Making Technology Accessible and Inclusive for All: Designing UIs for Individuals with Visual Impairments

Monica Iqbal
Department of Computer Science, University of Toronto
Toronto, Canada
monica.iqbal@mail.utoronto.ca

INTRODUCTION

Since we are currently living in a digital era, technology must be inclusive for everyone, including those with visual impairments. Given the recent advances in technology, many researchers have proposed user interfaces (UIs) to assist these individuals. wearable devices, haptic graphs, navigation systems, and accessible touch screens are examples of UIs that researchers have developed. After enough research was done, they made these technologies available for use. Technology greatly benefits those with visual impairments because it makes difficult tasks easier for them, such as navigation and communication. However, there is still room for more research in this area. In this literature review, I will discuss a few examples of these user interfaces from key papers as well as any limitations. I will then propose and discuss two interesting research ideas that the literature did not yet address.

KEYWORDS

Interface, visual impairment, visually impaired, blind, technology, accessibility

KEY RESEARCHERS

Researchers have developed UIs for the visually impaired for over a decade. Key researchers in this domain include the following:

Leah Findlater

Leah Findlater is an Associate Professor at the University of Washington. Her primary research area is human-computer interaction, with a focus on designing mobile and wearable interfaces for individuals with visual impairments. In general, she would like to ensure that the next generation of technology (e.g. mobile and wearable technology) is inclusive. Findlater's work on mobile and wearable technology for the visually impaired has been cited over 5,000 times. It has been featured in important conferences such as CHI and ASSETS, the latter being a conference that features research related to accessible technology. She is also the director of the Inclusive Design Lab, where she and her students work on various research projects related to inclusive and accessible technology, such as touchscreen interfaces.

Stephen Brewster

Stephen Brewster is a Professor at the School of Computing Science at the University of Glasgow, where he also leads the Multimodal Interaction Group. Hence, Brewster's research focuses on multimodal interaction, particularly interactions that involve pressure, gestures, haptics, or audio to convey information without the aid of visuals. Brewster also has experience in researching accessible interfaces for the visually impaired and has written many papers on the topic. He has amassed over 16,000 citations, making him one of the most prominent researchers in the field.

David McGookin

David McGookin is an Associate Professor at Aalto University. McGookin's areas of research include multimodal and non-visual interaction and how they are applied to accessibility. McGookin has worked with Stephen Brewster in his Multimodal Interaction Group. As well, he has co-authored several papers with Brewster about various interfaces for the visually impaired. McGookin has received over 1,000 citations for his publications.

Shaun Kane

Shaun Kane is an Associate Professor at the University of Colorado, Boulder. Kane is the director of the Superhuman Computing Lab, where he researches accessible mobile and wearable technologies. Ongoing projects in the lab focus on ways to enhance people's physical, sensory, and creative abilities. Many of Kane's papers have been published to the ASSETS conference. Overall, Kane's publications have been cited over 4,000 times. One of his most cited works is about the Slide Rule, a touchscreen interface that he designed for the visually impaired.

Jacob Wobbrock

Jacob Wobbrock is a Professor at the University of Washington. In addition to human-computer interaction, his research areas include accessible computing and mobile techniques. Moreover, Wobbrock aims to improve the experiences of users with visual impairments and other disabilities through design and engineering. He has written papers on accessible touchscreens, usable gestures, and adaptable user interfaces for the visually impaired. He has over 13,000 citations in total. Wobbrock directs the ACE (Accessible Computing Experiences) Lab, dedicated to enhancing interactive technologies to make them more inclusive.

KEY RESEARCH RESULTS

For this literature review, I have read nine key papers on the topic of user interfaces for the visually impaired. These papers cover a wide range of interfaces such as mobile, web, navigation, and haptic. In this section, I will explore specific examples of these interfaces and summarize the key findings from these papers.

Enhanced Text User Interface

A website's accessibility does not imply its usability. Websites use a Graphical User Interface (GUI), but GUIs are intended for sighted users. The Web Content Accessibility Guidelines (WCAGs) do not make a difference in terms of efficiency, errors, or satisfaction; in other words, these guidelines are insufficient in determining a website's accessibility [6]. Laws have been passed in the United States and Switzerland that enforce the accessibility of websites for people with disabilities, including visual impairments [6].

In response to these laws, Leuthold, Bargas-Avila, and Opwis [6] propose a new kind of interface for websites, known as an Enhanced Text User Interface (ETI). This interface makes it easier for visually impaired users to navigate websites because it relies solely on text rather than graphics [6]. The purpose of the ETI is to impose a structure containing visual cues rather than have blind users listen to auditive clutter from any visual elements of the website [6]. Furthermore, the ETI can be considered as an extension of the WCAGs because the guidelines within the ETI can satisfy at least 3 of the 14 WCAGs, developed for the blind and visually impaired [6].

When Leuthold et al. [6] tested the ETI with 39 blind users by providing them with a search task on the University of Basel's website (Figure 1), they discovered that they were able to execute the task a lot faster than they would with a GUI. Fewer errors were made when participants used the ETI [6]. Also, many users were more satisfied with the ETI than the GUI [6]. For the navigation portion of the study, performance did not improve, possibly due to labelling problems [6]. Overall, the ETI shows improvement from the GUI, making it more usable for blind users. The study also proves that WCAGs do not work well with blind or visually impaired users [6]. In the future, designers should ensure that blind users must understand navigation labels to help these users navigate websites [6].


Seitentitel

Universität Basel

Suchhilfen (enthält 2 Links)

1. Suche
2. Sitemap

Hauptnavigation (enthält 6 Links)

1. AKTUELL
2. UNIVERSITÄT
3. STUDIUM
4. FORSCHUNG
5. WEITERBILDUNG
6. UNI-LEBEN

News (enthält 3 Links)

1. 03.02.2005
Regenz billigt Verfahren zur Wahl des neuen Rektors

2. 03.02.2005
Antonio Loprieno zum Präsidenten der Planungskommission gewählt

3. 03.02.2005
Gesamterneuerung der Regenz im Sommersemester 2005

Veranstaltungen (enthält 3 Links)

1. 21.02.2005 18.15
'si chiama fagotto' - Zu einer Zeichnung mit Musikinstrumenten von Giovanni Ricamatori, genannt Giovanni da Udine

2. 22.02.2005 18.15
Baustellen im Parlament - eine wirtschaftspolitische Betrachtung

3. 22.02.2005 19.30
Die frühmittelalterlichen Kirchenruinen von Tomils/Sogn Murezi im Domleschg-Kloster, Wallfahrtsort oder Hospitz?

Weitere Links (enthält 5 Links)

Figure 1. The University of Basel's website using an ETI (Leuthold et al., 2008, p. 265)

Navigation

Many people use maps regularly for local navigation and trip planning. Online map systems, including Google Maps and MapQuest, make geographical information easily available, but people who are blind or visually impaired are unfortunately deprived of this benefit [7]. Thus, navigation can be quite challenging for the blind and visually impaired. Recent advances in technology can help make it easier, and researchers have used the latest technology to investigate this problem. Two navigation systems, Drishti and tactile-audio maps were designed by researchers to make navigation a lot easier for these individuals.

Drishti

Helal, Moore, and Ramachandran [2] strongly believe that recent advances in technology can help with the day-to-day tasks of the visually impaired. As a result, they created Drishti, a wireless, integrated navigation system [2]. Drishti means "vision" in Sanskrit [2]. It is based on augmented reality (AR) and user interfaces. The virtual world supplements the real world in the case of AR [2]. The goal of Drishti is to provide visually impaired users with adaptive navigation support to ensure safe navigation [2]. Previous navigation systems that have been developed lack dynamic interaction and adaptability to change and Drishti aims to solve this problem [2].

Drishti integrates wearable computers, voice recognition and synthesis, wireless networks, geographic information systems (GIS), and global positioning system (GPS) technology [2]. To make visually impaired users feel comfortable walking from one location to another, Drishti augments users' pedestrian experience with sufficient information [2]. Indoor navigation techniques are used to augment this system, and building plans are registered with the rest of the layers in Drishti's GIS database [2]. Much of Drishti's interaction comes from a voice interface designed for the visually impaired [2]. Information about current environmental conditions are queried from a spatial database and are provided on the fly via thorough explanatory voice cues [2]. Static and dynamic data within the system helps guide the blind user with navigation [2]. Drishti also calculates optimized routes based on user preference [2].

Interactive Tactile-Audio Maps

In addition to Drishti, interactive tactile-audio maps assist those with visual impairments in local navigation. Currently, some techniques contribute to helping tactile specialists convert a map image into its tactile form, but the procedures are tedious and time-consuming [7]. Thus, users who are blind or visually impaired are unable to access the map image in real-time [7]. Instead, interactive tactile-audio maps are developed automatically [7]. Ultimately, the goal is to make digital maps of local directions accessible in real-time [7]. As a result, users have direct and independent access to geographical navigation that helps them navigate [7].

The first step in this approach is to detect and segment text from a map image [7]. Next, the remaining graphics from the map image are recreated in a tactile form, which can be easily reproduced through a tactile printer [7]. The printer then generates a Scalable Vector Graphics (SVG) file that provides users with interactive access to the image via a touchpad [7]. The result is a tactile-audio representation of the original map image [7]. Figure 2 shows a user interacting with the system by freely exploring the tactile map with her hands.

Six volunteers were recruited to evaluate the system [7]. Each participant has been exposed to maps and tactile graphics before [7]. Five examples, from simple maps to complex maps, were selected for the evaluation [7]. All of the participants were asked to touch all examples one by one, locate two landmarks in each map, and determine the route from one landmark to the other [7]. All of the participants were correct for most landmarks [7]. In terms of speed, most participants navigated through maps 2-4 quite quickly but were slow with the first map and the last map [7]. The first map was the simplest, while the last map was more complex than the other maps [7]. All in all, the evaluation confirmed the effectiveness of interactive tactile-audio maps [7].

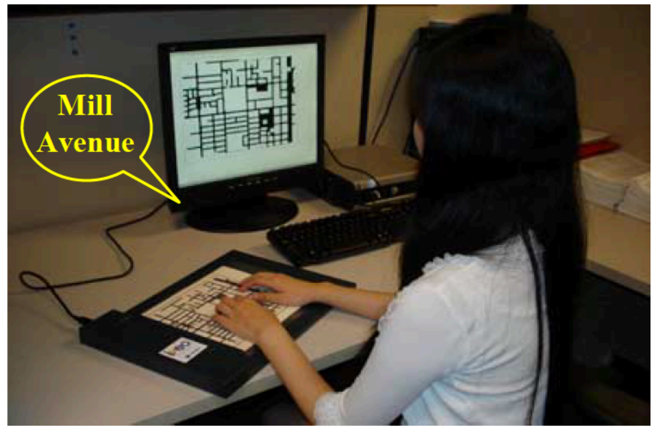

Figure 2. A user interacting with a tactile-audio map (Wang, Li, Hedgpeth, and Haven, 2009, p. 43)

Haptic Graphs

The purpose of haptic graphs is to make graphs accessible for visually impaired computer users [9]. Haptic refers to the sense of touch. Typically, graphs and diagrams are presented in Braille, but only a small proportion of visually impaired users know and use Braille [9]. The resolution of these graphs is inferior, only giving visually impaired users a rough idea about the graphs [9]. Haptic graphs use force feedback devices as well as 3D sound and computer assistance to help make it easier for the visually impaired to access graphs and diagrams; integrating surface property and auditory cues also help these users explore haptic graphs [9].

Engraving and texture usage were used to model curved lines on these graphs, and these techniques were based on experiment results conducted on both blind and sighted people [9]. Force feedback devices, such as PHANToM (Figure 3), allow information to be exchanged between humans and computers through a haptic channel [9]. PHANToM combines the sense of touch and representative soundscapes to assist users with visualization [9].

A study was conducted on both sighted and blind people to determine the effectiveness of haptic interfaces. Participants used the PHANToM device [9]. The study was divided into two parts. Part 1 was to test the friction key and explore two graphs in a minute [9]. At the end of the first part, participants were asked to identify the sticky and slippery lines as well as which line was steeper out of the two graphs [9]. Part 2 was to test the toggled gridlines as well as further test the friction key and general perception of the graphs [9]. For the second part, each participant had four minutes to obtain the minimum and maximum points on each of the six graphs given to them [9].

Based on the results from the study, friction and surface textures helped distinguish different objects on the line graph [9]. On the other hand, toggled gridlines could not provide approximate values on the lines [9]. The line graph, as perceived by the participants from the study, was usually distorted [9]. Overall, though, haptic interfaces are great at providing information about graphs to blind and visually impaired computer users [9].

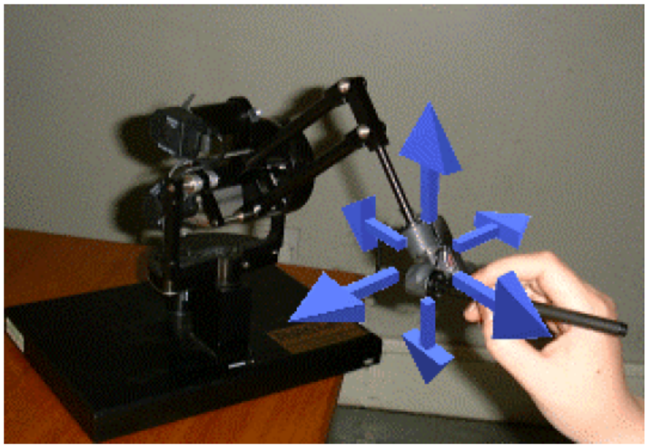

Figure 3. The PHANToM device (Yu, Ramloll, and Brewster, 2001, p. 102)

Haptic Data Visualization

Data visualization is the act of exploring real or simulated data by representing it in a form that makes it easy to understand for people [1]. Typically, this new representation of data is visual because vision conveniently enables us to perceive large amounts of spatial information, but this leaves blind and visually impaired users at a disadvantage [1]. Fritz and Barner [1] discussed the lack of available computer interfaces to display higher dimensional data for the visually impaired and designed a data visualization system to display data in 1D, 2D, or 3D. Haptic rendering and haptic enhancement techniques are incorporated into the data visualization system [1].

Fritz and Barner [1] discuss methods of representing data without using a visual component [1]. One of these methods is haptic modelling, which involves four components: a force reflecting device, a computer for a virtual environment (VE) representation, and the user [1]. Haptic modelling is done through sending input from a haptic device to the VE, either velocity or position [1]. The VE model then uses the input to determine which forces to output back to the haptic device [1]. The flowchart in Figure 4 displays how haptic rendering is done. Implementations of data can be done through the two-dimensional or three-dimensional plotting method to plot 2D and 3D data, respectively [1]. Overall, though, haptic interfaces can provide new visualization paradigms and improve human-computer interaction methods [1].

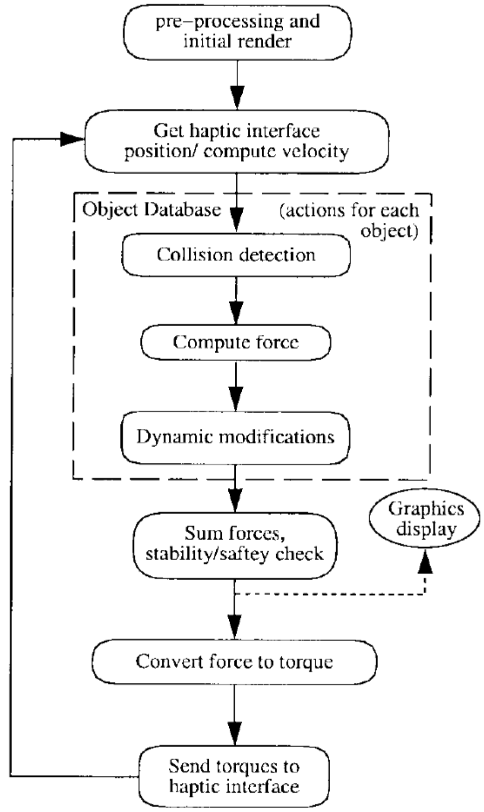

Figure 4. A flowchart displaying all the steps involved in the haptic rendering process (Fritz and Barner, 1999, p. 374)

Accessible Touchscreen Interfaces

Touchscreen devices, such as the iPhone, are incredibly common. The latest advances in touchscreen interfaces have revived the public's interest in touchscreen interfaces [3]. Despite this, touchscreens are inaccessible to the visually impaired. Luckily, researchers have developed techniques to help make touchscreen devices more accessible and easier to use. The following are examples of techniques created by researchers to increase the accessibility of touchscreens:

Slide Rule

Kane, Bigham, and Wobbrock [3] created the Slide Rule, which is a set of audio-based, multi-touch interaction techniques that let visually impaired users access touch screen applications. It is based on interviews they conducted with blind mobile device users and on user-centred design with these users [3]. It has a non-visual interface where the touch screen becomes a touch-sensitive surface that "speaks" [3]. There are four fundamental gesture interactions in this interface: a one-finger scan for perusing lists, a second finger tap for item selection, a multi-directional flick gesture for performing further actions, and an L-select gesture to access hierarchical information [3]. Figure 5 shows all the gestures that make up the Slide Rule.

An experimental evaluation was conducted in order to determine the effectiveness of the Slide Rule [3]. First, a pilot study was conducted with three blind users, and two sighted users to identify any significant usability issues [3]. After the pilot, the researchers recruited ten blind people to use the Slide Rule and a Pocket PC device [3]. Participants completed tasks quicker with the Slide Rule but made fewer errors on the Pocket PC [3]. As well, participants were able to scan through items quicker with the Slide Rule than the Pocket PC [3].

Based on post-evaluation qualitative feedback, users preferred the Slide Rule over the Pocket PC [3]. This may have to do with faster task completion and item scanning using the Slide Rule. From these results, it is safe to say that the Slide Rule can help improve the accessibility of touch screens in the future because it has many performance benefits [3].

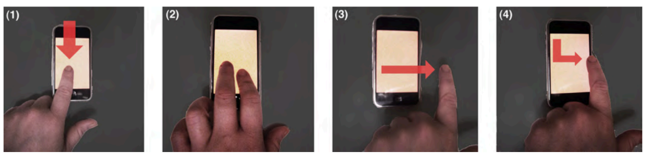

Figure 5. The Slide Rule and its multi-touch gestures (Kane, Bigham, and Wobbrock, 2008, p. 4)

Wearable Technology for Touchscreen Navigation

Mainstream wearable devices, such as the Fitbit Flex and Nike Fuel Band, are becoming increasingly popular. The popularity of wearable devices makes it essential to consider the effects of wearable technology on a wide range of users [8]. Ye, Malu, Oh, and Findlater [8] explored the idea of wearable technology to assist people with visual impairments with accessing mobile information more efficiently. People with visual impairments may not need the visual display of mobile devices, so wearable devices are quite appealing to these people [8]. Wearable technology has the potential to improve access to information and social interactions, according to a study involving wearable devices on visually impaired individuals [8].

To explore the impacts of wearable devices on individuals with visual impairments, Ye et al. [8] developed a prototype wristband that enables wireless control of the *VoiceOver* screen reading software for iOS (Figure 6). Afterwards, they conducted an online survey with 215 people and an interview study where they recruited ten people with visual impairments [8]. The online survey consisted of 26 questions, both open and closed [8]. Two scenarios for people with visual impairments were also part of the survey [8].

From the survey responses, it is found that participants used mobile devices regularly and for executing many tasks [8]. Those with visual impairments were more inclined to use optional tools such as Bluetooth keyboards, speech input, and refreshable Braille displays, and they reacted positively to the two scenarios [8]. The wristband was used for the interview portion of the study so that participants can complete a series of basic tasks [8]. These tasks include opening and closing apps and using Siri for voice commands [8]. In general, the wristband was reasonably easy to use, and participants did not require a lot of prior training [8]. The positive response by those with visual impairments to the wearable scenarios shows that wearable technologies offer great potential to increase the accessibility of mobile devices [8]. These wearable technologies can also help visually impaired access information more effectively and socialize with others better [8]. Ye et al. [8] suggest that wearable technologies in the future are designed with inclusivity for the visually impaired in mind [8].

Design Guidelines for Touchscreens

Kane, Wobbrock, and Ladner [4] have suggested design guidelines to make touch screens more accessible, including avoiding symbols used in print writing and favouring edges, corners, and other landmarks. These guidelines come from two usability studies. The first was a gesture elicitation study where participants created gestures to perform everyday tasks on a tablet computer [4]. The second was a performance study conducted by the researchers, and the same participants from the first study performed a series of reference gestures [4]. In the gesture elicitation study, ten sighted people and ten blind people were recruited [4]. Each participant was asked to invent gestures to execute everyday computing tasks to get a better sense of how blind people prefer to interact with a touchscreen [4]. There were significant differences in the gestures chosen by blind and sighted participants [4]. Blind participants preferred gestures that occurred on the screen’s edges and suggested new gestures that utilized spatial layouts that they were most comfortable with [4]. From the second study, it was discovered that gestures created by blind participants were more extensive and slower than the ones created by sighted participants [4]. Combining the results from the two studies, Kane, Wobbrock, and Ladner [4] came up with guidelines for future touchscreen designs. They include: avoid symbols used in print writing, favour edges, corners, and other landmarks, reduce the demand for location accuracy, limit time-based gesture processing, and recreate traditional spatial layouts if possible [4]. Based on this work, there is massive potential for creating robust and usable touchscreen interfaces that work equally for both blind and sighted users [4].

McGookin, Brewster, and Jiang [5] have also suggested guidelines for designers, including using different button shapes, avoiding small impact-related gestures, and providing feedback for all actions. These guidelines came from the results of a usability study that they conducted. A requirement capture study was conducted to illustrate issues with touchscreen accessibility and to see what choices visually impaired users make with assistive technology [5]. Twelve blindfolded participants and one visually impaired participant were recruited for this study [5]. Participants were asked to use a raised paper overlay touchscreen-based MP3 player and a touchscreen, gesture-based player as a way of comparing the two devices [5]. All participants were able to navigate through both players, although there were issues with short impact-related operations in the gesture-based player [5]. From the results of this study, guidelines were created. These guidelines consist of avoiding using small impact-related gestures, providing touchscreen awareness, providing an easily identifiable key on a tactile control pad, using different button shapes, and providing feedback for all actions [5]. These guidelines show potential to create more inclusive technologies.

DISCUSSION

Researchers conducted usability studies and recruited both sighted and visually impaired users to determine any differences in how both parties used these interfaces. Usability studies are prevalent in HCI. These studies allow researchers to see how these users interacted with the interfaces in real-time and to identify possible usability errors. Although there has been a significant improvement in developing such inclusive technologies, there are still many limitations in much of the existing work, including the interfaces discussed in this paper.

For example, the work done by Ye et al. [8] contains data which is nearly all self-report, and the projections of future wearable device impacts from their study results do not indicate what will occur in the future. The Slide Rule's usability study was not long enough; a more prolonged study is required to better understand the limitations and strengths of the interface [3]. Also, time constraints are a severe limitation of the ETI study; welcoming participants to the lab and getting them set up took over an hour, and short tasks were used in the study [5]. There were limitations in the force feedback device and modelling technique used in the study conducted by Yu et al. [9] These limitations include low accuracy and limited bandwidth, and they caused the line graph perceived by participants to appear distorted [9].

OPEN AREAS OF RESEARCH

Psychophysical studies to evaluate the effectiveness of various haptic enhancements

More research in the haptic data visualization system needs to be done. For a visualization system to be truly accessible, multimodal systems need to be adapted to meet the different needs of each user [1]. Fritz and Barner [1] placed a high priority on this area of research to realize the full potential of multimodal and non-graphical visualization systems. These studies can help determine the optimal formulations of data modulated textures [1].

Adding text entry methods for the Slide Rule

One way of extending the current implementation of the Slide Rule is to add additional text entry methods to handle additional tasks and scenarios [3]. Since the current Slide Rule prototype includes the QWERTY keyboard for text entry, gesture-based or Braille chording techniques may help improve text entry [3].

CONCLUSION

User interfaces for the visually impaired are well-researched and help the visually impaired with day-to-day tasks such as navigation, browsing web pages, using mobile devices, and accessing information. Researchers have made use of usability studies during development and recruited visually impaired participants to determine the usability of these interfaces. Results from each study show great potential in bridging the gap between technology and inclusivity.

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