to examine major methodologies available to make design accessible for visually impaired users. The paper will explain well-established guidelines and mechanisms available for designers, such as increased visual, auditory, and sometimes haptic feedback. We will also analyze recently proposed approaches to assist visually impaired people to navigate through the computer screen.

Introduction

Human-computer interaction is a field of science which is concerned with how humans interact with computing technology. It deals with creative ideas to overcome limitations and challenges that humans face when interacting with technologies. Designing systems that are efficient, safe and even enjoyable for the users who use them comes under the discipline of HCI.[1]

Alan Cooper, an American software designer, and programmer, once said: "If we want users to like our software, we should design it to behave like a likable person: respectful, generous and helpful"[2]. Fast technical development and popularity of touch screens in our lives have made it essential for the designers to empathize and understand the needs and difficulties of disabled people. Computers and smart devices are not perceived as distinct technological objects anymore, but as tools to support our everyday activities.[3]

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[1] MacKenzie, I. Scott. Human-Computer Interaction: An Empirical Research Perspective, Elsevier Science & Technology, 2012
[2] https://quotesondesign.com/alan-cooper/
[3] Sheth, A.: Computing for human experience: semantics-empowered sensors, services, and social computing on the ubiquitous web. IEEE Internet Comput. 14(1), 88–91 (2010)

According to a report by the world bank, 15% of the world population is experiencing some form of disability.[4] The World Health Organization estimates that approximately 1.3 billion people live with some form of vision impairment. 188.5 million have a mild vision impairment, 217 million have moderate to severe vision impairment, and 36 million people are blind.[5]

There are various reasons for vision impairment and most of the definitions originate in the healthcare community. This paper will focus on the disabilities defined in HCI. There are two visual impairments to consider in HCI: Situationally-Induced Impairments and Disabilities (SIIDs) and Health-Induced Impairments and Disabilities (HCIIDs).[6] The interactive relationship of humans and computers has evolved from static to highly dynamic and this nature of interaction has increased the chances of putting their physical integrity at risk. This can be identified as Situationally-Induced Impairments and Disabilities (SIIDs)[7]. An example of SIIDs can be, when a person is walking and trying to use a mobile phone, it can have negative effects on his/her experience with the product.[8] Poorly lit work environments will reduce the ability of a person to access the computer efficiently is an example of SIIDs . Whereas Health-Induced Impairments and Disabilities are permanent and last longer. Reduced visual acuity caused by a disease or an accident is an example of HCIID.[9] SIIDs are temporary and dynamic in comparison to HCIIDs. HCIIDs are generally uncorrectable and tend to become worse over time.[10]

This paper attempts to combine major methodologies and mechanisms available to help visually impaired users. It consists of three sections. The first section discusses established guidelines and technologies available for designers. The second section examines the use of 3D sound in auditory assistance which can help the user navigate through the computer screen. The third section briefly discusses tangible interfaces for completely blind users.

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[4] https://www.worldbank.org/en/topic/disability

[5] http://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

[6] "Impact of Spatial Auditory Feedback on the Efficiency of Iconic Human–Computer Interfaces under Conditions of Visual Impairment." *Computers in Human Behavior*, vol. 23, no. 3, May 2007, pp. 1211–31

[7] Sears, A., Lin, M., Jacko, J. A., & Xiao, Y. (2003). When computers fade . . . pervasive computing and situationally-induced impairments and disabilities. In Proceedings of the tenth international conference on human–computer interaction (pp. 1298–1302). Mahwah: Erlbaum.

[8] (Mizobuchi et al.,2005)(Lin et al., 2007)(Yatani and Truong, 2009)(Nicolau and Jorge, 2012c)

[9] Sears, Lin, Jacko, & Xiao, 2003; Sears & Young, 2003

[10] "Impact of Spatial Auditory Feedback on the Efficiency of Iconic Human–Computer Interfaces under Conditions of Visual Impairment." *Computers in Human Behavior*, vol. 23, no. 3, May 2007, pp. 1211–31

Web Accessibility

Web development and design are reaching new heights of innovation, but access to web continues to be a challenge for disabled people especially people with visual impairments. Before discussing web accessibility, we can acknowledge that online information can provide more advantages and dynamic experience in comparison to print information.[11] On the web, users can easily magnify the text or they can use auditory assistance to understand information. Due to the diverse needs of visually impaired, access to the web is still a challenge for the community. To utilize this technology in our favor, understanding of well-established guidelines is important.

The World-Wide Web Consortium (W3C) has developed the Web Content Accessibility Guidelines (WCAG). The purpose of these guidelines is to ensure universal design and equal access to web content. [12] The latest version of WCAG is 2.1 and was published by W3C on June 2018. There are four basic principles that are further divided into thirteen guidelines. The document can help both designers and developers in making their website more accessible to people with disabilities. The four principles defined in WCAG are: *perceivable, operable, understandable* and *robust*. To meet the needs of different groups in different situations, there are three levels of conformance. Each guideline has been assigned a level A (lowest), AA and AAA (highest).[13] These guidelines apply to all groups of people with different kinds of disabilities. The following section will briefly describe all four principles from the perspective of the visually impaired.

Perceivable is a very common principle in design. Like the title suggests, any form of information or user interface should present itself in a way that anyone can understand it easily. Non-textual content can be defined as a sequence which cannot be expressed in human language, for example, dropdowns or CAPTCHAs. The non-textual content on the website can

[11] https://www.nngroup.com/articles/accessible-design-for-users-with-disabilities/
[12] Harper, S., Yesilada, Y. (eds.): Web Accessibility: a Foundation for Research. Human Computer Interaction Series. Springer, London (2008)
[13] https://www.w3.org/TR/UNDERSTANDING-WCAG20/conformance.html#uc-levels-head

be easily converted into speech. If there is a design element in the website which is scrollable, there needs to be a way to communicate that information to the visually impaired user. Best way can be to convert that information into speech or audio. For time-based media like audio and video, alternative text should be provided. In the case of visually impaired, audio description added to the prerecorded video can be very helpful. For example, Netflix has an added "Audio Description" option with most of their content. The website can provide options like the ability to change the size of text, different levels of audio to help users. A few important points to consider are proper text spacing, contrast, and line spacing. [14]

Operable describes how the usability of a website can be improved by assisting users in navigation. This guidelines suggest that the website should give the user the ability to navigate through the content only by using the keyboard. The website can have keyboards shortcuts which users can customize and remap according to their needs. These criteria on keyboard navigability will not only benefit completely blind people but will also help the partially blind. There are Braille Keyboards available for blind users. These keyboards will be discussed later in the paper. To make the website operable, the user should be given enough time to operate and comprehend the content. [15]

Information content or user interface provided by the website must be **Understandable** by all groups of people. The human language in the passages or phrase can be programmatically determined. The data on the website should be provided in a way that assistive technologies can process it.[16]Assistive technologies can be defined as hardware or software available to help the disabled with different challenges, for example, a text to speech converter. It is recommended that a mechanism should be available on the website to explain abbreviations and unusual words, and to identify different pronunciations. The user should be able to predict

[14] https://www.w3.org/TR/WCAG21/#perceivable
[15] https://www.w3.org/TR/WCAG21/#operable
[16]https://www.understood.org/en/school-learning/assistive-technology/assistive-technologies-basics/assistive-technology-what-it-is-and-how-it-works

what is coming up and should not be surprised by inconsistent processes. Input assistant can also be helpful to prevent any kind of errors or irritations.[17]

Websites are expected to be **Robust** to make sure that any assistive technologies can interpret the information. This principle is more relevant for developers. It includes best coding practices. For example, all HTML elements on the web page should have start and end tags with proper unique IDs.[18]

WCAG is very well documented and describes everything in detail. But it seems like it still doesn't address all the accessibility issues. It is not completely fulfilling the needs of the visually impaired. [19] One commonly available assistive technology for visually impaired users is screen reader software. Screen readers can frequently fail to notice, and thus narrate, when dynamic content appears on the site. This can negatively affect the experience of a visually impaired user. [20]

Accessible touch screens

Over the past decade, touchscreen technology has increased the usability of mobile phones and smart devices for sighted users. We are witnessing a wave of touch-screen devices like smart watches, smart home systems etc. But this technology is yet not completely accessible to visually impaired people.[21]

Touchscreens with a large variation in size are available commercially. There are miniature touchscreens like the Apple Watch, and some are much larger touchscreens like Surface Hub, sold as collaborative tools for businesses. Small-sized touchscreens are orders of magnitude

[17] https://www.w3.org/TR/WCAG21/#understandable
[18] https://www.w3.org/TR/WCAG21/#robust
[19] Harper, S., Yesilada, Y. (eds.): Web Accessibility: a Foundation for Research. Human Computer Interaction Series. Springer, London (2008)
[20] https://www.nngroup.com/articles/accessible-design-for-users-with-disabilities/
[21] FULLY ACCESSIBLE TOUCH SCREENS FOR THE BLIND AND VISUALLY IMPAIRED Shaun K. Kane, Jeffrey P. Bigham and Jacob O. Wobbrock University of Washington

more sensitive to finger size, and thus more error prone, than larger screens. [22] Researchers have discovered that target sizes between 9.2mm and 9.6 mm are optimal for comfort and usability in performing targeting tasks. There are mainly three techniques available for touch screens: land-on, first-contact, and takeoff. The land-on strategy activates whatever was first touched on the screen, and if no targets were touched then nothing is activated. The first-contact strategy works like land-on but in this case, if nothing is immediately touched, the user could slide their finger to the target they wanted and whatever target was first touched would be activated. In the take-off method, there would be a cursor in the shape of a plus sign above the user's finger, and the user would move the cursor around the screen until it hovered over what they wanted. Researchers discovered that the performance time for the first-contact strategy was faster than land-on or take-off. The results also showed that the take-off strategy had far fewer errors than first-contact or land-on strategies. [23] Using take-off strategy while designing touchscreens can help both sighted and visually impaired users.

Visually impaired users can only feel or see what their fingers are touching. They are able to control their devices through a touchscreen by tapping on the selection and activating it. Their experience with the touchscreen is a blend of audio assistance, touch, and gestures. They must perform gestures like swiping with one finger or with two. Most importantly they must be able to enter text with being able to see the text. These inputs require minimal mistakes, high usability, and good reliability. The land-on and first-contact strategies can become very difficult for the users when combined with gestures. [24]

Translating Text into Synthetic Speech(TTS) is software that interprets words and pronounces them through synthetic speech. This can remove the dependency of human recorded audio. The most common example of TTS for visually impaired people is screen readers. Screen

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[22] Daniel Ashbrook, Kent Lyons, and Thad Starner. 2008. An investigation into round touchscreen wristwatch interaction. In Proceedings of the 10th international conference on Human computer interaction with mobile devices and services (MobileHCI '08). ACM, New York, NY, USA, 311-314. DOI=http://dx.doi.org/10.1145/1409240.1409276

[23] https://www.researchgate.net/publication/311372354_Accessible_Touchscreen_Technology_for_People_with_Visual_Impairments_A_Survey

[24] https://www.researchgate.net/publication/311372354_Accessible_Touchscreen_Technology_for_People_with_Visual_Impairments_A_Survey

readers are available for desktops, laptops and smartphones. Right now, major touchscreen platforms like iPhone and Android include screen readers.[25] In 2009, Apple iOS introduced VoiceOver(screen reader) with the iPhone 3GS. Later on, Google followed Apple and launched TalkBack in the Android operating system. [26]

iPhone accessibility features are a blend of gestures and VoiceOver. VoiceOver can be used in a way such that moving your finger over some text will read the text from start to finish. VoiceOver can be configured according to the user's needs. The configuration settings allow users to change the speed of the speech, an ability to change the voice itself with a different accent. Some of the most common gestures available for VoiceOver are

- **Drag one finger** over the screen to explore the interface and hear the screen reader speak what's under your finger.
- **Flick two fingers** down the screen to hear it read the page from the top down.
- **A single tap** brings a button or link in focus
- **Double tap** activates the control.
- **3-finger horizontal flick** is the equivalent of a regular swipe.
- **3-finger vertical flick** scrolls the screen up or down.[27]

Gestures are complicated and have low discoverability, but they do represent the only way to navigate efficiently through a system largely based on sequential access.[28] Easy and universal gestures can help users remember them.

Lack of visual information brings a challenge for user experience designers. Visually impaired users cannot glance around a page, scan lists, or quickly determine a goal. Visual cues cannot

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[25] http://www.afb.org/info/living-with-vision-loss/using-technology/cell-phones-tablets-and-other-mobile-technology-for-users-with-visual-impairments/touchscreen-smartphone-accessibility-for-people-with-visual-impairments-and-blindness/1235
[26] https://www.levelaccess.com/part-1-mobile-screen-readers/
[27] https://www.nngroup.com/articles/touchscreen-screen-readers/
[28] https://www.nngroup.com/articles/touchscreen-screen-readers/

help them in understanding hierarchies, or relationships between the content. The information is conveyed based on the text spoken by the screen reader. Keeping up with all this information and understanding it can put a lot of pressure on the user.

If user experience is slightly difficult for the sighted user, imagine how difficult it is going to be for visually impaired users. Improving the design for sighted users will also help people with different kinds of difficulty. Removing extraneous information and visual decoration and adding more textual labeling can mean more words for the visually impaired users to listen to. Another way to improve user experience is to reduce interaction cost. [29] Interaction cost is the mental and physical effort that users must deploy in order to interact with the website or application to achieve their goals. Lesser interaction cost will not only help sighted users but will also improve the experience of people with disabilities.

Input methods

QWERTY Keyboards

Major commercial implementations of screen reader software, like VoiceOver, read each letter of the on-screen QWERTY keyboard or number on the numeric keypad as the user moves their finger around. Once they hear the letter or character they want, double tap anywhere on the screen will select it. The important difference is that the keys on the keyboard are smaller than the usual icons on small screens. The right key can easily be missed. With this method, typing rate for visually impaired users tends to be around 4 words per minute.[30]

There have been many attempts to improve the performance of QWERTY keyboards for visually impaired users. A recent attempt tried to make the QWERTY keyboard faster with bimanual interaction and simultaneous stereo speech. The researchers used a large touchscreen where

[29] https://www.nngroup.com/articles/interaction-cost-definition/

[30] Shiri Azenkot, Jacob O. Wobbrock, Sanjana Prasain, and Richard E. Ladner. 2012A. Input finger detection for nonvisual touchscreen text entry in Perkinput. In Proceedings of Graphics Interface 2012 (GI '12). Canadian Information Processing Society, Toronto, Ont., Canada, Canada, 121-129.

users can put one finger on the left half of the keyboard and another finger on the right half of the keyboard. They combined this with the screen reader. The left speaker was used for the left side of the keyboard and the right speaker was used for the right side. The results were not positive. The speed of the exploration of the keys was similar to the QWERTY keyboards.[31]

Braille Keyboards

A Braille keyboard consists of six keys. On key for each Braille dot, which makes up one Braille cell and each Braille cell represents a character. Chording is a type of input that uses multiple key presses at the same time. Twiddler is a type which uses one-handed chording text entry approach on mobile phones. According to a research with Twiddler, users can achieve up to 60 WPM. With two-handed physical keyboards that use chording, professional typists can reach up to 225 WPM.[32]

Fig, 1 Braille Keyboard [33]

[31] João Guerreiro and Daniel Gonçalves. 2015. Faster Text-to-Speeches: Enhancing Blind People's Information Scanning with Faster Concurrent Speech. In Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility(ASSETS '15). ACM, New York, NY, USA, 3

[32] Mark David Dunlop and Michelle Montgomery Masters. "Pickup Usability Dominates: A Brief History of Mobile Text Entry Research and Adoption." Human-Computer Interaction and Innovation in Handheld, Mobile and Wearable Technologies. IGI Global, 2011. 42-59

[33] https://ul.gpii.net/content/braille-keyboard

Braille soft keyboard or touchscreen Braille keyboard was introduced in iOS 8. The keyboard is developed based on BrailleTouch and Perkinput. The Perkins Brailler is a "braille typewriter" with a key corresponding to each of the six dots of the braille code, a space key, a backspace key, and a line space key. Perkinput is based on the Perkins Brailler, a mechanical Braille embosser with a chording keyboard. The keyboard has six keys for character entry, each corresponding to one dot in a Braille character. [34] BrailleTouch is an effort of a team of researchers at the Georgia Institute of Technology.[35]

Fig, 2 Perkinput [36]

Spatial Auditory Feedback

This section is dedicated to innovative and experimental approaches utilizing auditory feedback to assist visually impaired users' experience. In Graphical User Interfaces (GUIs), four categories of interactions have been identified. One of them is object manipulation. Object manipulation requires physical functions and actions. Pointing, moving and clicking objects comes under object manipulation[37]. For example, when a user points to the *share icon* and selects it. Visually impaired users face difficulty in locating the objects because they don't understand the space

[34] http://wiki.systers.org/communities/lib/exe/fetch.php/perkinput/shiri_azenkot.pdf
[35] https://electronics.howstuffworks.com/gadgets/other-gadgets/braille-touch.htm
[36] https://plainaveragemind.wordpress.com/2014/01/18/phd-forum-on-mobile-experiences/
[37] Jacko, J. A., Scott, I. U., Sainfort, F., Barnard, L., Edwards, P. J., Emery, V. K., et al. (2003). Older adults and visual impairment: What do exposure times and accuracy tell us about performance gains associated with multimodal feedback?. CHI Letters, 5(1), 33–40.

they are interacting with. A possible solution to this problem can be *spatial auditory feedback*. Spatial auditory feedback is an audio feedback with 3D sound which can help users locate the position of the cursor on the computer screen.

Auditory icons and earcons are commonly accepted elements of audio feedback. Spatial auditory feedback is not as widespread as auditory icons and earcons but can serve as an aid for localization features in the design. Auditory spatial cues can be valuable in case of SIIDs. These cues can be produced by manipulation of loudness, pitch or timbre. Spatial auditory feedback can help the user in getting towards the right direction in case of visual changes. Combining auditory icons with spatial auditory feedback can assist visually impaired users with navigation. [38]

Earcons & Auditory Icons

Visual icons are the graphical representation of actions. We all encounter these icons during our interaction with devices. These visual icons are commonly used in our designs and are an integral part of GUIs. Visual icons require visual and motor functioning by the users. The user can locate the required icons from the set of items displayed on the screen. By using a mouse, the user can activate and select the icons. [39] Icons act as mediators between the user and the program. But long-term use can put considerable pressure on the user's visual cognition process. In order to help visually impaired users, audio feedback is used with these icons. In recent research, Jacko, Dixon, Rosa, Scott, and Pappas presented that the audio feedback can help both older and healthy users. The important thing for a designer is to understand what these auditory feedback mechanisms are and how we can use them to help our visually

[38] Armando B. Barreto a, Julie A. Jacko, Peterjohn Hugh "Impact of spatial auditory feedback on the efficiency of iconic human–computer interfaces under conditions of visual impairment",

[39] Field, A. (2000). Discovering statistics using SPSS for Windows. Thousand Oaks: SAGE Publications. Foley, J. D., Wallace, V. L., & Chan, P. (1984). The human factors of computer graphics interaction techniques. IEEE Computer Graphics and Applications, 89(8), 13–48.

impaired users.[40] There can be different ways to add audio feedback in your system. Most commonly used forms of audio feedback are *earcons and auditory icons*.

By definition, icons are graphical representations[symbol] of information whereas earcons and auditory icons are non-verbal audio messages used to provide information as well as feedback about the object, operation, and interaction[41]. Gaver has introduced auditory icons in GUIs.[42] Basing his work upon ecological perceptions, he suggested that humans don't listen to the acoustical dimensions of sound such as pitch. Instead, they pay attention to the source that created the sound.[43]

Based on this approach, *Sonic-Finder* [an interface] was developed for the Apple Macintosh Computers for sighted users. Sonic-Finder extended the user experience by mapping computer events to everyday sounds. The information is redundant to what is displayed but this can be valuable in the case of SIIDs. For example, if a person is distracted, the sound can bring back their attention to important tasks like deletion of all photos.[44]

Blattner et al. introduced a design approach for earcons and auditory icons. Earcons and auditory icons are abstract. They are composed of synthetic tones and constructed from elements called motives. Motives are composed of rhythm, pitch, timbre, register, and dynamics. Earcons can present certain challenges for designers. Earcons are different from the function they are representing and there is no semantic relationship between them. However, earcons are still better for presenting information than the simple collection of sounds. Earcons can be evidently helpful with error prevention.[45]

[40] Jacko, J. A., Dixon, M. A., Rosa, R. H., Scott, I. U., & Pappas, C. J. (1999). Visual profiles: a critical component of universal access. In Proceedings of the ACM conference on human factors in computing systems (pp. 330–337). New York: ACM Press.
[41] Earcons and Icons: Their Structure and Common Design Principles Meera M. Blattner, Denise A. Sumikawa, and Robert M. Greenberg Lawrence Livermore National Laboratory and The University of Calqornia, Davis
[42] Gaver, W. W. (1986). Auditory icons: using sound in computer interfaces. Human–Computer Interaction, 2, 167–177.
[43] Gaver, W. W. (1986). Auditory icons: using sound in computer interfaces. Human–Computer Interaction, 2, 167–177.
[44] Jacko, J. A. (1996). The identifiability of auditory icons for use in educational software for children. Interacting With Computers, 8(3), 121–133.
[45] Armando B. Barreto a, Julie A. Jacko, Peterjohn Hugh "Impact of spatial auditory feedback on the efficiency of iconic human–computer interfaces under conditions of visual impairment",

3D Sound Technology

Auditory information helps people who are visually healthy as well as those who are visually impaired. Auditory icons and earcons can be designed to provide spatial information using 3-D sound technology. 3-D sound provides the listener with the spatial auditory perception of a sound source. Fig. 3 is presented by Durand R. Begault [Ames Research Center, Moffett Field, California] in his research paper [3-D Sound for Virtual Reality and Multimedia].

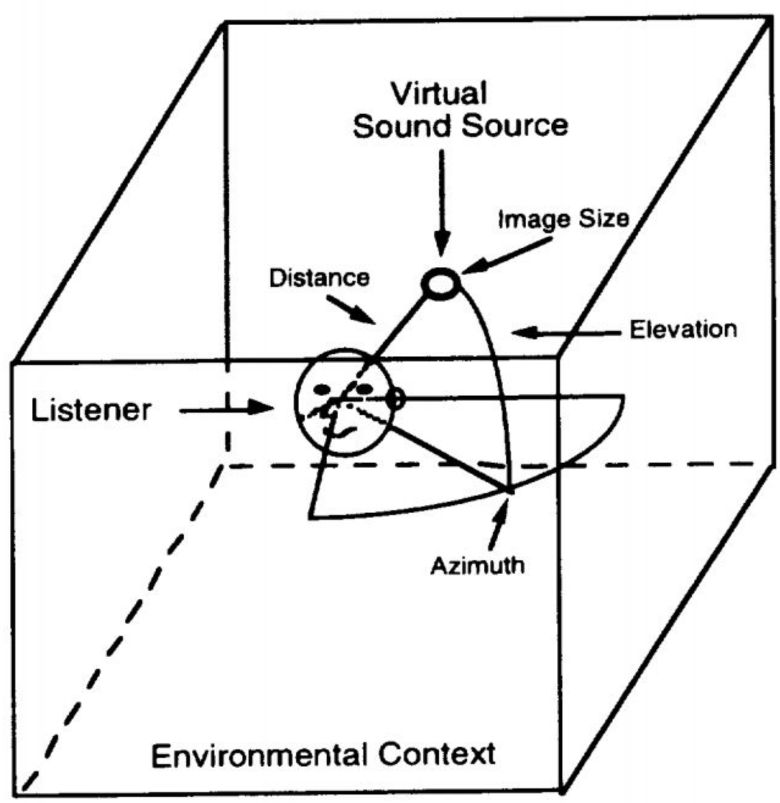

Fig. 3 Begault, D. R. (1994). 3-D Sound for virtual reality and multimedia.

The origin of this spherical coordinate system is at the center of the listener's head. There is a virtual sound source which is given a direction by defining azimuth and elevation at a magnitude distance.

- Zero degrees in azimuth and elevation points are directly in front of the listener
- Clockwise rotations in azimuth are positions to the right of the listener
- Counterclockwise rotations are positions to the left of the listener
- Downward rotations are positions below the head
- Upward rotations in elevation are positions above the head.

By using these 3-D sounds we can give a perspective to our visually impaired users. We can provide them with a sense of direction and distance using these spherical coordinates.[46]

Head-Related Transfer Function Technology

The head-related transfer function (HRTF) is a response that describes how an ear perceives a sound from a point in space. HRTF is the most important component for implementation of 3D-Sounds because it refers to spectral filtering of a sound before it reaches the eardrum of the listener and it is affected by the position of its source. Filtering of the sound is caused by the shape of the pinna, head, and body. It affects the way the user is going to perceive sound. User's perception of sound source results from intensity differences on a sound entering each eardrum. To artificially generate 3D-Sound these, differences are imposed with measured HRTFs at a desired azimuth and elevation. [47]

Impact of spatial feedback

Armando B. Barreto, Peterjohn Hugh (Florida International University) and Julie A. Jacko (Georgia Institute of Technology,) performed experiments to study the use of spatial feedback and utilization of auditory feedback to determine the identity and positioning of icons close to screen cursor.

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[46] Begault, D. R. (1994). 3-D Sound for virtual reality and multimedia. Chestnut Hill: Academic Press..

[47] Armando B. Barreto a, Julie A. Jacko, Peterjohn Hugh "Impact of spatial auditory feedback on the efficiency of iconic human–computer interfaces under conditions of visual impairment",

For the experiment, ten volunteers were recruited to perform 81 trials of icons identification and selection tasks. There were three interfaces under the artificial condition of visual impairment 1- ordinary icons 2- non-spatial auditory icon 3- spatial auditory icons. During the experiments, participants viewed this screen from a distance of 45 cm. A 2-D plane was presented to each user, where each of the icons and the screen cursor were represented with a specific pair of coordinates. In the interface, an audio cue was associated with each icon and processed through a 3-D audio channel. The audio cue was generated from the center of the icon. As the users were moving the cursor, audio cues were helping them in locating the position of the cursor on the screen. Data were collected on the basis of selection time, hit or miss and x-y coordinates of the mouse positions.[48]

Icons used in the experimental program

Visual traits		Audible traits		
Function	Picture	Sound	Duration (s)	95% Power (Hz)
Copy		Copier	2.16	9542
Cut		Scissors	0.73	190,445
Help		Gushing water	1.59	16,973
New		Door opening	0.86	5453
Open		Ruffling pages	1.35	14,011
Paste		Electrical buzz	0.47	15,693
Print preview		Helicopter	3.69	2608
Print		Printer	0.96	15,525
Save		Boomerang	1.25	4687

Fig. 4 Icons used in the experiment

[48] Armando B. Barreto a, Julie A. Jacko, Peterjohn Hugh "Impact of spatial auditory feedback on the efficiency of iconic human–computer interfaces under conditions of visual impairment",

The impact of auditory feedback was significant on the selection of icons. Accuracy in the presence of spatial auditory icons was markedly higher than accuracy in the presence of ordinary icons. Experiments showed that the lack of any auditory characterization of the icon just before the selection is completed, clearly deprives the participant from the icon identification. However, the results showed that the auditory assistance did not significantly decrease the average selection time. The results showed that participants recorded a shorter average selection time with spatial auditory icons than with non-spatial auditory icons.

The researchers summarized that the spatialization of the icon sounds does provide additional remote navigational information to the users, enabling diagonal movements towards the icons. The paper also provides insights into how we can further reduce the time and increase the accuracy of selection. The study suggests that introducing spatial auditory feedback has the potential to influence positively the navigational behaviors and strategies of visually impaired users when engaging in iconic search and selection.[49]

Tangible Interactions for Completely Blind Users

Tangible User Interfaces (TUIs) enable interaction with the digital world through the use of physical objects. TUIs have been studied in the field of HCI but the focus has always been on sighted users. Within the field of HCI, TUIs have been used in many areas, including education, information visualization, programming, entertainment, musical performance, planning, and social communication.[50] In previous sections, we have discussed the use of audio feedback to help visually impaired users. Most of the research and work in the field has been focused on audio assistance, only a few TUIs for visually impaired people have been designed.

[49] Armando B. Barreto a, Julie A. Jacko, Peterjohn Hugh "Impact of spatial auditory feedback on the efficiency of iconic human–computer interfaces under conditions of visual impairment",

[50] Anke Brock. Tangible Interaction for Visually Impaired People: why and how. World Haptics Conference - Workshop on Haptic Interfaces for Accessibility, Jun 2017, Fuerstenfeldbruck, Germany. pp.3, 2017, <http://wwwhome.cs.utwente.nl/elloumil/haptic_interfaces_for_accessibility.html>. <hal01523745>

According to research, TUIs can be more beneficial as compared to the standard mouse and keyboard computer interfaces.[51] By touching the physical objects, blind people can construct more realistic mind maps which can help them improve the understanding and memorization of spatial information in the absence of vision. But, there is a downside to TUIs that users can easily get tired by constant manipulation of physical objects.

Tangible User Interfaces | Example

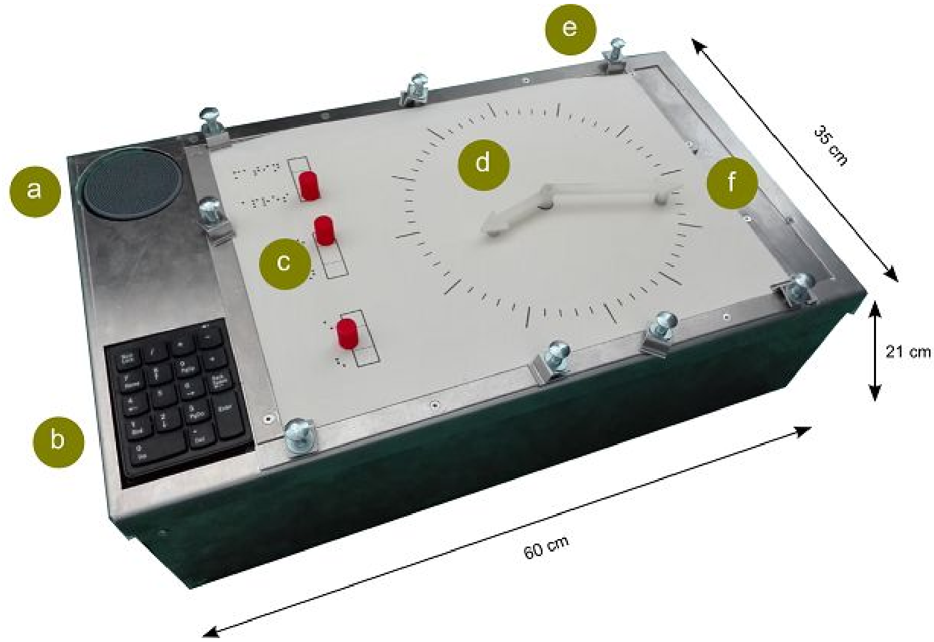

Fig. 5 The tangible box by Nicolas Biliote, Bernard Oriola, Marc Macé, Christophe Jouffrais

The Tangible Box is a project of Ph.D. students at the University of Toulouse, France. It is a compact and low-cost tangible interface for visually impaired students. A wide-angle camera is placed inside the box, along with a Raspberry and an LED string light. It enhances tactile graphics with tangible interaction, making them not only interactive but also manipulable. It can be used for a large variety of topics, such as maths, biology, geography, history. It supports different types of learning-by-doing activities: (re)construction, exploration, annotation, and

[51] O. Shaer and E. Hornecker, "Tangible User Interfaces: Past, Present, and Future Directions," Found. Trends® Human–Computer Interact., vol. 3, no. 1–2, pp. 1–137, Jan. 2009

edition. It can also be used with several types of tactile graphics, such as 3D-printed graphics, laser-cut wooden or plastic graphics, graphics printed on special paper, German film, and regular paper. A demonstration can be found at: https://vimeo.com/265334617 .

Conclusion

The pace with which technology is moving forward, it requires new ways of interaction for people with visual impairments. It demands designers and developers to work together and create products that include everyone. There are various guidelines available for designers, but guidelines alone are not sufficient. Besides providing cues and configuration options for users with mild visual impairment and for the partially blind, auditory feedback can be used to great effectiveness for users with all kinds of visual impairments. Spatial auditory feedback is a recent advancement that can bring the notion of 3D space to user interfaces and direct users' attention towards action items and notifications. I think Tangible User Interfaces are another promising development. Recent advances in 3D-printing can enable quick, templated construction of TUIs for different software. This will take usability for blind people to another level. One pitfall I have noticed with current research is that experiments are conducted with sighted users using simulations. Instead, visually impaired users should be involved in experiments to increase fidelity and improve inferences.

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