A Study of Mobile Accessibility for users of IOS VoiceOver

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Abstract

Nowadays mobile devices are being used by a huge number of users around the world, however, there are many people with different types of disabilities including vision, hearing, mobility, learning problems, and more having no ability to operate the devices properly and yet struggling with inaccessibility of them in their daily life. Assistive technologies are placed between users and mobile devices in order to help user interactions with mobile devices. Although these assistive technologies are absolutely assisting users to access mobile devices but, mobile content is not fully accessible for users yet. In this thesis work, the interactions between visually impaired users and Apple touchscreen iPhone 7 through built-in feature, VoiceOver screen reader was investigated. The purpose of the investigation was to identify the challenges and issues while visually impaired users interacting with mobile devices through VoiceOver.

In order to identify accessibility issues of VoiceOver, an evaluation inspection done on a set of five participants in form of a semi-structured interview. The result from collecting participant’s opinions, comments, and feedbacks acknowledged that VoiceOver basically makes the Apple iPhone 7 accessible to visually impaired users, however, there are still some usability issues that impediment full mobile accessibility available for visually impaired users.

User perspectives, experiences, and feedbacks are very much valuable for identifying and understanding usability and accessibility issues in order to improve the mobile accessibility. The results from the evaluation showed that it deserves more investigation on mobile accessibility in order to design simple, operable, understandable, and robust mobile hardware and software for fully supporting visually impaired users.

Keywords: mobile accessibility, usability, screen reader, visually impaired users, VoiceOver
Sammanfattning

Nu för tiden används mobila enheter av ett stort antal användare runt om i världen, men samtidigt finns det många människor med olika typer av funktionshinder som syn- hörsel- rörlighet- och inlärningsproblem med mera som inte har möjlighet att använda enheterna på ett adekvat sätt, men trots det anstränger de sig med att använda mobila applikationer i sitt dagliga liv. För att råda bot på problemet placeras tekniska hjälpmedel mellan användare och den mobila enheten för att underlätta interaktionen mellan användare och den mobila enheten. Även om dessa hjälpmedel hjälper användare med funktionshinder att komma åt mobila enheten, är mobilt innehåll ännu inte fullt tillgängligt för dessa grupper. I den här avhandlingen undersöktes interaktionen mellan användare med synskada och Apple Touchscreen iPhone 7, genom en förinstallerad VoiceOver-skärmläsare. Syftet med utredningen var att identifiera utmaningar och problem när synskadade interagerar med mobila enheter.

För att identifiera VoiceOver-problem, det gjordes en studie på en grupp av fem deltagare i en ostrukturerad och öppen formad intervju. Resultatet från deltagarnas åsikter, kommentarer och feedback visar att VoiceOver ökar i grunden tillgängligheten av Apple iPhone 7 för användare med synskada, även om det fortfarande kvarstår användbarhetsproblem som förhindrar fullgod mobil tillgänglighet för denna grupp.

Användarperspektiv, erfarenheter och feedback är mycket värdefull information för att identifiera och förstå användbarhets- och tillgänglighetsfrågor för att förbättra mobil tillgänglighet. Resultat visade att det behövs mer utredning om mobil tillgänglighet för att utforma enkel, operativ, förståelig och robust maskin- och programvara för att ge fullt stöd till användare med synskada.

Nyckelord: mobil tillgänglighet, användbarhet, skärmläsare, användare med synskada, VoiceOver
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1 Introduction

This chapter provides a general description of technology usage in everyday life and popularity of mobile devices in the society. Afterwards, inaccessibility of mobile content to people with disability and assistive technologies to improve mobile accessibility are elaborated. It continues with introducing the User Experience Design to develop websites, mobile applications, and assistive technologies according to user requirements. Research problem, thesis work purpose, and questions are presented afterwards. Research Methodology, risks, ethics, and sustainable development are mentioned briefly as well. At the end of this chapter outline presents the layout of thesis report.

According to a research [1] done in “Instituto Superior Técnico”, the largest and most reputed school of engineering, science, technology, and architecture in Portugal; digital technologies provide easy access to information, social interactions, online markets, purchases, and control of environment for people. Many people around the world are surrounded by various type of digital technologies and sensors in public places, homes or even their bodies. People’s everyday life has been touched by functionality of various devices in a way that was not available a few years ago.

A study regarding mobile device adoption and accessibility for people with visual and motor disabilities which was done in the university of Washington in 2009 [2], showed that technologies are turning to smaller and portable devices to be available and accessible everywhere. Mobile devices are increasingly becoming popular in the society. People now are able to surf the Internet, communicate, edit, send, and receive documents through mobile devices in different ways than they interact with desktop devices. Mobile devices functionality and quality of services are the same as desktop services but with higher availability everywhere.

Although websites and mobile devices are being used by a huge number of users around the world, there are many people with different type of disabilities including vision, hearing, mobility,
learning problems, and more, with no ability to operate these devices properly and still struggling with inaccessibility of them. According to S. Faulkner ‘s investigation [3], not all the browsers on all operating systems support screen readers properly. For instance, Mozilla Firefox offers screen reader support on the Windows, Linux, OSX, and Android operating systems. The Chrome browser also provides almost the same support except for the Linux operating system. The Safari browser on Windows and Chrome on Linux are two examples that do not have screen reader support.

In order to provide mobile accessibility for this group of people “Assistive Technology” is introduced by IDEA. According to “Individuals with Disabilities Education Act” (IDEA) [4], assistive technology or adaptive technology is a piece of hardware, software, device, or service which is used to increase, improve, and maintain the functional capabilities of people with disabilities. As a matter of fact, any device or object that is placed between people with disabilities and mobile content in order to facilitate communication between them is called assistive technology.

Vanderheiden [5] provides a definition of “accessible” in a general sense of information technology as “able to be used effectively by individuals either directly or with the assistive technologies that they will have with them and can use when they encounter the environment, device, or system”. According to Vanderheiden’s definition, mobile accessibility is defined as the degree of communication between assistive technologies which are used by people with disabilities and mobile contents. For instance, many people with vision disability use the browsers that support screen reader in order to have access to webpages. If an assistive technology is not able to process all the information on a webpage in a way that a sighted user can process, then that webpage is not accessible for visually impaired uses. On the other hand, if an assistive technology is able to successfully process a webpage, but the produced audio information is difficult to hear and understand for people with vision disability, that webpage is not accessible either. Therefore, an assistive technology must have capability to retrieve and transfer mobile content and webpages to people with disability properly.
Louise Veling is a research fellow at the Innovation Value Institute, has been working on research about User Experience Design (UED) [6]. Based on her research, organizations are moving from traditional techno-centric to user-centric method of development which means users are becoming more and more important to enterprises and market owners. Jacob Gube in his research about UED [7] defines “User Experience Design” capability as a strategy to design and develop products according to user requirements including users with disabilities. UED is about to put the user in the center of the design process from research to realization stage. UED provides tools and frameworks to achieve more efficient user interactions and ensures that the user is the most important topic to be focused on for information and communication technology. Louise Veling declares: “When user experience design...brings together business objectives, user requirements, and IT capabilities, then the IT organization is in a position to leverage these three inputs into a significantly large amount of business value”. Today organizations must embrace UED more than before to design and develop mobile content more accessible for all type of users including people with specific requirements for interacting with mobile devices.

1.1 Approaching the Research Problem

People with disabilities are in trouble to access information through mobile devices due to inaccessibility of the content. In order to reduce this deficiency of mobile content, assistive technologies are placed between users and mobile devices to present information in a way that is more perceivable for people with disabilities. Different assistive technologies are made for different type of disabilities such as vision, hearing, mobility, and more. Screen reader, screen magnifier, speech recognition, Braille printer, and different input devices including touch screens, joysticks, pointers, and keyboards are some example of assistive technologies.

Visually impaired users use screen reader, magnifier, and speech recognition which are built-in
features in most of the smart phones and tablets to read and query the data. Tom Babinszki in his research about how blind people use mobile phones [8], defines a screen reader as a form of assistive technology that converts text and graphics to speech, enables visually impaired people to read and navigate the content of the screen through hearing. Assistive technologies are developed on various operating systems to assist visually impaired people which some of them are built-in features available on smartphones, tablets, and more mobile devices.

Devices from Apple are available for visually impaired people very much in the market. The assistive technology which is built-in feature in Apple products provides mobile accessibility for visually impaired users. VoiceOver is the Apple gesture based screen reader available on the Mac OS and IOS operating systems, that makes the products such as iPhone, iPad and iPod touch accessible. VoiceOver is a built-in screen reader that speaks aloud the text and whatever appears on your computer screen or mobile devices. However, this built-in feature assists visually impaired people to read text and understand the content but also creates some challenges for users to deal with.

This thesis work focused on the investigation of accessibility parameters and evaluating mobile accessibility of VoiceOver as a built-in screen reader on devices from Apple. Evaluation inspection of VoiceOver in order to find out the accessibility issues and challenges while user interacting with mobile devices helps to improve mobile accessibility in the future and impacts visually impaired daily life in a way that has not influenced before.

1.2 Research Purpose and Questions
As mentioned in section 1.1, the focus of this thesis work was on investigating the impact of assistive technology on mobile user interactions. In order to narrow down the investigation on specific topic in mobile accessibility, visually impaired users were targeted to be inspected and VoiceOver, the Apple gesture based screen reader was selected to be evaluated.
The questions addressed in this thesis work were as following:

- What parameters can be used to evaluate mobile accessibility for visually impaired people?
- What usability and accessibility issues are identified during the inspection evaluation of VoiceOver?
- What proposals are suggested to improve mobile accessibility on VoiceOver?

The purpose of this study was to find out the answers for the research questions. This study was focused on VoiceOver, a built-in screen reader on devices from Apple as a case study for this thesis work. Iphone 7 with IOS version 10.2 was chosen as a particular case study for this evaluation as it was the latest available iPhone in the market when this thesis work was done.

### 1.3 Methodology

According to Buckley and Chiang study [9], research methodology is defined as “a strategy or architectural design by which the researcher maps out an approach to problem-finding or problem-solving.” Qualitative and quantitative research methodologies are used today for problem finding or problem solving.

The purpose of this thesis work was to evaluate mobile accessibility of VoiceOver and identifying the accessibility issues while users interacting with iPhone through VoiceOver. The first research goal was to find out, if the iPhone 7 is accessible through VoiceOver? In order to find out the answer, the VoiceOver and its feature functionality was investigated and analyzed. The most important outcome of this analysis was to study the VoiceOver and identifying the accessibility issues. According to the research question, a hypothesis or a belief was generated as “iPhone 7 is accessible through VoiceOver”. Therefore, the focus of the evaluation was on testing the hypothesis. In Order to perform the test a collection of data including the feedbacks and opinions of visually impaired users while interacting with iPhone 7 though VoiceOver was required.
Qualitative research methodology was the best candidate to target the thesis goal in terms of understanding the VoiceOver and identifying issues and challenges, while visually impaired people interacting with mobile devices. According to the book from Corbin J, Strauss A. [10], qualitative research methodology was considered for understanding of underlying reasons, opinions and motivations. Although quantitative was a good choice to generalize the result out of collecting feedbacks from sample population of visually impaired people, but due to the limitation of author of this thesis work for accessing a big group of people, this choice was rejected.

Considering the nature of the thesis study, interview was chosen to explore, discover and collect user behavior during the process of study. Interview is a well-known way of collecting data in everyday life. In order to do the inspection evaluation a small group of five people was selected to be interviewed. In addition, a study design including the structure of the interview was prepared. Designing the study design instrument was very much important and challenging in order to collect precise data from users. In order to perform the study design, these three phases suggested by Creswell [11] [12] were followed:
1) preparation for interview
2) constructing the interview questions
3) execution of interview

1.4 Risks, Ethics and Sustainable Development

This thesis work was concentrated on inspection evaluation of mobile accessibility of VoiceOver on iPhone 7. The purpose of performing this study was to identify impediments and issues while visually impaired people operating mobile devices. Feedbacks and comments from participants in the interview were very much valuable and anonymous. Their privacy was fully respected by
interviewer and never violated. Also their personal information was confidential. The participants have been well treated during the interview session, and well appreciated afterwards. They were all higher educated and familiar with VoiceOver on iPhone. They were very welcomed to get trained by interviewer and were honest and opened in giving their feelings and feedbacks.

Accuracy and validity of the feedbacks and comments were one of the most important concerns in this thesis, however in all the interviews, there is a risk of collecting inaccurate data. The feedbacks and comments collected from the participants were very much valuable. A lot of comments were about identifying the usability and accessibility issues of VoiceOver on iPhone 7. The result of this thesis work is worthwhile to be used by application designers to improve the functionality of VoiceOver and also remove the accessibility barriers. Improving mobile accessibility encourages people with disability of vision to get more involved in the society. Engagement of this group of people in work environment empowers the economy by using idle resources. On the other hand, mobile accessibility creates more opportunities in the job market for mobile designers and developers. Improving mobile accessibility helps social interactions and life satisfactions for visually impaired people. Regarding sustainability, the more use of electronic devices, lead to reduce paper waste and save more trees.

1.5 Thesis Outline
Chapter 1 presents an introduction to the main idea of the thesis work. The introduction starts with an overview of technology usage all around the world and explains how people’s lives have been touched with portable and thinner mobile devices. Afterwards, inaccessibility of mobile devices for people with disability are elaborated. Introduction continues to elaborate the research problem and concludes with explaining the thesis purpose and main questions. At the end of this chapter research methodology which is used for inspection evaluation is presented.

Chapter 2, background, starts with speaking about the ease of interaction with mobile devices
which is called “Usability” or “User Friendly”. Popularity of mobile devices and importance of mobile accessibility in the society are discussed and continued with explaining inaccessibility of mobile content for people with disability. After that the motivation for investigation on mobile accessibility is elaborated. Common barriers between people with disability and mobile users are elaborated. Then “Accessibility” is presented and continued with explaining mobile accessibility. Accessibility barriers, principle, guidelines, and parameters are elaborated afterwards. Background chapter continues with elaboration of assistive technology as an interface between people with disabilities and mobile devices. It concludes with introducing screen reader as an assistive technology for visually impaired people.

Chapter 3 starts with elaboration of related works which are done regarding mobile accessibility and continues with an overview on Apple VoiceOver, functionality and gestures. Afterwards, a review for evaluation of VoiceOver on iPhone 4 is presented and discussed.

In Chapter 4 research methodology is introduced. Qualitative and quantitative methodologies are elaborated. Considering the texture of the research problem, interview is selected as qualitative method to collect data from user experiences. The motivation for selecting interview method is elaborated in this chapter. Afterwards, study design including the structure, format and content of the interview is discussed. This chapter continues with explaining study execution, what happened during the interview and concludes with the results of the interview.

Chapter 5 presents a discussion around the results of the study execution. It continues with analysis of issues and challenges identified during the inspection evaluation and ends with the summary of the study execution, what happened and what results achieved during the thesis work.

Last chapter is about the proposal solutions for the issues are identified during the inspection evaluation. These proposals are considered as future work for this thesis work.
2 Background

This chapter starts with a brief discussion on usability of mobile devices and continues with introducing the parameters to evaluate it. Afterwards, mobile accessibility and parameters for evaluation of accessibility are elaborated. An overview on mobile devices popularity in the society is presented and continues with speaking about mobile inaccessibility issues that create challenges for people with disability when operating mobile devices. It continues with the motivation behind this investigation on visually impaired people. Afterwards, common barriers between mobile users and disabled users when interacting with mobile devices is elaborated. This chapter continues with extracting accessibility parameters from W3C principles and guidelines. “Assistive Technology” as an interface between people with disabilities and mobile devices is introduced and continues with presenting different type of assistive technologies and ends up with screen reader elaboration.

Usability is a known term since early 1980 for “User Friendly” which means the ease of interaction with a particular device or application. According to a joint research done in the university college Cork, Ireland [13] on Usability, it is defined as “the ease of use and acceptability of a product for a particular class of users carrying out specific tasks in a specific environment”. The usability of mobile devices is ease of performing desired interactions with applications or devices, navigating through different mobile built-in features and services, playing around with different applications, finding any required information without facing any problems. Usability is a necessary requirement for mobile devices to get survived in the market. If a mobile feature or an application is hard or failed to use, user leaves. User skips if there is any difficulty in use of mobile devices and applications, therefore it is extremely important to provide ease of interactions for all type of users including people with disability.

According to the International Standardization Organization (ISO), usability is “the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in a particular
environment” (ISO, 1998). Effectiveness refers to the extent to which a task’s goal is successfully achieved for instance, numbers of users that are able to perform particular interaction with mobile devices successfully. Efficiency refers to the amount of resources that a user spends to reach a task’s goal. For instance, amount of time is spent or number of actions taken by a user to complete an interaction with mobile devices. According to “International Encyclopedia of Ergonomics and Human Factors” [14], satisfaction is an attitude towards a product which can be measured by means of questionnaires. Five attributes are identified by Neilsen [15] for usability:

- **Learnability**: The system must be easy to learn that user is able to start interaction quickly. User must be able to learn the mobile device interface easily and complete an interaction rapidly.
- **Efficiency**: User must be able to perform interactions with mobile device quickly but accurate and complete.
- **Memorability**: System must be easy to remember for user even after a period of not working, user must be able to interact with mobile device easily.
- **Errors**: The system must have a low error rate. If user makes errors, system must be recovered easily.
- **Satisfaction**: How pleasant is it to use the system?

### 2.1 Accessibility


According to Web Accessibility Initiative (WAI) [17], web accessibility means people with disability can use, perceive, understand, navigate and interact with websites. However due to accessibility barriers in many websites, people with disability cannot operate properly. For instance, visually impaired people are not able to use web pages as sighted people use.
Therefore, all the websites must support assistive technologies such as screen reader to convert text to speech. Currently many websites are lacking accessibility which makes it hard for people with disability to operate. In order to satisfy all type of users, website designers must consider accessibility as a necessary requirement when planning to design a website. Millions of people have different type of disabilities including hearing, vision, speech, physical, and more. website accessibility must encompass all these disabilities. As more accessible websites developed, more people are able to interact properly. Removing accessibility barriers from a website has also benefit for people without disability. People with temporary disability or who has slow Internet also get benefited.

People with disabilities sometimes use mobile devices to access web pages. They experience similar accessibility barriers when interacting with laptop/desktop devices. For instance, they have difficulty to navigate the web pages that only support mouse. “Mobile accessibility” means to make a website or an application accessible for people with disabilities when they use mobile devices. Mobile devices are becoming increasingly popular around the world [1]. People using a broad range of devices such as phone, tablet, TV, and more to interact with websites. In order to satisfy millions of users, there has been a high interest in developing websites that are accessible from mobile devices.

According to W3C guidelines for web content accessibility [18], several principles must be considered to provide web content accessibility. These principles also are valid for mobile accessibility.

- **Perceivable**: Information and components must be visible and perceivable for user.
- **Operable**: User interface component must be operable by user. This means user must be able to perform intended actions.
- **Understandable**: Information and operation of user interface component must be understandable for user.
- **Robust**: Content must be robust enough that remain accessible for user agents and
assistive technologies.
If any of these principles is not considered for a website or a mobile application, therefore that resource cannot be used by people with disabilities properly. These are the essential principles for accessibility on website or a mobile device.

2.2 Mobile Accessibility
Mobile devices include mobile phones, tablets, TVs, and more, increasingly are being used in everyday people's lives around the world [1]. These devices particularly mobile phone have become a necessary device for most people. John Horiggan in his study which is called ”Mobile Difference” [19] claimed that around 75% of adults in United States have cell phone and believe that it would be hard for them to give up their cell phones. Mobile devices are being used to keep people in touch, access to information, business, and many other purposes. Whereas mobile devices ownership was luxury some years ago, but nowadays it is a necessity for most people.

There are many people with disabilities that use mobile devices in their everyday life. They need to have access to information as equal as other users but due to some limitations of these devices, they are not able to use them properly. For instance, according to several researches on young, adult, and older people regarding mobile accessibility [20] [21] [22] mobile devices interface is often inaccessible to visually impaired people due to some issues such as small keys or tiny screen text, and more.

Despite awareness of these issues, mobile device producers continue to develop smaller and thinner device including more features. While companies are attempting to produce these devices, people with disabilities are struggling with complexity of these devices. Mobile device manufacturers face accessibility problems through creation of special technologies such as assistive technologies for people with disabilities. Melissa Dave in her article about adoption of assistive technologies by people [23], claims that although these specialized technologies help
users to deal with accessibility problems but they have their own limitations including increased price and reduced features. However, these accessibility problems are known but people with disabilities continue to use these specialized technologies to interact with mobile devices.

In 2009, in university of Washington, a study done about mobile device adoption and accessibility for people with visual and motor disabilities [2]. This study showed that, most of the participants encountered accessibility problems when they were using mobile devices. They used different adaptation strategies to overcome mobile device accessibility problems such as customizing mobile device, memorizing device functions, using multiple devices, and more. Therefore, increasing the options for device customization could help to overcome the limitation of mobile devices accessibility. In addition, automatic user interface adaptation to environmental changes will influence the mobile accessibility.

A joint research from university of basque country, Donostia Spain [24], shows by growing the use of mobile devices, web based applications and web browsers on mobile devices are also increasingly being popular as well. Although mobile devices are growing fast but mobile content is not mature yet. There are some mobile accessibility problems such as size of screen display, handset capability in noisy places, technology support, and more. Many mobile device manufacturers and mobile application developers look into the mobile accessibility problems and put efforts to decrease the impact of limitation of mobile accessibility in order to provide high quality production. Despite of all the efforts that has been done till now, people with disabilities still encounter some problems while interacting with mobile devices.

According to a research done in India by Kalpana Johari and Arvinder Kaur, having access to web contents and applications on mobile devices has become very important [25]. More and more people are using mobile devices such as smart phones, tablet, iPhone, and more to have access to the Internet and communicate with each other. Today mobile devices are being produced and used increasingly with different type of resources such as memory, browser, screen size, input/output mechanism, and more.
Their investigation on measuring mobile accessibility for people with disabilities shows that people with special needs such as blind people find it difficult to interact with mobile devices. Most of the cell phone manufacturers and service providers made huge efforts towards accessibility but it is a long way to offer full accessibility to people with disabilities. According to the “American Foundation for the Blind” [26], not all the cell phone producers provide built-in mobile accessibility features for people with disabilities, only limited selection of devices offers accessibility features but still third-party applications are required to enable accessibility features. In addition, not all users are equipped with latest version of technologies to get served with better accessibility.

On the other hand, the idea behind the Internet was accessibility of web content to all type of users, therefore mobile accessibility became one of the big challenges for mobile device manufacturers and mobile developers which should be considered as a necessary requirement to ensure equal access for all users [24]. Despite of mobile accessibility limitation of some mobile devices, fortunately it is allowed to install third-party applications to provide accessibility for people with disabilities. With growing trend of smart phones, mobile devices, and application stores, having access to third-party applications became much easier than before.

In this thesis work, the investigation was focused on mobile accessibility for people with impaired vision. There are specific similarities between website use via mobile devices and accessibility for visually impaired people. Justin Thorp and Shawn Henry in their research about mobile web accessibility have mentioned these similarities [27]. As is obvious, mobile devices have no mouse to handle interactions. Similarly, visually impaired users usually avoid using mouse and instead use keyboard while listening to a screen reader. For many users include people with disabilities, navigation through website content is often performed via the tab key or similar forward functionality. Therefore, the similar navigation technique must be considered for mobile as well. Accurate focus order, correct tab, descriptive header and sub header, short page size, content
relevant, and many other parameters should be considered while designing mobile content to ensure equal access for all type of users.

In a research from Web Accessibility Initiative which focused on common barriers for mobile users and people with disabilities [28], some shared experiences are mentioned as following. Some features such as plug-in installation and CSS support are not always available for mobile devices users. People with disabilities often disable CSS to use their own customized style sheets. In order to give equal access to all users, mobile application developers should design web pages that do not require users to install plugin or use specific style sheets. Pop-up windows and automatic refreshing pages should be avoided on mobile websites because it distracts the user from focusing on current page. Similarly, these features can confuse visually impaired users who use screen reader to perceive the information. Text entry is one of the big challenges for all mobile device users due to the limitation of keyboards. Default values for text entry and other ways to minimize typing text must be considered by content developers to increase mobile accessibility. In addition, in case of not having audio turned on, appropriate text or vibration as an alternative to audio must be employed.

### 2.2.1 Motivation

According to “Visions” [29], services for the blind and visually impaired, currently 2.5 million individuals in United States are blind or partially sighted. As reported by the “Center for Disease Control and Prevention”, in the United States “Nineteen percent of persons 70 years of age and older had visual impairments”. Nektarios Paisios in his Ph.D. dissertation about mobile accessibility tools for visually impaired people claims that senior people are not viewed as productive members of the society, therefore the quantity of employment opportunities could suffer [30]. This assumption is confirmed by the U.S. National Center for Policy Research for Women and Families [29], which states that “Poverty is a fact of life for many blind adults, especially older women,” and “Few blind adults receive welfare”. In fact, visually impaired individuals of all ages are at a disadvantage, given that “Nearly one in five [of blind individuals]
live in poverty,” and “Only 19 percent are currently employed” [29]. Dean and Naomi Tuttle, authors of “Self-Esteem and Adjusting with Blindness” book mention that with such a devastating rate of unemployment, large group of visually impaired people may begin to feel negative self-esteem preferring to stay alone from the society and not to develop their interpersonal and practical skills [31].

Much of our social infrastructures is organized for full vision without considering visually impaired people. For instance, in many countries transportation systems are mainly designed based on the ability of sighted car drivers. Generally, most of social activities creates several challenges for visually impaired people to deal with them on daily life. Therefore, visually impaired people requirements are not addressed properly. Some of these obstacles can potentially be overcome with assistive technologies.

“There was a time when disabled people had no choice but to ask for help - to rely on the ‘kindness of strangers.’” American Council of the Blind [32]. Bruce B. Blasch in his research about accessibility and mobility of visually impaired people [33], elaborates living difficulty for these people some time ago, visually impaired people relied on assistance of others for their social and individual activities in daily life. Due to inaccessibility of many social infrastructures such as public transport, sidewalks, audio announcement, and more, most of the individual activities was hard and even dangerous for them. For instance, finding one’s way to an unknown place was quite impossible due to lack of Braille signage on buildings door and elevator. Therefore, mobility difficulty always was a big challenge for visually impaired people. On the other hand, any written form of communication was barely useful for blind or partially sighted people. Due to the inaccessibility and limitation of social infrastructures many visually impaired people were not accepted in the employment market [30].

Based on a research in USA in 1993 which is called “American with Disabilities” [34], during the past decades, social infrastructures and developments created much more equal positions for
visually impaired people in the society. Nowadays technological improvements including electronic devices especially smart phones and personal computers have given more opportunities to visually impaired people to overcome the accessibility barriers in their daily life. Gerber in his article “The benefits of and barriers to computer use for individuals who are visually impaired” [35] claims that these technologies have become carriers which enable visually impaired people to deal with their daily activities effectively. Mobile devices become ubiquitous which are available everywhere anytime for all users [28]. Visually impaired people have access to information via navigating online websites which was only available in print before with assistance of fully sighted people [30]. Fortunately, technological improvements and software based assistive solutions provide visually impaired people, social independence in modern society [2].

However, after years of progress, mobile devices have provided many advantages in mobility and communication to visually impaired people but created new accessibility challenges for them. This thesis work attempts to identify if mobile contents are accessible for visually impaired people and presents various parameters to evaluate mobile accessibility. What challenges and limitations are faced by visually impaired people while interacting with mobile devices through assistive technologies? Visually impaired people have a few everyday accessibility obstacles which create challenge on every single activity. First, mobility, the ability to move around without any assistance is the top desire of visually impaired people [30]. Their second most important concern is to be able to communicate with others via written text including reading road and building signs, reading mail and completing important documents, such as tax forms [30]. Finally, handling daily tasks, house cleaning, cooking and so on are also important. “employment barriers included attitudes of employers and the general public; transportation problems; and lack of access to print, adaptive equipment, and accommodations” [36].

2.2.2 Accessibility Barriers

Web content became ubiquitous that can be accessed with various mobile devices anytime
anywhere [28]. Due to some limitations of mobile devices such as poor lighting, small screen, and keyboard, manufacturers faced with several challenges regarding usability and accessibility of devices [30]. According to a research from IBM about physical usability and mobile web [37], and a study that done in Carnegie Mellon University about the future of mobile devices [38], and also another one in Maryland Rehabilitation Center about physical disabilities and computing [39], people without disabilities accessing mobile devices, experience the similar barriers to people with disabilities accessing the desktop. For instance, mobile users have difficulty in perceiving information when they use a mobile device with poor lighting. Similarly, people with visually impaired disability (low vision, partial sight or loss vision) experience the same difficulty facing with encoded color information. According to WAI (Web Accessibility Initiative) [17], Visually impaired people typically encounter difficulty in interacting with structural elements such as images and controls that do not have text alternatives, text and images that cannot be resized, websites and browsers that do not provide full keyboard support, videos content that do not have text alternatives, websites and browsers that have complex navigation system and more. Therefore, they need to change the presentation of web content into forms that are more suitable for them. For example, by:

- Enlarging or reducing text size and images
- Customizing settings for fonts, colors, and spacing
- Listening to text-to-speech synthesis of the content
- Listening to audio descriptions of video in multimedia
- Reading text using refreshable braille

Mobile users often perform similar actions while they are interacting with their mobile devices. This shared experience is called situationally-induced impairment. In order to fulfill these particular needs for visually impaired people and mobile users, website designers need to ensure that the presentation of web content is independent of underlying structure and also the structure is correctly coded and can be processed by assistive tools and software and presented in different ways. For instance, some people use customized colors, fonts, and format. Some people use keyboard instead of mouse for navigating through websites. Generally, an accessible
web page should support different presentations and different ways of interaction.

In order to improve accessibility, identifying issues and challenges that are shared between mobile and visually impaired users is the initial step. These common barriers are very important for evaluating web pages. If there is a high variety of barriers in terms of complexity, layout and the way web pages are developed, it can be very difficult to find shared ones between them. Therefore, commonality highly depend on the web pages are being evaluated. Common barriers are influenced by web pages’ design [40].

A research done in Middle East Technical University on several visually impaired people regarding shared mobile and accessibility issues [28]. Participants were invited to evaluate various web pages on mobile devices for both accessibilities for disabled people and mobile friendliness. They were given a judge number and asked to assign it to each barrier for corresponding web page. They were given random barrier list and random web page. They were asked to evaluate each barrier with respect blind, low vision and mobile web users. For each barrier and user category, they were asked to check whether that barrier exists.

According to this study various barriers are shared between visually impaired people and mobile web users. Figure 1 shows common barriers types between visually impaired people and mobile users. Those barrier types that commonly identified at least on one web page are ticked off. The bold barrier types are especially introduced for mobile web users. As it shown in figure 1, quite many barriers are common between visually impaired people and mobile users. These barriers must be considered by mobile designers to increase the range of accessibility for visually impaired users.
<table>
<thead>
<tr>
<th></th>
<th>Mobile-blind</th>
<th>Mobile-low vision</th>
<th>Mobile-blind</th>
<th>Mobile-low vision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambiguous links</td>
<td>✓</td>
<td>✓</td>
<td>Page size limit</td>
<td>✓</td>
</tr>
<tr>
<td>Cascading menu</td>
<td>✓</td>
<td>✓</td>
<td>No stylesheet support</td>
<td>✓</td>
</tr>
<tr>
<td>Dynamic menu in JavaScript</td>
<td>✓</td>
<td>✓</td>
<td>Rich images lacking equivalent text</td>
<td>✓</td>
</tr>
<tr>
<td>Functional images lacking text</td>
<td>✓</td>
<td>✓</td>
<td>Scrolling</td>
<td></td>
</tr>
<tr>
<td>Images used as titles</td>
<td>✓</td>
<td>✓</td>
<td>Skip links not implemented</td>
<td>✓</td>
</tr>
<tr>
<td>Inflexible page layout</td>
<td>✓</td>
<td></td>
<td>Too many links</td>
<td>✓</td>
</tr>
<tr>
<td>Internal links are missing</td>
<td>✓</td>
<td>✓</td>
<td>Using stylesheets</td>
<td>✓</td>
</tr>
<tr>
<td>Layout labels</td>
<td>✓</td>
<td>✓</td>
<td>Valid markup</td>
<td>✓</td>
</tr>
<tr>
<td>Long URLs</td>
<td>✓</td>
<td>✓</td>
<td>New windows</td>
<td>✓</td>
</tr>
<tr>
<td>Minimize markup</td>
<td>✓</td>
<td>✓</td>
<td>New page headings</td>
<td>✓</td>
</tr>
<tr>
<td>Missing layout clues</td>
<td>✓</td>
<td>✓</td>
<td>Mouse events</td>
<td>✓</td>
</tr>
</tbody>
</table>

Figure 1 - Common Barriers

### 2.2.3 Principles and Guidelines

The primary aim of “Mobile Accessibility” is to ensure that websites and applications are accessible to all users including people with visual, audio, speech, kinetic, cognitive impairments, and other disabilities when they are operating mobile devices such as phones, tablets, TVs, and more. An appropriate mobile designer considers accessibility rules to make a website or an application friendlier for all type of users. In order to ensure equal access to information for all users, WAI (Web Accessibility Initiative) introduced W3C accessibility guidelines [18] in four main
principles (Perceivable, Operable, understandable, and Robust). As a matter of fact, there is no separate guidelines for mobile accessibility, therefore the existing W3C accessibility guidelines apply for mobile devices as well.

2.2.3.1 WCAG 2.0
Web Content Accessibility Guidelines (WCAG) [18] is a shared standard for web content accessibility which is developed by WAI (Web Accessibility Initiative) in cooperation with individuals and organizations around the world to help making the web content including text, images, sounds, presentation, code or markup accessible to people with disabilities. This technical guideline is organized under 4 main principles:

1. Content must be perceivable. That means content and user interface components must be presented to users in a way that can be perceived. For instance, some mobile devices screen may limit by color or poor lighting, therefore information is not clearly perceivable. Due to these limitations, visually impaired people may not capture important contents. In this case, mobile device designer must provide text alternatives for resources. In order to make the content perceivable some general actions are proposed as below:
   - Provide text alternatives for non-text content.
   - Provide captions and text alternatives for multimedia.
   - Create content that can be presented in different ways and be processed by assistive technology without losing the meaning.
   - Provide content to be seen and heard.

2. Interface elements must be operable. Each user should be able to interact with user interface components and navigate through applications links, pages and contents without any difficulty. Mobile device users typically are intended to have access to specific piece of information rather than browsing lengthy documents. These users have different interests to desktop device users. They are more interested in having quick and fast access to relevant information to their demands. Therefore, mobile device contents and user interfaces must be very convenient to perform actions. In order to make the content
Operable some general actions are proposed as below:

- Make all functionality available from keyboard.
- Provide proper navigations and find content.
- Avoid using content that causes seizures.
- Give enough time to user for reading and using content.

3. Contents and controls must be understandable. Information, contents and operations must be easy to understand for users. People with special disabilities such as cognitive disabilities may have difficulty to process information. In addition, visually impaired people may not understand the contents with help of third-party applications. Generally mobile users may have difficulty to understand the contents due to small font, background noise, different language and so on. In order to make the content understandable some general actions are proposed as below:

- Make text readable and understandable.
- Make content operate in predictable way.
- Help users avoid and correct mistakes.

4. Contents must be robust enough to work with current and future technologies. Contents must be robust enough that can be interpreted reliably by user agents. Many mobile devices do not support embedded object or script and in some cases it is not possible for users to load plug-ins to ads support. Developers must provide the contents in form of text-only mode to make it readable. In order to make the content robust a general action is proposed as below:

- Maximize compatibility with current and future user tools.

2.2.3.2 Mobile Accessibility Guidelines

As mentioned in section 2.2.3.1, WCAG 2.0 introduces 4 main principles for web content accessibility. These principles apply for mobile accessibility as well. In this section mobile accessibility document [41], which has been published by W3C Web Accessibility Initiative is introduced. This document describes how WCAG 2.0 and its principles and guidelines can be
applied to mobile web content and mobile applications.

According to W3 mobile accessibility document [41], “Mobile” is a generic term for broad range of wireless devices, wearables and applications that are easy to carry and use. These devices include phones, smartphones, tablets, smartwatches, fitness bands, embedded computing devices, and more. Mobile devices functionality is different but very similar to desktop/laptop devices. For example, mobile devices now can be connected to external mouse and keyboard. Mobile operating system has been used for laptop devices. In addition, majority of user interface design patterns for desktop/laptop are applicable for mobile devices as well. Therefore, existing WCAG 2.0 techniques can be applied to mobile content. There are some mobile issues that can be addressed by WCAG 2.0 principles as below:

1. Perceivable
   - Small Screen Size: Small size of screen places limit on how much information people can view especially when magnification is used by people with low vision. In order to help users to make small screens some best practices include:
     - Minimizing amount of information on each page compared to desktop/laptop version.
     - Providing reasonable default size for content for zooming in and out for low vision users.
     - Adapting the length of link text to the viewport width.
     - Positioning form fields below rather than beside.
   - Zoom/Magnification: A variety of methods including OS-level (set default text size or magnify screen) and Browser-level (set default text size or magnify browser view point) features are available to assist users especially visually impaired people to control content size on mobile devices with small screens.
   WCAG 2.0 [41] has success criteria which is related to this issue:

1.4.4 Resize text (Level AA): requires text to be resizable without assistive technology up to 200 percent. To meet this requirement content must not prevent text magnification by the user.
- **Contrast**: Mobile devices are being used outdoor more than desktop/laptop devices where glare from the sun or other strong lightening resources are more. Therefore, providing good contrast especially for people with low vision on mobile devices is very important.

The WCAG 2.0 success criteria related to the issue of contrast is:

1.4.3 **Contrast (Minimum)** (Level AA) which allows for different contrast ratios for large text.

2. **Operable**

- **Keyboard Control for touch screen devices**: Mobile device design has moved from built-in physical keyboards towards on-screen keyboard and touchscreen area. However, supporting keyboard interfaces by mobile operating systems allow mobile devices to use external physical keyboards or on-screen keyboards which is very beneficial for visually impaired people especially physical keyboards over touchscreen keyboards.

WCAG 2.0 success criteria which is relevant to effective keyboard control:

2.1.1 **Keyboard** (Level A)

- **Touchscreen Gestures**: Many mobile devices are designed to be operated via simple gestures such as tap with one finger, or complex gestures such as multiple taps made on a touchscreen. Some mobile operating systems provide work-around features that let the user simulate complex gestures with simpler ones using an onscreen menu. Gestures in app should be easy as possible to carry out especially for visually impaired people when using screen reader, complexity of gestures impacts on functionality of screen reader.

- **Placing buttons where they are easy to access**: Mobile applications should place buttons in an appropriate position when the device is held in different positions.

3. **Understandable**

- **Changing Screen Orientation**: Both orientation (Portrait/Landscape) should be supported by mobile applications and if one of them is not supported, it must be ensured that it is easy for user to change the orientation to return to the default
orientation which is supported by mobile devices. It is very important especially for visually impaired people that change orientation is detected correctly by screen reader in order to avoid performing incorrect navigation commands.

- **Consistent Layout**: Components that are repeated across multiple pages should be presented in consistent layout. For example, a web page could contain a logo, a title, a search form and a navigation bar at the top of each page. If this order is repeated for multiple pages but on one page, one item is missing, on different screen size and orientation, some confusion might happen especially for visually impaired people regarding the missing item.

The WCAG 2.0 success criteria that are most related to the issue of consistency are:

3.2.3 **Consistent Navigation** (Level AA)

3.2.4 **Consistent Identification** (Level AA)

- **Positioning important page elements before the page scroll**: Small screen size on mobile devices limit the amount of data can be displayed without scrolling. Therefore, positioning important page before the scroll page allows visually impaired people who has the screen magnified to locate information without having to scroll the view. Consistent and predictable location of elements is a big help for visually impaired people.

- **Grouping operable elements that perform the same action**: When multiple elements perform the same action or go to the same destination these should be contained within the same actionable element. This has benefit especially for visually impaired people when using screen reader to avoid confusing with multiple elements.

The WCAG 2.0 success criterion that is most related to this:

2.4.4 **Link Purpose (In Context)** (Level A)

2.4.9 **Link Purpose (Link Only)** (Level AA)

- **Provide Instructions for gestures**: Custom gesture is typically hard to discover, perform and remember. Therefore, instructions such as tooltip, tutorials and
more must be provided to explain what gesture is and used for. These instructions must be easy to access and available anytime that needed by user. These WCAG 2.0 success criteria are relevant to this:

**3.3.2 Labels or Instructions** (Level A)

**3.3.5 Help** (Level AAA)

4. Robust

- Provide easy method for data entry: Users can enter data on mobile devices in different ways such as on-screen keyboard, touch, speech and etc. In order to save time and reduce certain difficulties, automatically entering known information (date, time, location) or default data (select menus, check boxes) must be provided by mobile application developers.

- Support characteristics properties of platform: Mobile devices provide platform characteristics such as zoom, larger fonts and caption. Mobile application must be able to support the essential features that are provided by the mobile device platform.

**2.2.3.3 Summary: Mobile Accessibility Parameters**

As elaborated in section 2.2.3.1, Web Accessibility Initiative (WAI) introduced an accessibility guideline, WCAG 2.0 [18], including instructions and success criteria for design and development of web content in order to meet accessibility requirements. This guideline also can be applied for mobile web content, since there is an obvious similarity between desktop/laptop and mobile devices interactions. WAI also recommended two more documents for mobile developers and designers including some best practices for supporting mobile accessibility. Mobile Web Best Practices [42] including best practices regarding web content appearance and functionality for delivering to mobile devices including. Mobile Web Application Best Practices [43], which is intended to develop dynamic mobile web application by mean of engineering practices to meet accessibility goals. WCAG 2.0 and applicable success criteria for mobile.

WAI proposed four essential principles including recommendations and guidelines which can be
used as mobile accessibility parameters for evaluation mobile web content and mobile applications. These parameters are as following:

- **Perceivable**
  - Text alternatives for non-text content
  - Captions for multimedia
  - Content is easy to hear or see
  - Content is fit to small screen size

- **Operable**
  - Functionality is available from keyboard
  - User have enough time to read and use content
  - User can navigate easily and find content
  - Buttons are placed in appropriate position when the device held in different positions
  - Appropriate changing screen orientation

- **Understandable**
  - Text is readable and understandable
  - Content appears and operates in predictable way
  - Users are helped with descriptive instructions

- **Robust**
  - Content is compatible with different browsers and assistive technologies
  - Easy method for data entry

### 2.3 Assistive Technologies

The term “Assistive Technology” is the idea related to any item, piece of equipment or system that is used to increase, maintain or improve functional capability of people with disabilities IDEA [4]. In medical system, it could be “any product or service designed to enable independence for disabled and older people” [44]. According to International classification of functioning, disability
and health (ICF) [45], assistive technology is defined as “any product, instrument, equipment or technology adapted or specially designed for improving the functioning of a person with a disability”. International Organization for Standardization (ISO) [46], says that an assistive product is “any product (including devices, equipment, instruments, technology and software) especially produced or generally available, for preventing, compensating, monitoring, relieving or neutralizing impairments, activity limitations and participation restrictions”. As mentioned by these definitions the range of assistive technology is wide and as John Borg, defines in “Assistive technology, human rights poverty in developing countries” [47] includes hearing aids, communication boards, wheelchairs, crutches, prostheses, orthoses, magnifiers, talking devices and adapted eating and drinking utensils.

Marion A. Hersh and Michael A. Johnson. in their research which is called “Assistive Technology for Visually Impaired and Blind People” [48] claim that the intention of assistive technology is to increase the capability of disabled people and adapt them to existing social infrastructure. Therefore “Adaptive Technology” is another term for assistive technology. These adaptive technologies could be equipment, devices, systems, applications, and more that are used to overcome the social and infrastructure barriers experienced by people with disability and prevent their full participation in the society. Based on “Applications of a capability approach to disability and the International classification of functioning, disability and health (ICF) in social work practice” [46] from the perspective of the capability approach, assistive technology is a commodity that can be instrumental in enhancing the capability of its user.

Marcia J. Scherer in his book which is called “Living in the state of stuck: how assistive technology impacts the lives of people with disabilities” [49] says that although assistive technologies have the potential to improve quality of life and participation in society, accessibility of the environment is a prerequisite for using certain type of assistive technologies. In two other works regarding assistive technology [50] [51], she concluded that is necessary to look beyond the technology, the environment and the physical features of the user, his or her needs, preferences and expectations must also be met.
2.3.1 Type of Assistive Technologies

According to a Microsoft research [52], there are various types of assistive technologies available in the market today:

**Alternative input devices** allow individuals to control their computers through means other than a standard keyboard or pointing device. Examples include:

- Alternative keyboards
- Electronic pointing devices
- Sip-and-puff systems
- Wands and sticks
- Joysticks
- Trackballs
- Touch screens

**Braille embossers/printer** transfer computer-generated text into embossed Braille output.

**Keyboard filters** are typing aids such as word prediction utilities and add-on spelling checkers that reduce the required number of keystrokes.

**Light signaler alerts** monitor computer sounds and alert the computer user with light signals.

**On-screen keyboards** provide an image of a standard or modified keyboard on the computer screen that allows the user to select keys with a mouse, touch screen, trackball, joystick, switch or electronic pointing device.

**Reading tools and learning disabilities programs** include software and hardware designed to make text-based materials more accessible for people who have difficulty with reading.

**Refreshable Braille displays** provide tactile output of information represented on the computer screen.

**Screen enlargers, or screen magnifiers** work like a magnifying glass for the computer by enlarging a portion of the screen which can increase legibility and make it easier to see items on the computer.

**Screen readers** are used to verbalize, or "speak" everything on the screen including text, graphics, control buttons, and menus into a computerized voice that is spoken aloud. In essence, a screen reader transforms a graphic user interface (GUI) into an audio interface. Screen readers are
essential for computer users who are blind.

**Speech recognition or voice recognition programs**, allow people to give commands and enter data using their voices rather than a mouse or keyboard.

**Text-to-Speech (TTS) or speech synthesizers** receive information going to the screen in the form of letters, numbers, and punctuation marks, and then "speak" it out loud in a computerized voice. **Talking and large-print word processors** are software programs that use speech synthesizers to provide auditory feedback of what is typed. **TTY/TDD conversion modems** are connected between computers and telephones to allow an individual to type a message on a computer and send it to a TTY/TDD telephone.

### 2.3.2 Barriers to use assistive technologies

Jeffrey Bigham in his article “Webanywhere: a screen reader on-the-go” [53] says that assistive technologies help people with disability to access information and technology via a method that fits with their capabilities. For example, visually impaired people use screen reader to perceive web or mobile content auditorily (text-to-speech) or tactiley (text-to-Braille). This access to technology allows people with disability to become more independent, experienced social integration and security more than before which have direct positive impacts on their social and economic positions [2]. However people with disability may feel dependent on certain devices especially if those fail or according to a study of 100 blind users in Towson University [54] feel frustrated and angry if those don't function as expected. A research in University of Washington about assistive technology use and social interaction [55], shows that amount of time that is acquired for people with disability to learn, impacts the use of assistive technology, therefore people with disability may be reluctant to learn new assistive technologies with high learning curves. Adopting or abandoning (according to a research which is called” Predictors of assistive technology abandonment” [56]) assistive technologies is a very challenging topic in assistive technology communities [2]. However, people with disabilities may abandon use of assistive technologies for many reasons. According to a joint research [57] done by Microsoft and University of Rochester, there are several reasons that people have for not using assistive
technologies as following:

- **Not having personal access to accessible technologies.** This could be due to the cost or incompatibility of assistive technology with the device is used by user.
- **Not knowing that accessible options existed.** User could be unaware of assistive technologies that have been developed for different operating systems.
- **Not having the time or resources to learn how to use the technologies.** Learning new assistive technologies needs training course which some users do not have time for that.
- **Difficulty installing operating systems or screen readers.** Some users find it hard to install software and operating systems and need help of non-disabled people to perform that.
- **Satisfaction with existing devices.** Some users are satisfied with their existing device and lifestyle and are not interested to try new ones.

### 2.3.3 Screen Reader

Screen reader is a form of assistive technology that converts text and graphics to speech, enabling visually impaired people to read and navigate the content of screen through hearing [8]. This assistive technology helps users to perceive the content and make it possible to perform daily tasks which is available for both computers and mobile devices including physical buttons and touch screens. Most of the assistive technologies (built-in or applications) on mobile devices are similar to those ones used on desktop/laptop computers however their capabilities may limit by nature of mobile devices.

The purpose of a screen reader is to give a blind person access to, and control over, a computer system [48]. The content of screen is normally presented to a blind person either speech or Braille. Due to high cost of a Braille line and levels of Braille literacy, majority of screen reader users use speech as output [48].

According to a joint research done in Norwegian school of IT [58], 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 [8].

Visually impaired people use keyboard to control computer not mouse. This is because use of mouse needs user to see position of mouse pointer and where it will be moved which is not possible to perform by a blind person [58]. Therefore, visually impaired people need to learn to work with keyboard to even on GUI-based operating system such as Windows to be able to operate their computers. A screen reader must track the focus and present the information at the current focus to speech. The output of screen reader includes the text associated with the focus plus indication of the type of the element that has the focus. For example, when a menu item has the focus, the name of menus will be spoken or similarly when a checkbox has the focus, the name of it is spoken followed by its status (checked or unchecked) and type of the element.

The primary goal of screen reader is to present screen information at the current focus which is very dependent on the type of element and associated information at that focus. One important note is screen reader should give the maximum amount of information with minimum amount of speech to avoid making users frustrated and confused with too much unnecessary verbal outputs [58].


3 Related Work

This chapter introduces VoiceOver, overview of interaction with VoiceOver using cursor, keyboard and touch screen for browsing and navigating the content. It continues with presenting previous works that have been done regarding mobile accessibility and elaborating the related study about evaluation of mobile accessibility on devices from Apple.

Mobile devices such as smartphones and tablets are increasingly being used in people’s daily life for learning, entertainment, access to services, and more. Considering the number of people with disability, mobile accessibility should be available to anyone in the society. Research on mobile accessibility is shifted from user interface design to interaction paradigm such as touch, voice and gesture. A lot of research works has been done regarding mobile accessibility and more is ongoing. Schultz et al. discussed the concept of a Universal Mobile Device intended as a multifunctional accessible and usable mobile device for everyday user activity, and described technologies that currently are available for developing such solutions [59]. A lot of studies have been done regarding the impact of touch screen on mobile interaction specially when users are visually impaired [60]. In addition, creating the accessible touch screen interfaces for visually impaired users is still a big challenge [61] [62]. According to a study done by Wobbrock [63], the focus of design is shifted from system to user. He argued this “just as user-centered design shifted the focus of interactive system design from systems to users, ability based design shifts the focus of accessible design from disability to ability”. Therefore, user centered design became much more important. A study done by Guerreiro, T, Oliveira J, and more researchers on visually impaired people showed that the differences between people, impacts the interaction with mobile devices [64].

A study done by Barbara L. regarding mobile devices interactions showed that tactile or touch improves the usability of virtual buttons since the user can feel the object of interaction [65]. Brewster and Brown proposed the use of a new type of tactile output: tactons, or tactile icons,
structured, abstract messages that can be used to communicate information [66]. A tacton is characterized by parameters such as frequency, amplitude and duration of a tactile pulse, but also rhythm and location [66]. Using tactons could enhance accessibility of mobile devices for blind users as well as for sighted people in movement.

### 3.1 VoiceOver and Gestures

According to Apple accessibility document[67] “VoiceOver is a gesture-based screen reader that lets you enjoy the fun and simplicity of iOS even if you can’t see the screen. With VoiceOver enabled, just triple-click the Home button to access it wherever you are in iOS. Hear a description of everything happening on your screen, from battery level to who’s calling which app your fingers on. You can adjust the speaking rate and pitch to suit you”.

Devices from Apple are becoming more and more accessible to people with disabilities. The assistive technology which is included in Apple products provide mobile accessibility for visually impaired users. VoiceOver is an Apple gesture based screen reader available in Mac OS and iOS operating systems, that makes products such as iPhone, iPad, and iPod touch accessible. VoiceOver is a built-in screen reader that speaks aloud the text and whatever appears on your computer screen or mobile devices.

Visually impaired people can use this product to get spoken interaction with mobile devices. VoiceOver speaks in the language specified in International settings, which may be influenced by the Region Locale setting. When a user selects an element, it’s enclosed by a black rectangle, voiceOver reads the name or describes the item. The VoiceOver gestures can be used to physically interact with items on the screen, allowing the user to move around the screen and control the selectable individual elements. VoiceOver gestures use one, two or more fingers to tap or drag. When a control (such as a button or switch) is selected and Speak Hints is turned on, VoiceOver may tell the action of the item or provide instructions, for example, “double-tap to open.” When user goes to a new screen, VoiceOver plays a sound and automatically selects and
speaks the first element of the screen, typically the item in the upper-left corner. VoiceOver also
lets user know when the display changes to landscape or portrait and when the screen is locked
or unlocked [68].

IPhone offers many accessibility features including VoiceOver, which is built to assist visually
impaired people. To turn on this feature go to Settings > General > Accessibility, or use the
Accessibility Shortcut. The shortcut is to press the Home button quickly three times to turn any
accessibility feature one or off. The language that VoiceOver speaks in is specified in Settings >
General > Language & Region.

VoiceOver changes the gestures that are used to control iPhone. When VoiceOver is on, user
must use VoiceOver gestures to operate even to turn VoiceOver off. Following information is a
short reference on how to operate with iPhone through VoiceOver. Detailed elaboration is
available on iPhone user guide for iOS [67].

**Explore:** “Drag your finger over the screen. VoiceOver speaks each item you touch. Lift your finger
to leave an item selected.”

**Select an item by name:** “Triple-tap with two fingers anywhere on the screen to open the Item
Chooser. Then type a name in the search field or swipe right or left to move through the list
alphabetically or tap the table index to the right of the list and swipe up or down to move quickly
through the list of items.”

**Pause speaking:** “Tap once with two fingers. Tap again with two fingers to resume or select
another item.”

**Mute VoiceOver:** “Double-tap with three fingers. Repeat to unmute. If you’re using an external
keyboard, press the Control key.”

**Silence sound effects:** “Go to Settings > General > Accessibility > VoiceOver, then turn off Use
Sound Effects.”

**Use a larger VoiceOver cursor:** “Go to Settings > General > Accessibility > VoiceOver, then turn
on Large Cursor.”
**Control audio ducking:** “To choose whether audio that’s playing is turned down while VoiceOver speaks, set the rotor to Audio Ducking, then swipe up or down.”

The iPhone guide also includes the information about how to use and operate iPhone through VoiceOver. For example, unlock iPhone, enter passcode silently, open an app, adjust slider, switch between apps, open notification center, and more.

There are set of simple gestures to do navigation on iOS device. For example, user can touch the screen to know what’s there and tap a button to hear a description. Swiping up and down, flicking left and right to move between applications. VoiceOver gestures include two, three, and four finger taps and swipes. In addition, when user composes an email or types a text VoiceOver speaks each completed word. Having Speak Auto-test enabled, suggested word will be spoken. For visually impaired user VoiceOver includes a Braille keyboard that enabling direct braille entry without the need for physical braille keyboard. Here are some key VoiceOver gestures:

- **Tap:** Select and speak the item.
- **Swipe right or left:** Select the next or previous item.
- **Swipe up or down:** Depends on the rotor setting.
- **Two-finger swipe up:** Read all from the top of the screen.
- **Two-finger swipe down:** Read all from the current position.
- **Two-finger tap:** Stop or resume speaking.
- **Two-finger scrub:** Move two fingers back and forth three times quickly
- **Three-finger swipe up or down:** Scroll one page at a time.

In addition, using VoiceOver with Map, browsing the Internet (For example Safari), editing text, sending email/SMS and making phone call are the challenges faced by visually impaired people which are elaborated on user guide as well.
3.2 Evaluation of VoiceOver on iPhone4

Barbara Leporini and two other researchers, Maria Cludio Buzzi and Marina Buzzi have investigated usability and accessibility issues on interacting with mobile devices through VoiceOver [65]. In this joint research work, interaction of visually impaired users with Apple touch screen mobile devices such as iPad, iPhone, and iPod touch were analyzed. The investigation was focused on VoiceOver, a pre-installed screen reader to assist visually impaired users. Usability inspection of devices user interfaces integrated with user feedback confirmed that VoiceOver makes Apple devices accessible for blind people but there are still some accessibility and usability issues. For example, writing of long text takes too long and not comfortable for blind users. Generally, results showed that although VoiceOver basically plays an important role in making devices accessible for visually impaired people but does not offer a generic interaction approach for all mobile devices. There are still some accessibility issues that need to be investigated.

In the research work from Barbara Leporini, first some accessibility and usability issues in interacting with Apple mobile devices through VoiceOver was described. Afterwards, survey used as evaluation methodology to identify issues and collect qualitative feedback from visually impaired users on accessibility and usability of mobile devices. Finally, the study concluded by collecting user’s opinions on possible solutions for improving interaction.

3.2.1 Method

In order to find out how visually impaired users interact with mobile devices through VoiceOver some applications and actions that are available on mobile devices were selected to be tested. Afterwards, investigation focused on an inspection evaluation for identifying accessibility and usability issues on interacting with mobile devices through VoiceOver. Later a survey was created to verify these issues while visually impaired users interacting with mobile devices and collect suggestions and comments regarding resolving these issues. Inspection evaluation concluded with several key aspects for evaluating the gestures available through VoiceOver.
• Clarity of user interface by having appropriate label and comments
• Logical navigation order of contents and elements
• Quick and easy identification of elements and content

According to the inspection evaluation key aspects, a questionnaire was composed of 32 questions grouped in 6 parts [65]:

1. user characterization
2. general use of the devices
3. numeric keypad
4. text editing
5. focus
6. comments and suggestions

3.2.2 Results

After performing the inspection evaluation, it was confirmed that mobile devices from Apple are basically accessible, as their contents could be perceived by visually impaired users through VoiceOver. But there were some usability issues which limited the accessibility of mobile devices. Questionnaire was filled by 55 visually impaired users and the result was categorized and presented with figures. First, number of participants who used different mobile devices was presented. Afterwards, the activities performed on mobile devices and user satisfaction on using VoiceOver gestures were presented. In addition, user’s opinion regarding ease of use and preferences of user interface elements such as reading emails, writing text, use of punctuations, symbols, and more were categorized and presented.
4 Methodology

This chapter starts with explaining the motivation for choosing qualitative research methodology and interview as particular method for this study. It continues with elaborating interview method and how it is used for collecting data. Study design including structure, content and questions are presented afterwards. Study execution, how the interview with participants is executed and the result of inspection evaluation concludes this chapter.

4.1 Motivation

Buckley and Chiang define research methodology as “a strategy or architectural design by which the researcher maps out an approach to problem-finding or problem-solving.” [9] Research methodology is a comprehensive strategy that illustrates the choice of solution for solving the problem but the choice of research methodology is based upon the type and features of the research.

The purpose of this thesis work was to evaluate mobile accessibility of VoiceOver screen reader and identify the accessibility issues. The first research question was, if the mobile device is accessible through VoiceOver? In order to find out the answer, the VoiceOver and its feature functionality investigated and analyzed. The purpose of this analysis was to understand the VoiceOver and identity the accessibility issues. According to the research question, a hypothesis or belief was generated that claimed “iPhone 7 is accessible through VoiceOver”. Therefore, the purpose of the evaluation was to test the hypothesis. In Order to perform the test a collection of data including the feedbacks and opinions of visually impaired users while interacting with iPhone 7 though VoiceOver was required. Qualitative research methodology was the best candidate to target the thesis purpose in order to understanding the VoiceOver and identifying issues and challenges while visually impaired people interacting with mobile devices. Qualitative research methodology was considered to gain an understanding of underlying reasons, opinions and motivations [10]. According to Johnson and Christensen academic work on qualitative and quantitative research methodology, appropriate methodology must be selected based on the
texture of the problem [69]. Creswell in his research about qualitative methodology claims, there are many qualitative methods which developed to have an in-depth and extensive understanding of the issues by means of their textual interpretation and the most common types are interviewing and observation [70]. In qualitative method the focus is on a small group of people whose characteristics are known to the researchers and the researchers’ biases are also clear for the participants. Although quantitative was a good choice to generalizing result out of collecting feedback from sample population of visually impaired people, but due to the limitation of author of this thesis work for accessing a big group of people, this choice was rejected.

Considering the nature of the thesis study, interview was chosen to explore, discover and collect user behavior during the process of study. There was a strong motivation behind choosing this method for this research as interview is a well-known way of collecting data in everyday life. People all have been interviewed in school, university, for jobs and other places and are familiar with the format and what and how to do it. Rosalind and Janet in their study regarding interview [71] claim that qualitative interviews are known to people when one person interviews the others on particular topics to explore their perspectives on a particular idea, program or situation in order to understand the underlying reasons, opinions and motivations. Boyce C. and Neale also claim that qualitative interview gives possibilities to collect information about particular object. In this research method interviewer has direct control over the flow of data collection and analysis specially if it is in structured format [72].

In order to do the inspection evaluation a small group of five people were selected to be interviewed. In addition, a study design as an instrument including the structure of interview form and questions was prepared. There are three different formats of interviews: structured, semi-structured, and unstructured. Structured interview consists of series of predefined questions which is more straightforward and reliable in data analysis compared to unstructured interview. In semi-structured there is a set of prepared questions plus some additional questions might be asked to clarify the issues.
4.2 Study Design

The purpose of this thesis work was to answer the study questions regarding mobile accessibility. VoiceOver was selected as a case study to be evaluated in terms of mobile accessibility and usability. In order to do the inspection evaluation, a study design instrument was required to collect study feedbacks and comments from the participants in the interview while operating iPhone 7 through VoiceOver. As it elaborated in methodology section, interview was selected as a method of collecting detailed information regarding a topic or object from people. The result of this thesis work was very much directly related to the knowledge and experience of the interviewees. Therefore, designing and structuring the interview content was a big challenge to perceive in-depth and precise information.

In order to allow the interviewees to express their opinions and feedbacks, semi-structured interview was selected as type of the interview. However, according to what Kvale Steiner says in his book [73], more structured interview provides the same questions to find the likelihood between responses for generalizing and testing the hypothesis but semi-structured was more coupled with the texture of this thesis work. Gall and Borg [74], elaborate format of interview design as following:

1) informal conversational interview
2) general interview
3) standardized open-ended interview

The first two forms are more unstructured with a bit of flexibility in their content and composition. The latter one is extremely structured, with identical open-ended questions for participants.

In this thesis work, designing the study instrument was very much important and challenging in order to collect the most precise data from the participants in the interview. These three phases for designing the interview instrument suggested by Creswell [11] [12] were followed.
1) preparation for interview

2) constructing the interview questions

3) execution of interview

Interview preparation was an important part in the whole interview process in order to obtain the maximum efficiency in the interview execution. Proposal principles for interview preparation from McNamara [11] were followed during the interview.

1) setting with no distraction

2) explain the purpose of interview

3) indicate how long the interview takes

4) explain the format of interview

5) indicate terms of confidentially

6) present researcher contacts in case participants want to get in touch

7) ask if they have any questions before interview get started

8) record the interview to recall the answers.

Selecting the interview participants was done according to the Creswell suggestion as the interviewees who are open and honest in sharing information are the best candidate for the interview [11]. Constructing effective open questions that reflect the interview purpose and allow the interviewees to express their feelings and impressions easily was very challenging in this thesis work. The proposal from McNamara regarding creating effective research questions for interview were followed. This proposal was as following:

1) Questions should be open-ended to give an opportunity to interviewees to fully express their opinions

2) Questions should be neutral not influencing the answer

3) Questions should be asked one at the time

4) Questions should be composed clearly to be understood
In summary, in this thesis work, the recommendations from Creswell and McNamara for preparation, construction, and execution of the interview were considered as principles for designing the study instrument.

### 4.2.1 Study Design Structure

Particular experiences and perspectives from the participants are important input to improve accessibility on assistive technologies. In order to get the most beneficial result, appropriate study design including structure and content was required. There were different aspects of interactions that could be selected to be evaluated in this study. In order to achieve the most accurate result, the evaluation narrowed down to particular interactions. The main focus of the evaluation in this study was on performing following interactions:

1. Make phone call
2. Send/Read SMS
3. Edit email/text
4. Navigation/Browse
5. Play Music

There were a lot of activities that could be selected to be evaluated. These five activities were selected as the main and basic interactions that people performing every day. Making phone call as a primary daily activity can be done by selecting the contact from contact list instead of entering the numbers. In this thesis work both ways of phone call were evaluated. Today using social applications such as Viber, WhatsApp, Telegram, and more are very popular, however people still use SMS to contact each other as well. Evaluating send/read SMS as the primary feature of all mobile phones was considered in this thesis work. Editing email, browsing the Internet and playing music are also included in daily interactions with mobile devices, however inspecting remaining battery, playing game, listening podcast, navigating mobile applications, and more are also performed everyday by users, but due to the limitation of time and resources, this study was focused on selected main activities.
As elaborated in chapter 2, according to WCAG 2.0 principles, in order to fulfill mobile accessibility four main principles must be considered as following:

- **Perceivable**
  - Text alternatives for non-text content
  - Captions for multimedia
  - Content is easy to hear or see
  - Content is fit to small screen size

- **Operable**
  - Functionality is available from keyboard
  - User have enough time to read and use content
  - User can navigate easily and find content
  - Buttons are placed in appropriate position when the device held in different positions
  - Appropriate changing screen orientation

- **Understandable**
  - Text is readable and understandable
  - Content appears and operates in predictable way
  - Users are helped with descriptive instructions

- **Robust**
  - Content is compatible with different browsers and assistive technologies
  - Easy method for data entry

Considering these principles, study design content was included particular highlighted topics regarding user characteristics, quality of the interactions, what and how it was performed. In addition, user opinions and rate of satisfaction of doing interactions was questioned. According to the rules and guidelines for study design which were elaborated in study design section, the interview topics were designed and categorized as following:
1) User characteristics
2) User satisfaction on using gestures
3) User satisfaction on keyboard usability, typing letters vs numbers
4) User satisfaction on audio feedback
5) User satisfaction on ease of key functions
6) User satisfaction on preferred editing mode, numbers vs letters
7) User satisfaction on reading email/SMS

Content of the interview was prepared to collect information regarding user characteristics including name, age, sex, eye sight situation, education, and disability issues. Interview format was semi-structured in order to be flexible and comfortable as much as possible with the participants also to have a set of questions to control the flow of interview. The reason of having informal interview was to achieve the most accurate feeling, perspective and feedback by giving freedom of driving the interview to user while performing the interactions with iPhone 7 through VoiceOver.

On performing each activity, the participant was requested to verify four principles of WCAG 2.0 as following:

- Perceivable: Can content be seen or heard by VoiceOver without losing the meaning?
- Operable: Is mobile device generally operable through keyboard, touchscreen?
- Understandable: Is interaction with mobile device through VoiceOver understandable for user?
- Robust: Is content robust enough to be remained accessible through VoiceOver?

The participants were being asked to give feedback regarding learning touch screen, gestures, operations, issues, challenges, and propose solutions for enhancement of usability and accessibility of mobile devices.
4.3 Study Execution

The main purpose of this thesis work was to detect the most common accessibility and usability issues that users faced while interacting with iPhone 7 through VoiceOver. In this study the focus of the inspection evaluation was on iPhone 7 with iOS 10.2. As mentioned in study design section, 5 main interactions were considered to be evaluated in order to identify challenges and issues during performing the actions. The result of the interview was very much depending on the participant's characteristic, experiences, and skills of working with mobile devices through VoiceOver. In this thesis work, participants were selected from similar age and education level. They were all had higher education and familiar with new technologies and build-in features of devices from Apple. The author of thesis work targeted the participants in the same work area where, abled to contact them easily to get their feedbacks and comments. All the participants had vision issue, partly visually impaired but not totally blind, however in this thesis work the experiment was simulated as blind people by mean of “curtain” feature in VoiceOver which turned on the mobile screen into black.

The interviewees were familiar with VoiceOver but have been trained before the interview as well. The interview was face to face individually session around one hour including the thesis author and the interviewee. In order to get the accurate result, “curtain” feature in VoiceOver turned on to simulate the condition similar to blind users. The interviewer booked a session with the interviewees prior to the interview. The interview room was booked for couple of hours to avoid the disturbance from the others. Inside the room was silent and comfortable.

The interview session began with introducing the author, research topic and aim of the interview. It continued with speaking about the format of the interview, what, why and how to perform each activity of the interview. The interview terms and conditions were explained to the interviewee and s(he) has been kindly asked to raise questions once ever needed during the execution of interview. In addition, the interviewee was informed that all the activities are recorded by interviewer. Before starting the experiment, the interviewee was offered by intense training of VoiceOver on iPhone 7. It was included with elaboration of using screen reader in
order to perform interactions with iPhone. Gestures, touches, activities, and operations were examined. The interviewee was asked to practice operations several times in order to get the idea behind each gestures and touches. There is a useful feature provided with VoiceOver which turns off the screen while interacting with mobile devices. In order to ensure the user privacy, avoid distractions, and simulate the condition similar to blind users, curtain screen was turned on to make the screen black.

Evaluation part was included with two main activities. First one, interacting with iPhone 7 through VoiceOver and second activity was collecting feedbacks, comments, and suggestions from interviewee during the interaction with iPhone 7.

For evaluation process, 5 main activities were considered as following:

1) Make phone call
2) Send/Read SMS
3) Edit Email/text
4) Navigate/Browse
5) Play Music

The interviewee was asked to perform all of these activities one by one patiently. During the interview, all the user interactions with iPhone7 were monitored by interviewer. The comments and suggestions were recorded by a voice recorder and also interviewer made note of all the activities, during the interview. If there was any doubt or question, the interviewee asked for help and kindly get offered by the interviewer with more information to clarify the situation. The interview execution was done clearly particularly when changing between topics to avoid confusion for the interviewee. In order to collect accurate data, specific experiences in detailed activities were questioned. Performing these five activities took different time for different users according to their experiences and personality characteristics in terms of adaptability and speed of performing an action. In average the evaluation inspection took around one hour for each participant.

Meanwhile the interviewee was performing the activities, interviewer started a conversation
regarding the quality of the interactions and user satisfaction on particular characteristics of VoiceOver according to WCAG 2.0 accessibility principles as following:

User satisfaction on using gestures

1. User satisfaction on audio feedback
2. Keyboard usability, letters vs numbers
3. Ease of key functions
4. Preferring editing mod
5. Touchscreen learnability
6. Ease of typed text checking

All the comments and feedbacks were collected and detailed in following section results.

4.4 Results

The Interview was performed with five individuals, three women and two men. Age ranged from 30 to 40, with mean age around 35. They all had higher education and were familiar with recent technologies and specifically products from Apple. The interviewees were asked to use an iPhone 7 with iOS 10.2 which was provided by interviewer. The purpose of the evaluation was to collect user opinions and feedbacks regarding mobile accessibility of VoiceOver. After the inspection evaluation of VoiceOver, it acknowledged that VoiceOver basically makes mobile devices (particularly iPhone 7) content accessible to visually impaired people. VoiceOver gestures helps the iPhone users performing the main activities such as make call, send text, edit email, play music, and more. In addition, the interviewees were requested to provide their feedbacks regarding user satisfactions on performing tasks, using gestures, using different edit mode and the quality of the interactions, and more. Level of user satisfaction (easy, difficult, functional, and more) on performing these tasks were borrowed from the research that was elaborated in the related work section.

Visually impaired people have been facing some issues regarding usability of mobile devices while performing activities through VoiceOver. These issues are as following [65]:
● Clarity of user interface by having appropriate label and comments
● Logical navigation order of contents and elements
● Quick and easy identification of elements and content

During the inspection evaluation the interviewees were asked to identify these issues if they are still existed.

**Clarity of user interface by having appropriate label and comments:**
VoiceOver announces an element while focus is on that. It was acknowledged that element announcement was appropriate, however speaking name of the element such as “text field” was not meaningful and valuable for users. In some cases, too much information given by VoiceOver was not needed. For example, on keypad for phone call, announcing the letters under numbers was not necessary since it was not possible to edit the letters at all. Another example, when focus was on the text field to edit number or text, VoiceOver speaks that “Double tap to edit” which was a useful hint for user in the beginning of the inspection however after a while it was confusing as repeated unnecessarily.

In reading email, VoiceOver speaks all the elements from the beginning to the end, which was more confusing rather useful. In addition, some elements were ignored to be announced by VoiceOver. For instance, in Play music, the button called “Shuffle All” in list of music was ignored. Speech to text did not function properly, totally wrong text written and was not spoken by VoiceOver unless cancel button pressed.

**Logical navigation order of contents and elements:**
In some cases, for example navigating the contact with three fingers, users lost the order due to VoiceOver ignorance of elements. Finding specific call when browsing with three fingers to the next page was slow and sometime malfunction. For instance, browsing a page opened in Safari with three fingers was hiding the last line of the page. Problematic situation was identified by browsing to left, right, down, and up shown. Speaking about logical navigation order, it turned out that when user intended to recheck the text or number, sometimes the focus gets lost due
to the place of bar element which was close to the text or number field.

**Quick and easy identification of elements and content:**
The participants in evaluation still had issues for handling the focus especially when they intended to edit a text and verify the correctness of it. Also when search on contact was done and result found, no hint was given to the user before s(he) scrolled down the page and selected the result. In addition, it was easy to mix close and open page buttons as they were hard to get recognized.

After inspection evaluation it turned out that the easiest accessible activities on iPhone included make call, read/write SMS, send email, play music, and Internet navigation. Other activities including game, podcast, Memo, and more were less accessible for users. The feedbacks, comments, and opinions from participants in the evaluation were categorized as following:

**Use of gestures:**
There were some challenges in learning VoiceOver gestures in the beginning, however after practicing, the participants found them easy and functional. Most of the users were satisfied working with gestures, however only one user believed that it was difficult to adapt with.

**Audio quality:**
The main functionality of VoiceOver is to speak loud elements and components for visually impaired users. In inspection evaluation participants were questioned about the quality of audio for signaling elements and functionalities such as open/close application, navigation, delete, confirm actions, and more. Three users found that very clear and useful, one user acknowledged that as enough useful and one user was not satisfied with the intonation and speed of the audio.

Speed of announcement was acknowledged too slow from some participants which made the interaction frustrating for them. In addition, having the same female sound with very similar intonation for all the interactions made the actions such as select and delete hard to get
recognized. Pronunciation of letters in some languages was wrong for example Swedish letters “Ä”, “Ö”. However, speaking letters provided with samples as well for example A for Alpha.

Learnability:
One of the important challenges for visually impaired users is to deal with touch screen devices. Although these devices are very popular and available everywhere but not easy to use for everyone. Visually impaired people should be trained and practiced touches in order to feel comfortable while interacting with mobile devices. In this thesis work all the participants were well experienced with touch screen devices however for this specific experiment they were required to learn VoiceOver gestures and touches. After practicing the gesture, it was acknowledged as easy to learn and adapt. Four users acknowledged that easy and one neither difficult nor easy.

Edit letters/numbers:
UI usability has huge impact on accessibility of mobile devices in terms of operability and ease of interactions. The participants were asked to acknowledge regarding usability of keyboard when typing numbers or letters. Four users found number /letter typing enough functional, however one user believed, it was functional but with difficulty. In general, it turned out that all the participants found number typing less problematic than letter typing.

Operate function keys:
Considering making a phone call on a numeric keyboard, detecting the key buttons such as delete, contacts, recent calls, and more was challenging for the interviewees. However, it was acknowledged easy to identify these function keys after practicing the location of buttons.

Edit mode:
Visually impaired people have different taste for editing mode, some prefer standard mode, double tap and some go for single tap. In this inspection evaluation, most of the participants preferred single tap as it is more convenient while editing numbers or letters.
Checked typed text/number:

Checking typed text or number is a very common activity for visually impaired people. Therefore, entry verification must be easy and functional. Three participants in evaluation inspection acknowledged the verification enough functional and two users found that low functional and slow.
5 Discussion

This chapter starts with speaking about the mobile accessibility principles and continues with discussing the result of evaluation inspection and concludes the discussion with several proposals for mobile accessibility enhancement. This chapter ends with the summary of thesis work.

In this thesis work, the impact of mobile accessibility on visually impaired people’s daily life was investigated. The investigation focused on identifying main accessibility and usability issues when visually impaired people using VoiceOver screen reader. According to the W3C guidelines for Web content accessibility [18], several principles must be considered to provide web content accessibility. These principles also are valid for mobile accessibility.

- Perceivable: Information and components must be visible and perceivable for user.
- Operable: User interface component must be operable by user. This means user must be able to perform intended actions.
- Understandable: Information and operation of user interface component must be understandable for user.
- Robust: Content must be robust enough that remain accessible for user agents and assistive technologies.

As elaborated in Background chapter, last section 2.2.3, several parameters were identified for each principle for evaluation of mobile accessibility.

- Perceivable
  - Text alternatives for non-text content
  - Captions for multimedia
  - Content is easy to hear or see
  - Content is fit to small screen size
- Operable
  - Functionality is available from keyboard
  - User have enough time to read and use content
○ User can navigate easily and find content
○ Buttons are placed in appropriate position when the device held in different positions
○ Appropriate changing screen orientation

● Understandable
○ Text is readable and understandable
○ Content appears and operates in predictable way
○ Users are helped with descriptive instructions

● Robust
○ Content is compatible with different browsers and assistive technologies
○ Easy method for data entry

Considering these parameters, and recalling the belief or hypothesis that was generated in methodology chapter, the result of inspection evaluation showed that iPhone 7 is basically accessible through VoiceOver for users. It was acknowledged that content and elements were initially perceivable through speaking of captions, labels and comments. Interaction with the mobile device through user interface was operable and understandable for user. Generally, user was able to operate the device and perform intended actions, however there were some challenges regarding usability and accessibility of mobile device. In order to support fully accessible content, it must be robust enough as well.

Although it was acknowledged that iPhone 7 was fundamentally accessible through VoiceOver for visually impaired users but there are several usability issues that must be considered to improve the mobile accessibility. As discussed in methodology chapter, these issues still are unresolved impediments that violate full mobile accessibility on iPhone [65]:

● Clarity of user interface by having appropriate label and comments
● Logical navigation order of contents and elements
● Quick and easy identification of elements and content
The first initial step to support mobile accessibility is to ensure appropriate label, caption, and comments for all elements that need to be hearable. The focus of evaluation inspection was not on the content but rather on functionality of VoiceOver in capturing all the elements without ignoring them. Quick and easy identification of elements and exposing them with appropriate and useful information are big values for users. Meanwhile logical navigation order of elements and content makes the interaction meaningful and understandable.

Touch screen devices bring new challenges through gestures to visually impaired users. Integrating these gestures in daily habit requires time and effort from users. Relying on voice is another big challenge as the quality of voice in noisy environment, voice speed, intonation, and voice gender may impact the perception of information. Therefore, touch screen keyboard is harder to work than physical keyboard since it is relying on voice.

There were several proposal solution regarding usability from interview participants to speed up the interactions as following:

- Having function keys such as “Cancel”, “Delete” in the same place.
- Using vibro-tactile for identification of the function keys.
- Using iPhone button to display a bar containing function keys at specific place preferably vertical side of the phone.
- Having function keys at mobile edges

### 5.1 Summary

Mobile devices are getting tinier and popular in the society. As they get decreased in the size, but increased in power and resources. Although they are available everywhere but not accessible for everyone. Many users with disability of vision, hearing, cognition, and more are not able to have fully access to mobile content. In order to provide mobile accessibility for all type of users,
assistive technologies are placed between users and mobile devices. For instance, screen reader assists visually impaired users by speaking the content loudly, making the content accessible for this group of users.

In order to provide mobile accessibility, designers must consider accessibility and usability issues and make effort to resolve and improve them. WCAG 2.0 offers essential principles for design and development of the mobile content. According to this accessibility principles, mobile content must be achievable, operable, understandable and robust. The purpose of this thesis work was to identify mobile accessibility issues while interacting with mobile device. An inspection evaluation was done on built-in screen reader VoiceOver on Apple iPhone 7 with OS 10.2. Qualitative methodology and interview method were used for collecting feedbacks while interacting with iPhone 7 though VoiceOver. A group of five participants selected to be interviewed. They were asked to perform different activities mainly making phone call, editing/reading email, playing music, and more. The interview execution took around one hour for each participant in an appropriate silent place without any distraction. Visual impairment was simulated with VoiceOver feature called “curtain” which turned the screen to black. The idea behind the interview was to collect feedbacks, opinions, and comments regarding the quality of interactions from participants and identify the usability and accessibility issues that impede full mobile accessibility to visually impaired users. The purpose of the evaluation inspection was to test the hypothesis which claimed “iPhone 7 is accessible through VoiceOver”.

The result of the inspection evaluations confirmed that Apple iPhone 7 is basically accessible through VoiceOver but there are still some usability issues which make the mobile device inaccessible and malfunctioned while performing interaction [65]:

- Clarity of user interface by having appropriate label and comments
- Logical navigation order of contents and elements
- Quick and easy identification of elements and content
The feedbacks, comments, and opinions from participants in the inspection evaluation showed that more than average number of participants were satisfied from use of gestures, learnability, quality of voice, editing, and checking text/numbers. They acknowledged that VoiceOver capabilities for making the iPhone 7 accessible were enough functional, however there were some difficulties for users.
6 Further Work

Due to limitation of time and resources, the study was narrowed down to visually impaired users and the inspection evaluation was focused on Apple iPhone7. It is worthwhile to consider other mobile devices such as tablet and iPad in future work as well. Receiving user feedback on other mobile devices would be a big help to identify common issues between mobile devices. Furthermore, due to time and resource limitation, the inspection evaluation was performed on a small group of five users. Although the feedbacks were very much valuable but the more information from users helps to identify more issues and improve the quality of the assistive technologies.

There were several proposed solutions regarding usability from the participants in the interview to improve quality of the interactions as following:

- Having function keys such as “Cancel”, “Delete” in the same place.
- Using vibro-tactile for identification of the function keys.
- Using iPhone button to display a bar containing function keys at specific place preferably vertical side of the phone.
- Having function keys at mobile edges

Considering the issues that participants have been facing while interacting with iPhone 7 through VoiceOver, in future work, prototyping user interface according to the proposed solutions for improving the usability issues could be yet another way of collecting more feedbacks from users. However, the issues and proposed solutions were more related to the usability of touchscreen mobile devices but usability enhancement ensures mobile accessibility as well.
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