MAKING TOUCH-BASED MOBILE PHONES ACCESSIBLE FOR THE VISUALLY IMPAIRED

Alexander Dreyer Johnsen
Norwegian School of IT
alexander@adj.no

Tor-Morten Grønli
Norwegian School of IT
tmg@nith.no

Bendik Bygstad
Norwegian School of IT
bendik.bygstad@nith.no

Abstract

Today increasing shares of mobile phones are so-called "smart phones". They come equipped with touch-based screens, enabling the user to interact in an easier and efficient way, compared to standard buttons. However, such screens require visual navigation, apparently ruling out access for the visually impaired. In this paper we ask, how can touch-based phones be extended to be applicable for the visually impaired? Two possible technologies are screen-readers and haptics (tactile feedback). In this paper we suggest a solution based on a combination of voice and haptics. Design research was chosen as the methodology for the project. Design research highlights the importance of developing a solution over the course of several iterations, and to perform product evaluation using external participants. The research contribution is an Android based prototype that demonstrates the new user interface, allowing the visually impaired to seamlessly interact with a smart-phone. Operation relies on voice and haptic feedback, where the user receives information when tapping or dragging the finger across the screen. The proposed solution is unique in several ways, it keeps gestures to a minimum, it does not rely on physical keys, and it takes the technologies of screen readers and haptics one step further.

Introduction

According to the World Health Organization (WHO) [1], around 314 million people are visually impaired, of which approximately 45 million are blind. Visual impairment blindness can be defined as the collective term "vision loss", which refers to either the loss of the ability to see, or vision reduction. The terms "low vision", partially sighted, or visually impaired, can be used for a person who has not lost the capability to see, but whose vision is significantly reduced compared to normal vision [2].

Common for both groups is their encounters with situations and problems that a sighted person would not consider an issue. This can be seen in everyday situations, where the environment is designed for the sighted. Accessing stores and businesses, or simply crossing the street, can turn out to be challenging tasks. Much of our means of communication is through the use of signs and signals; visual symbols that a person with vision loss cannot see. Examples of this include danger signs or signs providing direction, roadblocks or general information on public transportation [3,4,5]. The same restrictions apply to other ordinary situations; TV's radios, mobile phones, stoves and ATM's It can be argued that companies do not consider this user group when designing new products [6].

In this paper we investigate how touch-based phones can be extended to be applicable for the visually impaired? We begin by reviewing the available technologies. Then we present our method, design research, and our case. Finally, we discuss our results and point to further research.

Related Work

Studies on mobile phone accessibility for elderly and people with disabilities; all conclude that mobile phones are not designed for these user groups. They point out several aspects that could improve mobile phone accessibility. Mobile phones should be of adequate size and shape and have texture with good grip. The screen should be large and the buttons should have a logical placement for easier memorization of layout. Voice feedback should provide information and confirm execution of commands. The phone should also provide easy access to emergency numbers. Finally, the number of features should be kept to a minimum to ensure ease of use [6,7,8,9,10].

Despite the fact that mobile phones are not designed for use by people with vision loss, there are solutions that can compensate or improve such use. These are defined by the general term assistive technology; they include any product, instrument, equipment or technical system designed for or used by a person with disabilities, which prevents, compensates, supervise, alleviates or neutralize the effects of the disability [11]. For an individual who is blind, it is impossible to read the content on a screen; hence the aid of assistive technology is a great benefit in their personal and professional life.

Screen readers

Software applications called screen readers can convert text to speech, enabling the user to read and navigate the content of a screen through hearing. By listening to voice communication provided by the screen reader application, users are able to perceive and navigate the content on the screen, making it possible to perform tasks like word processing, e-mailing, listening to music and surfing the web. Screen readers are available for both computers and mobile phones, where on mobile phones, screen readers have been most common for phones with physical buttons, but are becoming available for phones with touch screens [12].

A screen reader is generally made of two components; the application that monitors the content on screen, and a synthesizer, which provides the spoken feedback. This is produced through text-to-speech, where the text input is provided by the screen reader and the synthetic voice is produced by the synthesizer. For a screen reader to work efficiently, applications need to follow common standards so that the content can be interpreted and presented correctly [12]. Mobile Speak is a commercial screen reader designed for mobile phones that run the Windows Mobile or Symbian OS. It is considered one of the best solutions for mobile phones, and it supports phones both with physical buttons and with touch screens [13]. TalkBack and Spiel are two open source screen readers designed for the Android OS; both enable developers to incorporate screen reader functionality into their applications. Although they are not as advanced as commercial versions, they provide developers with an easy and convenient way of making their applications more accessible [14,15].

Haptics

Haptics is a technology that provides tactile feedback, resulting in a more intuitive and less visually reliant interface. However, haptics can never replace hearing or vision; rather, it provides an additional sense. For touch-based interfaces, haptics can make a user "feel" and visualize the shape of an item without looking at the screen, or it can provide feedback when the finger reaches the border of an element or a button. Haptics is anticipated to become more

sophisticated in the feature, with an expected ability to provide even more fine-grained details [16,17,18]

Yu and Brewster [19] have developed a solution for presenting graphs and tables to users with vision loss. Users can explore virtual graphs and tables through a force feedback device that creates haptic feedback, while audio is used to present detailed and abstract information.

In a study on user reactions to haptics, Rassmus-Gröhn [20] found that some rely more on the audio feedback than the haptics feedback. This suggests that, although haptics can be a valuable additional modality, some users depend more on the senses they are used to. Hence, solutions that incorporate haptics will likely be greatly improved if they also implement sound.

User interface

Mobile phone manufacturers have noticed the inadequacies in usability of the UIs native to various OS. Most manufacturers develop their own set of UIs for the mobile phones, replacing the OS's own UI [21,22]. In addition, Nokia, Intel and the University of Oulu have established a dedicated research centre, which focuses on improving the UI on mobile devices [23].

Raman and Chen [24] argue that the UI is only a means to an end and should blend seamlessly into the user's way of operating the mobile phone. In contrast to a computer OS, the mobile OS should provide access to what the user needs and remain unattended when not in use. According to Karampelas and Akoumianakis [25], the layout for mobile phones should include the following, consistent presentations, alternative navigation tools, accessibility to common options and functions and self-explanatory navigation.

Hence, several solutions have been put forward to improve the navigation of touch screens for users with vision loss, essentially providing eyes-free navigation. Karlsen et al. [26] presented this in a study on a user-interface designed for one-hand thumb use. The interface created a 3x3 square-grid; with each square containing a link to an application or a sub-menu. Tapping one of the squares performed selection and gestures were introduced for zooming and to navigate between menus. Results showed that the participants liked the way the navigation and selection of applications worked, although they were hesitant with the gestures.

Kane et al. [27] have developed Slide Rule; a UI that solely operates through the use of gestures and auditory feedback. By using several combinations of gestures, Slide Rule allows the user to open applications and perform commands. Results revealed that the proposed solution performed significantly faster than button-based menus. However, due to the gesture commands, more errors were produced.

With their application, Strumillo et al. [28] have abandoned the default phone menu on the Symbian OS and offer a new, simpler menu that provides audible feedback and access to common functions and features. While navigating through menus, the user is informed of what is a displayed and possible action to take. The solution has received good feedback; however, it was developed for an older version of Symbian, making it incompatible with today's Symbian phones.

Eyes-free Shell is an open-source project for the Android platform created by Chen and Raman [24]; it replaces the phone's existing UI with a new menu system, providing easy

access to applications, as well as information on time and current location. Eyes-free Shell uses auditory feedback and gestures to navigate between menus. The user can search for applications by using the same type of technique presented earlier [29]. The application is part of a larger open-source initiative, sponsored by Google, which aims to make touch-based mobile phones more accessible. However, some features require physical buttons, rendering the proposed solution inaccessible to certain phones. The reliance on gestures can also be problematic, as indicated from the findings in other projects mentioned above [30].

We have pointed out several aspects that hinder the effective use of mobile phones with touch screen for people with vision loss. Although several factors could warrant further scrutiny, the aspect that stood out as the main obstacle is the operation of the touch screen itself. Further in this article we highlight how touch-based phones can be extended to be applicable for the visually impaired by building a prototype application.

Methodology

This research was conducted based upon as the Design research [31] methodology. Design research highlights the importance of developing a solution over the course of several iterations, and to perform product evaluation using external participants. Vaishnavi and Kuechler's [31] five-step model were used throughout the project, designed to guide a project from start-up to a finished solution. The research started with a general assumption, that an increasing share of today's mobile phones are touch-based and designed for those with no visual impairment. An initial research was carried out, focusing on the mobile market, the identification of existing assistive solutions and to understand more of the experience of vision loss. In the second step, a more thorough literature review was carried out in the suggestion phase, focusing on all elements and issues regarding the development of assistive technology for people with vision loss. The work that came out of the literature review supported the earlier assumptions, highlighting the need for a UI for touch-based phones, designed specifically for those with visual impairment. The new design would require operation using touch and sound, menu elements placed in a logical arrangement, and well-defined categories for assistive functionalities and standard mobile phone functionality. Next followed the development step, which focused on the development, documentation and planning of the solution. During several iterations a working prototype for people with vision loss where created. This early prototype of the application was developed to test core functionality. Evaluations of the prototype were performed through two iterations of user experiments, where external participants tested and provided feedback on the prototypes. To conclude the research, the data gathered from the two user iterations were categorized and further reviewed. Important findings from the surveys and the evaluations are analyzed and discussed in this paper. The results presented and provide new knowledge to the research field of assistive technology and mobile phone user access for people with vision loss.

Prototype application

Related work highlighted the need for a UI for touch-based phones, designed specifically for those with visual impairment. The new design would require operation using touch and sound, menu elements placed in a logical arrangement, and well-defined categories for assistive functionalities and standard mobile phone functionality.

From the related work, several projects with similar solutions came to the author's

attention. However, the projects relied mainly on gestures and hardware buttons, functionalities that could make the solutions harder to learn, and that are certainly incompatible with mobile phone that are not equipped with buttons. Based on the feedback from these projects, it became evident that the use of gestures should be kept to a minimum and that the dependency on hardware buttons should be removed.

A virtual prototype was created to show a possible solution for replacing a touch-based mobile's GUI. The virtual prototype was created in Microsoft Expression Blend 4 with SketchFlow. The virtual prototype served as a foundation for the outcome of the project and was used to communicate the idea and the vision throughout the project. During several project meetings, discussions centred on what would be realistic outcomes from the allocated time.

The application was developed in Java for Android, to support Android version 1.6 onwards. Android OS was chosen as the developmental platform for the UI, a decision based on several factors. The Android platform is adopted by several phone manufacturers and is currently one of the fastest growing mobile OS in the market [32,33,34].

Interaction with the new UI is made possible through two sensory systems, using sound and tactile feedback. An organized and intuitive menu system provides the user with access to relevant information and functionalities. The UI is designed in accordance with Nielsens' [36] usability principles, and adapted based on the findings from related work. It also follows Brook's [37] recommendation in keeping the number of available functions to a minimum, avoiding potential confusion.

Figure 1 portrays screenshots from the UI running on a mobile phone; the key words represent the different menus and functions available. The intended audience is people who are either blind or that have strongly reduced vision; the text is for the benefit of the latter group. The key words can also serve as reference points for external users, for instance if customer support is needed.

Figure 1 - Menus available in the UI

As mentioned, the UI is operated through sound and haptics. A single tap on the screen initiates the UI's screen reader, which states the function of the selected element, while the gesture "tap and drag finger" executes the element. The gesture was implemented to simplify the execution of elements, and to reduce the number of incorrect selections. Moreover, dragging a finger across the screen commands the UI to read out functions and at the same time makes the phone vibrate when a new item is available. A back element is placed at the bottom of every screen, with the exception of the main menu, allowing the user to easily navigate to the previous menu.

To help the user create a mental map of the different menus and elements, the UI will also state the level it is currently displaying and give feedback when successfully executing an element. Furthermore, the UI can be customized to read out the selected element's position on a list, for example, number three of five. The UI was tailored specifically for people with vision loss and it does not depend on existing functionality or layout. This approach differs greatly from other solutions that typically rely on a screen reader and the manufacturer's UI implementation. By creating a new set of menu elements, we did not have to focus so much on compatibility issues and could instead focus on creating new functionality. At the same time, this allowed freedom to customize the UI and optimize solutions for the visually impaired.

Base Activity contains standard functionality and provides communication with the external modules TTS Extended and Kickback; both are modules used for creating voice feedback (screen reader) and vibration (haptics). All feedback to the user, menus, voice and haptics are provided through functions called Activities. Each Activity has an OnTouchlistener, which measures where and how the user is tapping on the screen. All menu elements reside in XML format, which can easily be translated to different languages. The current version supports multiple languages and more can be added as appropriate.

Evaluation

The participants were recruited with assistance from Statped, a Norwegian agency, which provides guidance to municipalities for supporting people with learning disabilities and vision loss. All participants had previous experience from volunteering to other projects aimed at people with vision loss; moreover, before commencing, they were informed of their rights and of relevant ethical regulations.

Two iterations of user testing were carried out. A total of four people participated in the first iteration, three women and one man with an average age of 50 years; a total of five people took part in the second iteration, the same four with an extra man, making the average age 49.4. As mentioned, statistics from WHO [1], show that women over 50 make up the largest share of the world's blind population; thus the project's sample is representative of this population. Of the participants, three were blind, one was diagnosed with very low vision, although her interaction could indicate complete vision loss, the final participant had low vision and could see objects in very close proximity.

How testing were performed

The user tests were planned according to usability guidelines from Nielsen [36], with usability measured relative to certain users and certain tasks, and where every test should define a representative and measurable set of tasks relevant to the users. For consistent measurements, a survey should be completed subsequently. The mean value of the measured attributes should exceed a specific minimum; on a Likert scale ranging from 1 to 5, the mean value should be at least 4 and 50% of participants should provide the score of 5 [36]. With two iterations of user testing, the ratings from the two surveys can be compared to evaluate whether the improvements affected usability ratings and if further improvements are still required [36].

Participants all performed the same steps, starting with a general introduction to the project

with its goals and aims, followed by ten minutes of training and some time to become familiar with the UI, finally performing a couple of exercises and providing feedback and completing a survey. Each test was performed on a HTC device, with an average duration of one hour. Participants were monitored throughout the test. The introduction to the project emphasized to the participants that the UI was only a prototype and that the aim was to improve the navigation on touch-based mobile phones, they could therefor expect limitations and fewer available options.

After the exercise, participants were asked to complete a survey. This collected background information and presented a set of statements for participants to mark their level of agreement with. From 1, "strongly disagree" to 5 "strongly agree". Statements were grouped in categories according to the assessed function of the UI (Table 1).

Survey on UI	
Menu system:	
1	The menu system was easy to use
2	The menu system made the touch phone easier to use
3	The spoken options were easy to understand
4	It was easy to navigate between menus and sub-menus
5	The vibration made it easier to change between menus/options
6	The categorization of sub-menus was logical
The solution/product:	
7	I personally felt that the menu system was limiting my use of the mobile phone (Note: All features have not been implemented in this prototype)
8	Please provide suggestions to improvements

Table 1 - Survey completed by participants

Data gathered and analysed in the first user experiment resulted in a new version where the major issues and concerns uncovered in the first iteration were improved upon. In the first iteration, a single tap of the finger would state the function of the selected function, while a second tap would select the function. Although, this served the purpose, the solution caused frustration among the participants; they pointed to difficulties with tapping the correct area and mistakenly opening elements. To overcome these issues, the navigation of the UI was changed so that a single tap would still state the function of an element, but dragging the finger to the right would open it.

The second iteration also introduced numbering and made changes to the naming of elements. One set of numbers reflected the elements; current position in a list, while another set presented the total number of elements in a list. A new list view, for lists with several elements, was also introduced. The new list introduced a second row of letters, ranging from A to Z, on the right side of the screen.

With the introduction of the new functions, the participants were asked to perform the same exercises and survey once more. Additionally, they were asked to test the new list view and answer a couple of new questions related to the added functionality.

Results

Survey questions were categorized to the features they were set to evaluate, these are listed in Table 2. "Menu system" and "The solution" are considered the two most important categories, as they measure how well the UI works and the success of the solution. The participants received the same set of questions in both rounds.

Category	Description
Menu system	Questions on how well the UI works, measuring functions such as, navigation, activating elements, feedback through speech and touch, and ease of use. A low score here will indicate that the product is not well received among the participants
Phone	Questions relating to Phone functionality
Navigation	Questions relating to the Navigation functionality
Applications	Questions relating to Applications list
Information	Questions relating to Information functions
The solution	This category summarizes the success of the solution, defining whether the participants likes or dislikes the solution and would use it as the preferred tool for interacting with a touch phone. A low score here will indicate that the product is not well received among the participants

Table 2 – Summary of survey categories

Figure 2 presents the results from round one and two, with an overview of the mean scores for each functionality category. Several questions make up a category, thus the mean scores are averaged across questions as well as participants.
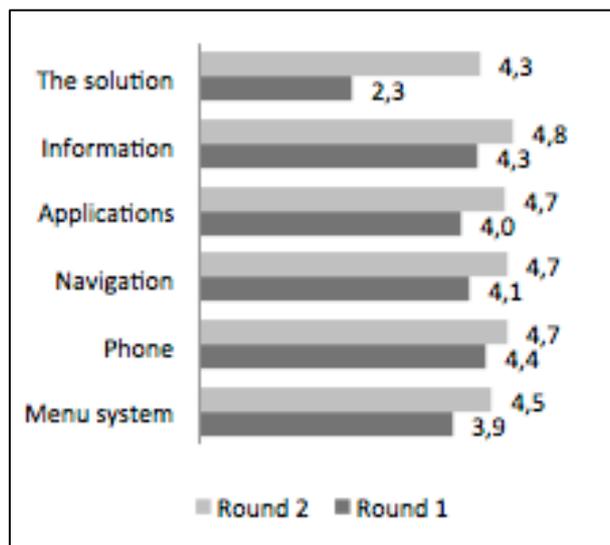

Figure 2 - Graph displaying mean scores from the first and second round of testing

The difference between mean scores from round one and two clearly shows responses were more positive in round two, where mean were higher for all categories. The two categories of particular interest, "Menu system" and "The solution" both presented fairly poor feedback in the first round, with initial mean scores as low as 2.3 for "The solution" and 3.9 for "Menu system". According to Nielsen [36] criteria, these low scores would constitute a project failure. However, round two of testing provided a substantial increase in positive feedback; thus, it can be concluded that the solution tested in round two is more

efficient and better received among the participants.

Figure 4 shows the results from the individual questions for the "Menu system" category (Question numbers from table 1). The mean scores illustrate the changes in the participants reaction between the first and second iteration.

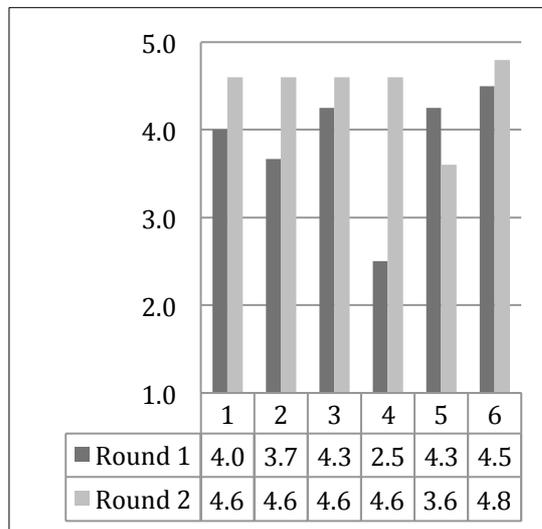|	1	2	3	4	5	6
Round 1	4.0	3.7	4.3	2.5	4.3	4.5
Round 2	4.6	4.6	4.6	4.6	3.6	4.8

Figure 3 - Graph displaying a comparison between results from first and second round of testing on the menu system

The results show an increase in scores for all but one question, indicating that the second menu system received a better acceptance than the first version. The reduction in scores for the questions relating to the vibration function was clarified through verbal feedback from participants. In the first round of testing, a greater reliance on haptic feedback was required to navigation; however, in the second round of testing, the improvements facilitated the auditory feedback and participants chose to rely more on sound than touch. These results are consistent with findings from Rassmus-Gröhn [20], who found that people tend to rely more on the sense they are accustomed to.

Feedback were grouped in Positive, Negative, Suggestions for improvements, and Observations made during testing. The positive feedback from participants shows how much they appreciated the second iteration of the solution, with statements such as "Everything works much better now", "It is fun to use a touch phone" and "I have a more positive view on touch phones with this solution"; this is consistent with the survey results. The negative feedback mainly focused on the new functionality introduced in the second iteration, with statements such as "The list view is too sensitive when selecting elements" and "The letters in list view for large lists of elements are too small". This suggests that that the issues encountered in the first iteration had been solved and that a third iteration should aim at solving the new problems. Suggestions for improvements focused on providing individual settings for each user, better search functionality, and the number of elements, in addition to a gesture of moving back instead of a separate back button.

Discussion

In this section we discuss our result and assess our contribution. A total of five versions of the solution were developed, three for internal testing and two for external evaluation. As presented in the research results chapter, the UI received positive feedback from the

participants. The development of the prototype followed findings from the related work, with a framework that pointed out several factors for improvement and experience from previous solutions to learn from. The decision to design the UI for the Android OS, was based on reports from The Nielsen Company [32] and Gartner [33], which indicated that the Android OS is the fastest growing mobile OS. Key considerations for the new solution included minimal use of gestures, replacement of the native UI, providing independence from phone manufacturers [24,26,28], and no reliance on physical keys, making the solution compatible to all Android based mobile phones. Moreover, to improve navigation, a feature was implemented to allow users to find available elements by tapping anywhere on the screen.

The solution is intended for people who are either blind or that have strongly reduced vision, and differentiates itself from previous implementations in several aspects. Where most other solutions typically rely on a screen reader and the manufacturer's UI implementation, the proposed solution created a completely new set of menu elements. As observed in the literature review this is nothing new and has been tested by other implementations. However, this proposal differentiates itself were the menu system was inspired by the layout of Nokia based mobile phones with vertical navigation. The menu system used in most such phones have been tested and used on several million devices, and have proved itself to be reliable and easy to operate. The decision to design the UI according to this principle provides a foundation that is well accepted without the need to re-invent the wheel and attempts to smooth the transition for participants' currently using Nokia phones. Font sizes were formatted according to guidelines from, ensuring that people with low vision could choose to operate the UI either through sound or visual navigation.

Another significant difference compared to other implementations is the dependency on hardware buttons was circumvented, as this could result in compatibility issues with certain phone models. Depending on phone manufacture implementation, some models come with buttons such as a call button where others just come with a screen. By removing the use of buttons, the project did not have to focus so much on compatibility issues and could instead focus on creating new functionality and optimize the UI. The proposed UI is operated through taping on the screen, performing gestures, haptic and verbal feedback. Where other solutions provide an intricate set of gestures and ways of tapping, this solution tries to reduce the number of gestures and keep the menu system simple and carried over from each selection to minimize the learning curve. As a limitation, the prototype cannot be applied to text writing or web-browsing. Thus, the solution is just scratching the surface of assistive aid solutions. Furthermore, applications launched by the UI will need to be coded correctly to work for people with vision loss. The fact that the current solution replaces the phone's factory UI, might make it uninteresting for certain users, some may prefer to preserve the original UI and rather use a dedicated screen reader.

Conclusion

This paper has presented our work regarding how touch-based phones can be extended to be applicable for the visually impaired. Through related work an in-depth overview of issues and rights facing people with vision loss has been presented. Furthermore, an evaluation of the current mobile market and available solutions and technology followed. The literature review pointed out that most modern mobile phones require visual navigation, to operate the touch-based screens. Although mobile phones are accessible through the use of applications

called screen readers, those currently on the market are inefficient and difficult to use with touch screens. Hence, this research aimed to find a new solution. Build upon voice and haptic feedback prototype application was developed. Evaluation found this to be an effective solution that most of the participants would use if it became commercially available.

The developed prototype presents a unique combination of techniques resulting in, for the user, a new and user-friendly UI with vertical navigation. Operated through sound and haptic, where tapping on the screen would provide information, a limited need of gestures to execute commands and no reliance on hardware buttons to ensure increased mobile phone compatibility. Thus taking the best from previous research and presenting a solution that focuses on providing a system easy and intuitive to operate, in addition to providing access to all relevant applications and functions on the mobile phone.

For future research it would be interesting to investigate how the mobile phone can be implemented for assistive living, or leverage on augmented reality and GPS positions, to better present intelligible content and information based on current location.

References

[1] World Health Organization, 2009. Visual impairment and blindness. Available at: http://www.who.int/mediacentre/factsheets/fs282/en/index.html [Accessed October 23, 2010]
[2] Colenbrander, A., 2002. *Visual standards. Aspects and Ranges of Vison loss with Emphasis on Population Surveys*, Sydney.
[3] Tjan, B.S. et al., 2005. Digital Sign System for Indoor Wayfinding for the Visually Impaired. *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05) - Workshops*, pp.30-30
[4] Joseph, C., 2009. Challenges of Being Blind. *eHow*. Available at: http://www.ehow.com about_5185162_challenges-being-blind.html [Accessed August 14, 2010].
[5] Maines, S., 2008. White Cane Walk makes visible the daily challenges of blindness. *The Lawrence Journal-World*. Available at: http://www2.ljworld.com/news/2008/oct/19/white_cane_walk_makes_visible_daily_challenges_bli/ [Accessed August 14, 2010]
[6] Picard, K., 2010. Minibanker med touch screen. *Dinside.no*. Available at: http://www.dinside.no/851363/minibanker-med-touch-screen [Accessed January 4, 2011].
[7] Abascal, J. & Civit, A., 2001. Universal access to mobile telephony as a way to enhance the autonomy of elderly people. *Workshop on Universal Accessibility of Ubiquitous Computing Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly*, pp.93-99.
[8] Plos, O. & Buisine, S., 2006. Universal design for mobile phones: a case study. *CHI 2006*, pp.1229-1234. Raman, T.V. & Chen, C.L., 2008. Eyes-Free User Interfaces. *Computer*, 41(10), pp.100-101.
[9] Smith-Jackson, T., Nussbaum, M. & Mooney, A., 2003. Accessible cell phone design: development and application of a needs analysis framework. *Disability and rehabilitation*, 25(10), pp.549-60.
[10] Kane, S.K. et al., 2009. Freedom to roam: a study of mobile device adoption and accessibility for people with visual and motor disabilities. In *Proceeding of the eleventh international ACM SIGACCESS conference on Computers and accessibility*. ACM, pp. 115–122.
[11] Perea, G., Usero, M. & Angel, J., 2006. Strategies for tailoring web contents for specific devices: the case of usable and accessible contents for assistive technologies of web mobile devices. *Annals of Physics*, 54(July), pp.1-5.
[12] Babinszki, T., 2010. How Do Blind People Use Mobile Phones. *Even Grounds*. Available at: http://www.evengrounds.com/blog/how-do-blind-people-use-mobile-phones [Accessed September 19, 2010]. Brooks, F.P., 1995. *The Mythical Man-Month: Essays on Software Engineering* Anniversar., Addison-Wesley Professional.
[13] Code Factory, Introducing Mobile Speak. Available at: http://www.codefactory.es/en/products.asp?id=316 [Accessed August 27, 2010].
[14] Chen, C. & Raman, T.V., 2009. Announcing Eyes-Free Shell For Android. Available at: http://google-opensource.blogspot.com/2009/04/announcing-eyes-free-shell-for-android.html [Accessed January 5, 2011].
[15] Darilek, N., 2010. Spiel: Features. Available at: http://spielproject.info/wiki?name=features [Accessed January 4, 2011].

[16] Buxton, B. et al., 2008. Big data: the next Google. Interview by Duncan Graham-Rowe. *Nature*, 455(7209), pp.8-9.

[17] Gemperle, F., Ota, N. & Siewiorek, D., 2001. Design of a wearable tactile display. *Proceedings Fifth International Symposium on Wearable Computers*, pp.5-12.

[18] Rassmus-Gröhn, K., 2006. Enabling Audio-Haptics. *Licentiate Thesis,Certec, Department of Design Sciences*, pp.1-126.

[19] Yu, W. & Brewster, S., 2003. Evaluation of multimodal graphs for blind people. *Universal Access in the Information Society*, 2(2), pp.105-124.

[20] Rassmus-Gröhn, K., 2006. Enabling Audio-Haptics. *Licentiate Thesis,Certec, Department of Design Sciences*, pp.1-126.

[21] HTC, HTC Sense. Available at: http://www.htc.com/europe/press.aspx?id=127750&lang=1033 [Accessed August 16, 2010b].

[22] Topolsky, J., 2008. Samsung's new TouchWiz UI gets previewed on video. *Engadget*. Available at: http://www.engadget.com/2008/02/15/samsungs-new-touchwiz-ui-gets-previewed-on-video [Accessed August 16, 2010].

[23] Darling, P., 2010. Intel and Nokia Create First Joint Laboratory. Available at: http://newsroom.intel.com/community/intel_newsroom/blog/2010/08/23/intel-and-nokia-create-first-joint-laboratory [Accessed January 4, 2011].

[24] Raman, T.V. & Chen, C.L., 2008. Eyes-Free User Interfaces. *Computer*, 41(10), pp.100-101.

[25] Karampelas, P., Akoumianakis, D. & C, 2003. User interface design for PDAs: Lessons and experience with the WARD-IN-HAND prototype. *, Practice, and Experience*, pp.474-485.

[26] Karlson, A.K., Bederson, B.B. & SanGiovanni, J., 2005. AppLens and launchTile. *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '05*, p.201.

[27] Kane, Shaun K., Bigham, J.P. & Wobbrock, Jacob O., 2008. Slide rule. *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility - Assets '08*, p.73.

[28] Strumillo, P., Skulimowski, P. & Polanczyk, M., 2009. Programming Symbian Smartphones for the Blind and Visually Impaired. In *Computers in Medical Activity*. Berlin: Springer-Verlag Berlin and Heidelberg GmbH & Co. KG, pp. 129-136.

[29] Yfantidis, G. & Evreinov, G., 2005. Adaptive blind interaction technique for touchscreens. *Universal Access in the Information Society*, 4(4), pp.328-337.

[30] Helft, M., 2009. For the Blind, Technology Does What a Guide Dog Can't. *The New York Times*. Available at: http://www.nytimes.com/2009/01/04/business/04blind.html [Accessed January 5, 2011].

[31] Vaishnavi, V. & Kuechler, W., 2007. *Design Science Research Methods and Patterns: Innovating Information and Communication Technology* New Editio., Taylor & Francis, Inc.

[32] The Nielsen Company, 2010. Android Soars, but iPhone Still Most Desired as Smartphones Grab 25% of U.S. Mobile Market. Available at: http://blog.nielsen.com/nielsenwire/online_mobile/android-soars-but-iphone-still-most-desired-as-smartphones-grab-25-of-u-s-mobile-market/ [Accessed August 7, 2010].

[33] Gartner, 2010a. Gartner Says Android to Become No. 2 Worldwide Mobile Operating System in 2010 and Challenge Symbian for No. 1 Position by 2014. Available at: http://www.gartner.com/it/page.jsp?id=1434613 [Accessed January 5, 2011].

[34] Comscore, 2010. comScore Reports May 2010 U.S. Mobile Subscriber Market Share. Available at: http://www.prnewswire.com/news-releases/comscore-reports-may-2010-us-mobile-subscriber-market-share-98031904.html [Accessed August 7, 2010].

[35] Ableson, F., 2009. Introduction to Android development. *IBM*. Available at: http://www.ibm.com/developerworks/opensource/library/os-android-devel/ [Accessed January 23, 2011].

[36] Nielsen, J., 1993. *Usability engineering* 1st ed., Morgan Kaufmann

[37] Brooks, F.P., 1995. *The Mythical Man-Month: Essays on Software Engineering* Anniversar., Addison-Wesley Professional

[38] Nielsen, J. & Landauer, T.K., 1993. A mathematical model of the finding of usability problems. In *Proceedings of the INTERACT93 and CHI93 conference on Human factors in computing systems*. ACM, pp. 206-213

[39] Richtel, M., 1998. Making Web Sites More "Usable" Is Former Sun Engineer's Goal. *The New York Times*. Available at: http://www.nytimes.com/library/tech/98/07/cyber/articles/13usability.html [Accessed December 16, 2010].

[40] Nielsen, J., 2000. Usability Testing with 5 Users (Jakob Nielsen's Alertbox). *Jakob Nielsen's Website*. Available at: http://www.useit.com/alertbox/20000319.html [Accessed December 16, 2010].