# Beyond Accessibility – A Universal accessibility framework for blind-friendly user interfaces on smartphone

**Akif Khan[1], Shah Khusro[2]**
Department of Computer Science, University of Peshawar-Pakistan
Department of Computer Science, University of Peshawar-Pakistan
**Corresponding Author:** Akif Khan, Department of Computer Science, University of Peshawar-Pakistan
**Email-id:** nawabsher80@gmail.com. **Tel:** 0092-320-2233202.

*There is no conflict of interest.*
*Article type: Original Research Article*

## Abstract

*Smartphone has become an essential tool for visually impaired and blind people in performing their daily activities stimulating independence, productivity and social inclusion. The smartphone user interfaces are equipped with accessibility features such as talkback, voice assistant, etc. however; the blind people are still facing several challenges in performing common activities such as placing a call, sending messages etc. We have proposed universal accessibility framework for blind-friendly user interfaces by semantically enriching the existing smartphone user interaction paradigm. The framework re-organizes/regenerates user interface components, layouts, etc. extracted from common mobile application into a simplified blind-friendly user interface on the basis of user preferences, device-logging, and context-of-use. In this study, the user experience of blind people in operating smartphone interface was explored through principal component analysis. A total of 41 blind people with an average age of 33.8 (SD=1.58) participated in the study. The user experiences have been collected in performing several everyday activities. The results revealed an improved interaction experience, task completion accuracy, and user satisfaction.*

**Keywords:** *Accessibility, Usability, Human-Computer Interaction, Blind people, Smartphone, Adaptive User Interface, UI*

## 1. Introduction

Information and communication technologies are adding capabilities for rapid and inexpensive solutions for people with disabilities. Smartphone-based technologies have proven its potential in the provision of accessibility-inclusive services to improve the quality of life of visually impaired and blind people [1]. Touchscreen as an input interface became a standard feature of smart devices such as smartphone, tablets, and smartwatches [2]. These devices provide an easy-to-use alternative to the traditional mobile phone device. Recent advancements in the smartphone capabilities in processing information, large screen display, availability of sensors for capturing and processing the context-aware objects are surfacing a value-addition in devising new solutions and services.

Visually impaired and blind people are using smartphones for performing several common tasks such as making calls, sending a message, taking a picture, listening to music, etc. [3, 4]. The interactions of blind people with smartphone transpire through accessibility services such as screen readers, speak screen, text to speech, larger font size, etc. in accessing information, selection of non-visual objects, etc. on smartphone interfaces [5, 6]. The device cost[7], lack of physical control[8], non-availability of screen readers in the local language, speech speed adjustment [9], text entry on traditional keypads with small keys[10] and limitation in the existing accessibility features[11] are few problems of smartphone user interfaces.

The provision of user-centric personalized and simplified user interface design will significantly overcome the issues of accessibility [12]. The usability of existing user interface paradigm can be markedly improved through the re-organization and personalization of user interfaces to reduce the cognitive overload, inconsistency in navigational structure, and real-time adaptation of user interface in response to changing user requirements. Adaptive user interfaces leverage flexibility in the user interface elements to customize/personalized according to the user needs thus reducing the burden of accessing over-crowded non-visual items on the screen. However, Kane et al. [4] contended the need for an alternative accessible interface to use smartphone potential.

We proposed a Universal Accessibility Framework (UAF) for blind-friendly user interfaces on smartphone. The framework incorporates the potentials of adaptation mechanism, users profiling, context of use and semantically enriched user interfaces. The outcome of this design will be an improved accessibility service, which will generate an optimal user interface for blind people. The interface will improve the user experience of blind people in performing common activities on a smartphone; institute a sense of quick learning, quick memorization and initiative learning experience.

## 2. General problems in the literature

Through a series of studies, researchers have analyzed and identified recommendation for usability, adaptive interface and how efficiently using a smartphone for blind people. Recently, touch-based interfaces have a significant impact on the mobile communication market, due to non-availability of tactical clues; researchers has contributed in making these devices more accessible for blind people. Large display surface with the ability to create visual interaction components has gained the opportunity for interaction with touchscreen interfaces. For instance screen reading applications including JAWS[1], NVIDIA[2], Narrator[3] of windows, Metal mouth[4], Windows Eyem Desktop, Talkback, Sound back[5], Mobile Speak[6] and voice over[7] read the contents of screen on desktop as well as mobile/smartphone, assisting blind people to interpret the non-visual objects on touch screen, besides the users can also read and understand the contents of screen through refreshable Braille display [13-19]. The use of Automatic Speech Recognizer(ASR) enables the blind people to convert the speech into text [20]. Krajnc et al. [21] suggested talking touch for interacting blind people to communicate with a smartphone by reducing the interface complexity. The “talking touch” and “talking touch list” composed of a list of pages deployed on a number of screen sizes of a smartphone device, thus providing ease in faster input with audio feedbacks. Aaron [22] designed dialer for blind people, they have made a fixed position’s digit keys on the screen. The first impression of the key represents the center represented by digit 5, while the rest of digits occupied the relative places. The top center represents the digit 2; top left represent digit 1, top right represents digit 3, left side from center represent digit 4, right side form center represents digit 6, bottom left represent digit 7. The bottom center represents digit 8; bottom right represents digit 9 and bottom of these three digits are represented by the symbol of start 0 and hush from left to right sequence. Young [23] proposed typing Braille letter and sending message developed their Braille typing application. They proposed the “self-adhesive” plastic, which has a hole for identifying the keys positions on the screen according to their application.

Borodin et al. [24] have developed the “HearSay” a non-visual web browser for blind people using voice XML. The browser reads the web page contents in two navigational modes, which continuously reading the contents while skipping extra information such banner, menus, and ads. The HearSay non-visual web browser uses a geometrical clustering algorithm [25]. However, there is no unique function of reading the content of an email. Similarly, Borodin et al. [26] introduced a Tele web services; they have integrated the traditional and usable phone incorporated with the features such as context-oriented browsing. This helps blind users to access the web from the phone, search on web, check their email and other web activities by speaking and using phone keys. This system had initially developed for desktop users, and there is no difference in using email activities with other content surfing mechanism. Chu. [27] proposed two dimensional interactive voice browsers whereas they have integrated voice functions. IBM voice to Chinese text-to-speech synthesizer was embedded to speak loud all web contents. The browser is based on IE running engine on windows platform; at startup, browsers read all structure of web page elements including frame, table, links, menus, and forms. A coding numbers are assigned to the section of the page in increasing order, which usually starts from one side to the other end for reducing time in speaking commands. However, the solution confronts issues in punctuations. Ghose et al. [28] proposed open source browser architecture, allowing blind people to navigate web sites through voice commands. This design supports text-to-speech and text-to-Braille, all keyboard operation have voice feedback.

---

1http://www.freedomscientific.com/products/fs/jaws-product-page.asp
2http://www.nvda-project.org
3https://marinersoftware.deskpro.com/kb/articles/281-what-is-narrator
4https://code.google.com/p/metalmouth/
5https://play.google.com/store/apps/details?id=com.google.android.marvin.talkback&hl=en
6http://webcache.googleusercontent.com/search?q=cache:mhUrXg4ZEWYJ:www.itu.int/ITU-D/sis/PwDs/Documents/Mobile_Report.pdf+&cd=1&hl=en&ct=clnk&gl=pk
7http://www.apple.com/accessibility/osx/voiceover/

Enhancing accessibility is a demanding experience for blind people. Screen reading applications are facilitating blind people in translating contents, labels and rendering non-visual items. Text to Speech such as Talkback and Soundback[8] are the accessibility service used to operate the smartphone, read the content and provide directions to respond. Mobile Speak[9] is a screen reading application generates all displays contents of the screen to speech-to-text and text-to-Braille. Voice Over[10] is screen reading application for blind people based on gestures; by dragging the finger reads the contents of the screen, voice-over reads the text in the textbox and converting screen contents to Braille display if Braille display is connected to Smartphone.

A number of gesture-based interaction techniques have been introduced on touch-enabled devices. Some of the operations include flicking, rotating, flipping, flat hand; the horizontal hand is few single and multi-finger gesture available[29]. Slide rule[4] uses multi-touch interaction to make touchscreen accessible for blind users. They have designed a set of multi-touch interaction associated with other functionalities. Similarly, touch player[30] provides directional gestures and non-speech feedback to the blind people for interaction purpose. McGookin et al. [31] designed the raised paper embedded solution for making smartphone accessible to blind users by delivering tactical sense through raised paper control fixed on the object of the screen. MessagEase [32] uses the slide and tap model for touchscreen-based entry. Selection of primary characters in the layout is performed via tapping while secondary layout menu can be operated by sliding in certain directions. NavTouch [33] is a gesture-based interface where the user can use gesture anywhere on the screen providing benefit of extended interface and layouts. Gesture to left and right navigate alphabetically horizontally and vertically; vowels are used as intended letter whereas speech feedback assists a user in navigating the alphabets. Egoki System [34] outline a framework for automatic generation of a user interface for people with disability to have universal access to several ubiquitous services. The structure suggests a suitable multimedia interaction pattern for each function duly mapped with the user requirements and expectations. An empirical study was conducted to check the viability of the system, resulting in a better response. Similarly, Supple System [35] generates user interfaces adapted on the basis of user preferences, device feature and disability profiles. The system provided a successful adaptation in less than 20 minutes from abstract UI to final UI.

Interpersonal communication through electronic aids like mobile or smartphone is possible. However, several changes in interaction mechanism need to be in place. Interaction through audio and touch-based interfaces are already available in commercial products. However, the significant disadvantage of touch-based interfaces is the lack of tactical sense [31], Identifying a widget or control button with the same interface is quite a complicated job. While, Interaction through voice mechanism are suffered from the inherited issues of poor performance, noisy environment, and change of ascent thus may lead to increase cognitive overload in memorizing voice instruction [36, 37]. Moreover, the gesture performance of a user is dependent on his experience and understanding of the application[38]. Potential of touch-based interfaces can be achieved up to a great extent while addressing the eight rules of Shniderman [39]. This includes consistency in design and controls, immediate feedback (tactical or auditory), error handling and error prevention in a manageable way, reduce cognitive overload, and always provide a home back in case of the user deviate from their path.

In summary, the usability of touchscreen user interface merits further investigation and revamping of existing user interfaces into the demands and expectations of the blind people. Few studies have proposed a usable and accessibility-inclusive user interface; however, the results need further improvement. The results should also consider the improvement in the accessibility, usability, the technical and operational effectiveness of the smartphone user interfaces for blind people. From the findings of literature review in the area of human-computer interaction, usability, accessibility and diversified requirements, we come up with a universal accessibility framework on smartphone user interfaces for blind people.

## 3. Universal Accessibility Framework (UAF) for blind-friendly user interfaces

We have proposed a universal framework to automatically generate a simplified user interface from the existing mobile application based on user preferences, device history, and context awareness. The logical description of user interface components of existing common mobile applications is extracted through reverse

8https://play.google.com/store/apps/details?id=com.google.android.marvin.talkback&hl=en
9http://en.wikipedia.org/wiki/Mobile_Speak
10http://www.apple.com/accessibility/ios/voiceover/

engineering methodology [40]. The UAF framework is implemented as part of the accessibility services installed on a smartphone device. We have implemented the framework on the Android operating system. The accessibility service first scans and check the availability of mobile applications in the smartphone. We have initially personalized four common applications including Call, Message, WhatsApp and Email applications. However, further applications can be added into the customize application utility. Our UAF accessibility service scans the corresponding Android Application Package (APK) file of the application needs to be personalized for the blind people. The UAF framework analyzes an application user interfaces, activities, and resources used in an application in real time. A mobile application consisting of one or many activities. The activity provides basic user Interface structure of a process or application. The framework also extracts Service, Broadcast Receiver and Content Provider of the application. The Android system loads a resource file automatically once an activity is a call to action. Figure 1 shows the UI decomposition of the Email application.

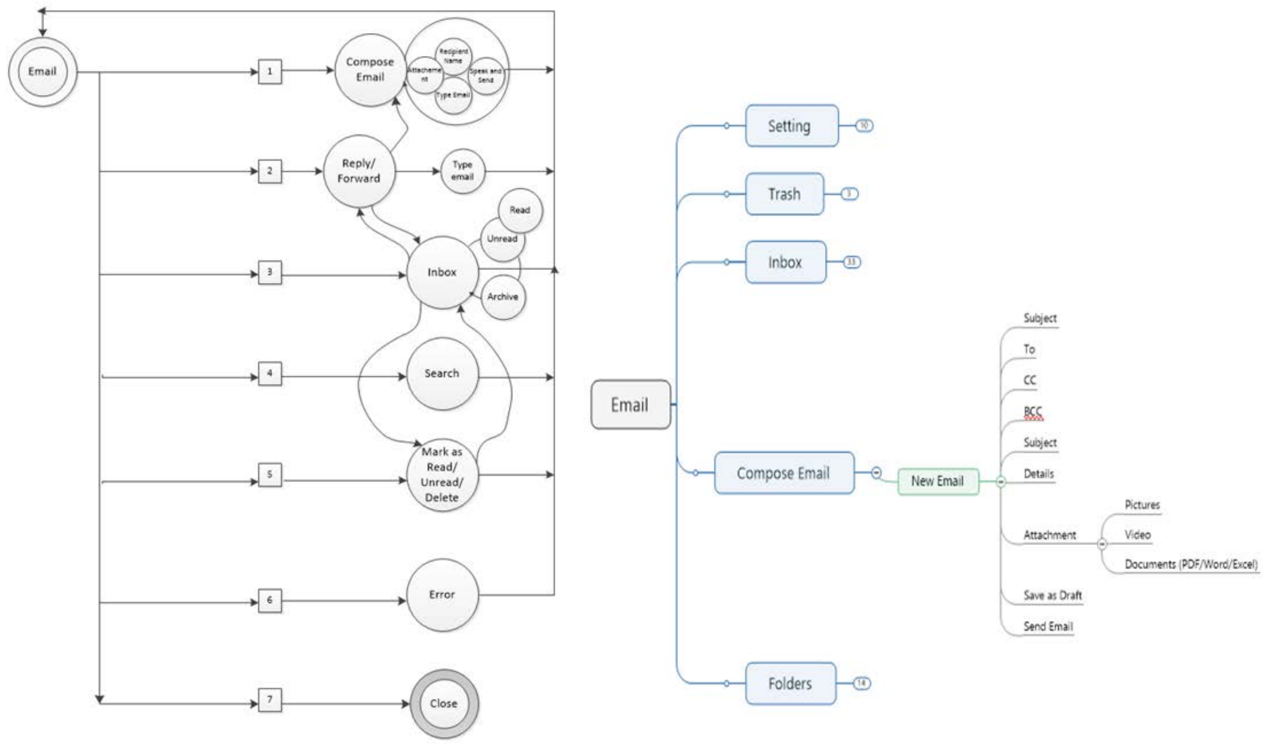


**Figure 1: State Transition Diagram and Mind Map of an Email Application**

The UAF accessibility service iterates activities in different phases including UI decomposition, analysis of UI and annotation of user preferences, device history and context-aware information on the interface component framework. The UAF framework is illustrated in Figure 2. The UAF used UI parameterization technique in which the elimination, substitution, and realignment of user interface widgets are fine-tuned into a final user interface. The UAF first extract the activities, UI resource, layouts and draw-able form the application. On the user end, the blind people provide preferences about layout partitioning, Input/output preference, interaction type and mode of accessibility feature (haptic, voice). The user requirements are collected through the direct input, device history, and context feature. These features are stored in the UI adaptation ontology for reasoning and further inferencing. The user preference, device capabilities, decomposition of user interface elements are processed in transformation layer of the framework. Through specific adaptation rules, the UAF delivered a simplified user interface on the smartphone. The simplified interface can be enriched with a number of available templates of screen design and screen partitions etc. In addition, context layer consistently annotating context data into the framework and mapped accordingly with the user preference. For instance, specific user applications are be made available to users in specific contexts such as news reading or book reading application can be surfaced to the main grid in the indoor environment and will be moved to the outside grid in case of the outdoor environment.

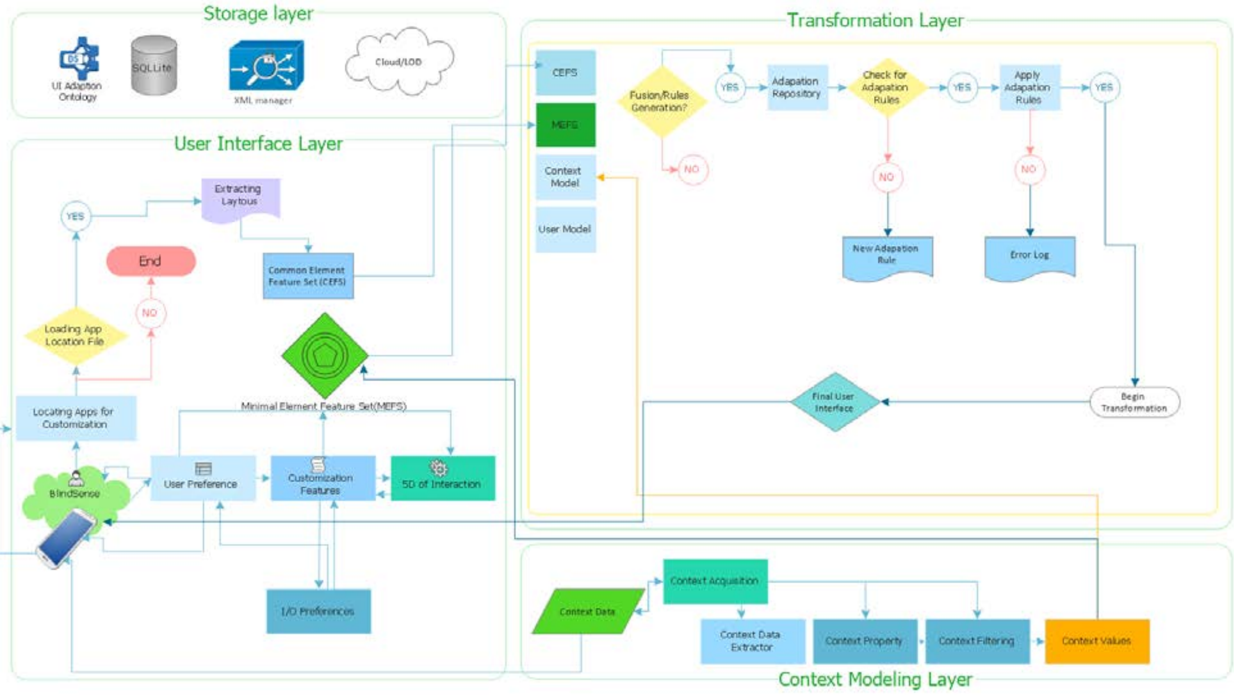


**Figure 2 Universal Accessibility Framework for User Interfaces for blind people**

## 4. Methods

The study investigated the user experience of the blind people in the personalization of automatically generated user interfaces from existing mobile application thus providing universal access to blind people in using any mobile app in a standardized and simplified manner. The user experience is the degree of perception of the user interaction with an application, device or an interface[41]. We have collected the responses from the blind people on several parameters of usability and accessibility during the study.

### 4.1. Participants

A total of 41 blind people participated with an average age of 33.8 years having one year of experience using smartphones. These people were recruited from the National School of Blind, Peshawar- Pakistan. University of Peshawar Institutional Review Board (IRB) has approved the study procedure for the study. Written consent was obtained from the caregiver of the blind people.

### 4.2. Apparatus and Stimuli

The experimental material includes a smartphone, UAF accessibility service, and 5-point Likert scale questionnaire. The UAF accessibility service was developed in Android 5.1.1 and was the primary stimuli of the entire study. A set of interactive tasks were designed through which the blind people have recorded their experience in operating the smartphone, accessing several features and performing common activities. The experimental stimuli were presented on Android smartphone with a 5.7-inch touchscreen, a maximum resolution of 1440 x 2560 pixels and weight of 171g. Table 1 describes the factor item collected on the Likert scale. These items are collected from related user interface research found in the journal, books, conference proceeding of Human-computer interactions [42-44].

**Table 1 Usability of Smartphone Factors Items**

| Factor | Sub Factors |
|---|---|
| System Usability Scale | Placement of non-visual item on screen, effect of Vibrotactile and sensitivity of screen in response to user action |
| Consistency | Information Sequence, Logical order of menu items, Screen sequence, flow of information |
| Flexibility | Adaptation of new interfaces, layouts, and item of interests |
| Learnability | Screen exploration, identification of button, links, images and videos, learning curve, Touch clue, gesture shape, edges |
| User Experience | User attitude, mood, and pleasure |

### 4.3. Procedure

All participant were brief about the purpose and scope of the study. These participants were asked to perform 21 tasks on a smartphone, composing of basic, intermediate and advanced tasks. They were informed to complete the task in particular time so that the efficiency and effectiveness of the tasks can be calculated accordingly. An except of the workflow of tasks are illustrated in Figure 3, 4 and 5 respectively. The facilitators have recorded the response of the participants in 5-point Likert scale questionnaire along with the observation notes taken by the facilitators. The quality metrics are describes in table 2. The experiment was implemented in implemented in ICT Accessibility Center of Department of Computer Science, University of Peshawar. Each participant completed the study in 35 minutes. The trial establishes the basis of how blind people use smartphone using UAF to accomplish specific tasks. The trial collected the quantitative and qualitative information about blind people and user expectation about the system in performing advanced and straightforward tasks. Several usability test techniques are used in the study. The usability method applied is a modification of established usability technique called Think-aloud reflection method [45]. Reflection method is composed of multi-dimensional analysis including short interview, questionnaire, and user observation. The subjective information is collected through a structured survey where responses related task performance, satisfaction, and user experience were articulated in the Likert scale. The verbal comments, emotions, and expression of the user regarding the execution of several tasks are recorded accordingly. A summary of quality metrics and necessary parameters are provided in table 2.

**Table 2: Quality measurement metrics**

| Evaluation Parameter | Metrics | Mechanism |
|---|---|---|
| Temporal | Time to accomplish each task | Smartphone built-in watch |
| Level of Cognitive load | Level of ease of working while performing a task | After identifying the interaction pattern in specific tasks. |
| Effectiveness | Number of tasks completed | Through Observation |
| User experience | Level of satisfaction with own performance of each task<br>Level of satisfaction with the time spent for each task | Subjective Evaluation |

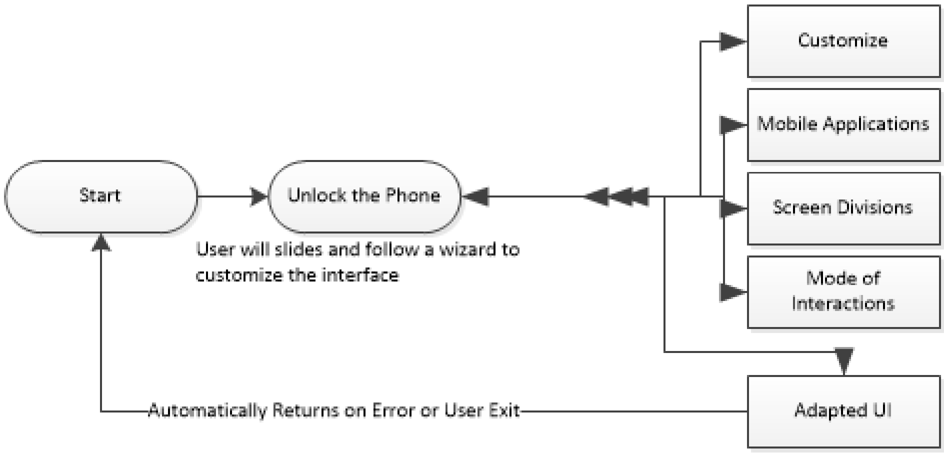


**Figure 3 UAF Task Scenario 1**

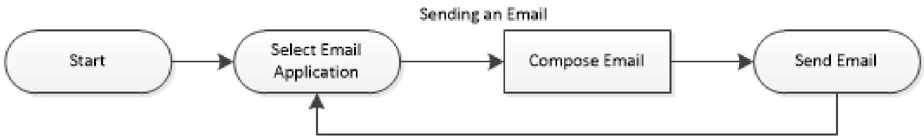


**Figure 4 UAF Task Scenario II - Composing Email**

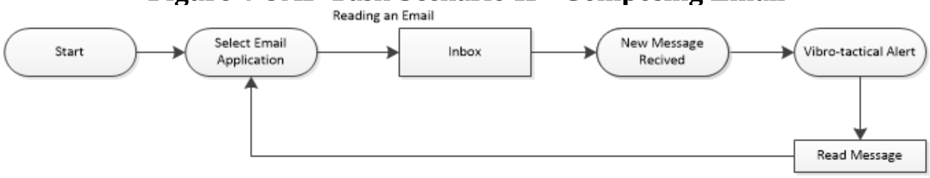


**Figure 5 UAF Task Scenario III - Checking Email**

The following usability parameters used to assess the effectiveness of the overall study, this includes. **Efficiency** of the user tasks was determined through temporal and mental workload analysis (human-centric ability) [46]. The time requires in completing a particular task completed.

**Effectiveness** The difficulty faced by the blind people in performing the activities are observed through the observation stage, and a number of queries were asked after completion of the task such as which kind of difficulty you have faced? Either they difficult was related to interface selection, response, or input. **User experience**: The level of satisfaction, performance with time is recorded in performing the individual task. The overall user experience of the blind people in performing the overall activities.

### 4.4. Data Analysis

We run analyses of statistical correlation to analyze the data using SPSS 21 as a primary statistical tool. Principal component analysis, reliability analysis, independent t-test and variance analysis was performed.

## 5. Results and Discussion

The section illustrates the finding of the data collected from the blind people on the usage of UAF. The findings were collected after the task interview and observation carried out in the task scenario. This study uses the Cronbach's α reliability coefficient to determine the reliability of the factors and items listed in the responses. The result publicized that the questionnaire item has high reliability (Cronbach's $\alpha$ =0.84) thus demonstrating the five Likert scale is well appropriate for the participants. Besides, the Chi-Square value for Barlett test was (178.17 ($p<0.01$) and Kaiser-Meyer-Olkin value was 0.752 demonstrating efficient factor analysis.

### 5.1. Factor influencing blind-friend user interface

Principal Component Analysis (PCA) was used to extract and analyze the factors affecting blind-friendly user interfaces on a smartphone for blind people. The factor loading metric was created using Varimax orthogonal rotation method and number of factors having an Eigenvalue of greater than 1 was determined using Kaiser's rule [47]. The results of factor loading and variation are explained in Table 3.

**Table 3 Factor analysis of UAF for blind People**

| Factor | Item | Factor Loading | Cronbach's Alpha | Cumulative %age | Eigenvalues |
|---|---|---|---|---|---|
| System Usability Scale | Placement of non-visual item on screen | 0.85 | 0.82 | 72.61 | 1.45 |
| | Effect of Vibrotactile and sensitivity of screen in response to user action | 0.89 | | | |
| Consistency | Information Sequence | 0.95 | 0.90 | 79.43 | 3.17 |
| | Logical order of non-visual items | 0.81 | | | |
| | Sequence of information | 0.91 | | | |
| | Flow of user interface components | 0.87 | | | |
| Flexibility | Adaptation of new interfaces | 0.84 | 0.88 | 82.20 | 1.64 |
| | Layouts and item of interests | 0.58 | | | |
| Learnability | Screen exploration | 0.78 | 0.80 | 74.20 | 1.56 |
| | Identification of button, links, images, and videos | 0.60 | | | |
| | Learning curve | 0.77 | | | |
| | Touch clues | 0.82 | | | |
| | Gesture shapes and recognition | 0.82 | | | |
| | Edges detection | 0.88 | | | |
| User Experience | User attitude | 0.89 | 0.92 | 86.60 | 2.59 |
| | User mood | 0.97 | | | |
| | User pleasure | 0.92 | | | |

The previous studies have illustrated that an explicit interface is an essential and critical feature in Human-Computer Interaction[48]. Thus, this critical factor is considered in the usability paradigm of smartphone user interfaces. The first factor influencing the universal accessibility framework for blind people is the System Scale Usability (SUS)[49]. This includes the usability of the system in response the usability and accessibility of the framework. The SUS is a reliable usability scale for global benchmarking of any system's usability to determine the level of the user experience of a particular application or service. This includes placement of the non-visual item on the screen, the effect of Vibrotactile and sensitivity of display in response to user action, level of complexity, inconsistencies, and confidence in the system. Perceiving and identifying the object of interest on smartphone user interfaces is a challenge for blind people because the screen surface does not carry any tactical or physical touching. Therefore, the blind people perceive the object nearby on the screen through haptic feedback or touch perception and establish a pattern of the surrounding non-visual item on the screen [50]. To determine the reliability of the SUS questionnaire, we have used the Cronbach's Alpha. The Cronbach's Alpha coefficient for SUS factor achieved 0.82 score which is acceptably good score whereas the score higher than 0.80 represents good internal consistency among the co-related items. The results showed that all users have found the system usable and easy to use by performing several tasks of interacting with application UIs.

The second factor is the consistency, which provides a unified access to the smartphone UI components. This includes the sequence of information presented on the screen, logical order of non-visual item on the screen, sequence of information spread over the screen, flow of user interface components in the form or text-entry forms. Blind people receive less information as compare to sighted people. Thus, a highly consistent and productive user interface layout should be presented to the blind people to follow the right sequence of commands. During the experiments, the participants have reported that the consistency in the ongoing screen of an application helps them in memorization of the commands without exploring the entire screen repeatedly.

The third factor that influences the accessibility of smartphone interfaces is a UI flexibility. The user interface flexibility is the degree to which the user interface is adaptable to the requirements of the blind people. The user can customize their user experience irrespective of their impairment, technical abilities, and capabilities. [51]. This factor includes an adaptation of new user interface, layouts, an item of interest, user interface component and templates for re-arranging and organization of smartphone user interfaces based on the user requirements, device capabilities and context-sensitivity.

The fourth factor is the learnability which entrails screen exploration, identification of buttons, links, the effect of prospecting on the learning curve, touch clue, gesture shape and size and edge detection. Blind people through their finger positioning on smartphone interface can recognize with form or the object. Thus the screen partition and screen division in flexible portion help him in quick identification and learning of interface dynamics. In the study, the participants reported the difficulty in accessing/selecting/picking the region and suggested that if a haptic feedback will inevitably reduce the chances of wrong touches. For example, if a blind people click on the screen item they item should speak out the name of the function such as Home button or Compose New Email, Next or Previous, etc.

The last factor is user experience entrails information about user attitude, user mood and user pleasure/displeasure over using our accessibility service. The user experience includes all those factors which directly or indirectly affect the user interaction with an application or system [52]. In our experiment, the participants have felt a pleasured experience in performing common activities on a smartphone using UAF.

**Table 4 Items wise ranking (descriptive statistics)**

| **Item** | **N** | **Mean** | **Std. Deviation** |
|---|---|---|---|
| User attitude | 41 | 2.59 | 1.04 |
| User mood | 41 | 2.29 | 1.07 |
| User pleasure | 41 | 2.29 | 0.90 |
| Placement of non-visual item on screen | 41 | 2.76 | 0.79 |
| Effect of Vibrotactile and sensitivity of screen in response to user action | 41 | 2.76 | 0.79 |
| Information Sequence | 41 | 2.63 | 0.73 |
| Logical order of menu items | 41 | 2.95 | 0.83 |
| Sequence of information | 41 | 2.93 | 0.87 |
| Flow of information | 41 | 2.71 | 0.75 |
| Adaptation of new interfaces | 41 | 2.85 | 0.85 |
| Layouts and item of interests | 41 | 2.83 | 0.86 |
| Screen exploration | 41 | 2.93 | 0.87 |
| Identification of button, links, images, and videos | 41 | 2.93 | 0.81 |
| Learning curve | 41 | 2.71 | 1.00 |
| Touch clue | 41 | 3.20 | 0.90 |
| Gesture shape | 41 | 2.51 | 1.00 |
| Edges Detection | 41 | 2.80 | 1.00 |

In addition, the importance of these factor items has evidenced from the descriptive statistics reported in table 4. Blind people considered user attitude, mood and pleasure most critical item in influencing their interaction with smartphone applications. Besides, placement of non-visual item, the effect of Vibrotactile and sensitive of user action, and information sequence has considered a second level of priority. The gesture shape and touch clues have given a less essential score. This is mainly due to an inbuilt feature of screen division covered cater the needs for gesture shape and touch clues. Smartphone provides an interaction paradigm for blind people in performing common activities. However, the non-tactical and smooth surface contributes some issues in identifying, selecting and responding to non-visual items on the screen [53]. The physical tracking behavior of smartphone interface such as feeling bumps to identify the regions and edges of the screen. However, the accessible interface should provide more clues, touch perceptions and haptic response to perform several activities on a smartphone effectively. The study presents a universal accessibility framework for blind people enabling them to access and operate mobile application efficiently, with greater control and improved user experience. We have identified from the study that the accessibility demands are more concerned about the place and location of a non-visual item on the screen rather exploring the entire screen item one by one through direct exploration.

All participates have experience smartphone user interfaces on the Android operating system. The user has performed 121 tasks in specific order. The tasks were having basic to advance level of difficulty. Besides, they have also experienced the operating of these task on using one hand and two hand exploration techniques. Blind people have indicated that the home button in the middle of the screen is very useful in going back to the main screen or knowing about the current name of the screen. Also, it assists in finding out the exact location in a provided navigational path. However, it is not ideally possible to perform all activities without wrong selection, wrong touches and making errors. Even such erroneous touches are common for all smartphone users. We have incorporated the user disability, and impairment features into the design ensure accessibility-inclusive design for blind people based on their preferences.

## Conclusion and Future Work

In this study, the proposed accessibility-inclusive framework is validated the user experience of bind people in using universal accessibility interactions. The study investigates the benefits of adaptive user interfaces for blind people in performing several daily life tasks. Currently, blind people are facing issues in interacting with a diversified mobile application having multiple layouts, interfaces, and interactions paradigms. Our results are consistent with earlier studies on improving the user experience of people with visual impairment [38, 54, 55]. Thus to improve the accessibility-inclusive interface, the interface should provide positioning layers supported by haptic feedback layers. The finding of the result can be applied to facilitate in developing adaptive user interface promoting user interface flexibility. The major contribution of this work lies on the improvement in the user experience, and satisfaction of blind people in performing common applications such as call, SMS, email, massagers, calendars, etc. a number of tasks were performed by blind people and these responses were recorded in the questioner and interview session. The statistical results relived that the internal reliability of item reflects acceptable scores. The Future research work should include the optimization of user interface adaptation, integration of wearable user interface, and interactive adaptation of cross devices corporation.

## Acknowledgments

This research work has been undertaken by the first author as a partial fulfillment of Ph.D. degree with the support of the Higher Education Commission (HEC) of Pakistan.

## References

[1] Damaceno, R.J.P., J.C. Braga, and J.P. Mena-Chalco, *Mobile device accessibility for the visually impaired: problems mapping and recommendations.* Universal Access in the Information Society: p. 1-15.

[2] Billinghurst, S.S. and K.-P.L. Vu, *Touch screen gestures for web browsing tasks.* Computers in Human Behavior, 2015. **53**: p. 71-81.

[3] Kane, S.K., et al. *Freedom to roam: a study of mobile device adoption and accessibility for people with visual and motor disabilities*. in *Proceedings of the 11th international ACM SIGACCESS conference on Computers and accessibility*. 2009. ACM.

[4] Kane, S.K., J.P. Bigham, and J.O. Wobbrock. *Slide rule: making mobile touch screens accessible to blind people using multi-touch interaction techniques*. in *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility*. 2008. ACM.

[5] e Silva, J.d.S., et al. *State of the art of accessible development for smart devices: From a disable and not impaired point of view*. in *Information Systems and Technologies (CISTI), 2014 9th Iberian Conference on*. 2014. IEEE.

[6] Hakobyan, L., et al., *Mobile assistive technologies for the visually impaired.* Survey of ophthalmology, 2013. **58**(6): p. 513-528.

[7] Crossland, M.D., R. S Silva, and A.F. Macedo, *Smartphone, tablet computer and e-reader use by people with vision impairment.* Ophthalmic and Physiological Optics, 2014. **34**(5): p. 552-557.

[8] Miura, T., et al. *Usages and demands to touchscreen interface: A questionnaire survey in Japanese visually impaired people*. in *Systems, Man, and Cybernetics (SMC), 2012 IEEE International Conference on*. 2012. IEEE.

[9] Strumillo, P., P. Skulimowski, and M. Polanczyk, *Programming Symbian smartphones for the blind and visually impaired*, in *Computers in Medical Activity*. 2009, Springer. p. 129-136.

[10] Chakraborty, T. and D. Samanta. *BlindGuide: An audio based eyes-free caller guide for people with visual impairment*. in *Intelligent Human Computer Interaction (IHCI), 2012 4th International Conference on*. 2012. IEEE.

[11] Leporini, B., M.C. Buzzi, and M. Buzzi. *Interacting with mobile devices via VoiceOver: usability and accessibility issues*. in *Proceedings of the 24th Australian Computer-Human Interaction Conference*. 2012. ACM.

[12] Akiki, P.A., A.K. Bandara, and Y. Yu, *Adaptive model-driven user interface development systems*. ACM Computing Surveys, 2015. **47**(1).

[13] Basu, A., et al., *A PC based multi-user Braille reading system for the blind libraries‖*. IEEE Transactions on Rehabilitation Engineering, 1998. **6**(1): p. 60-68.

[14] Blenkhorn, P., *A system for converting Braille into print*. Rehabilitation Engineering, IEEE Transactions on, 1995. **3**(2): p. 215-221.

[15] Blomquist, M. and P. Burman, *The WinBraille approach to producing braille quickly and effectively*, in *Computers Helping People with Special Needs*. 2002, Springer. p. 618-619.

[16] www.brailler.com., b.R.f.

[17] 1Dasgupta, T. and A. Basu. *A speech enabled Indian language text to Braille transliteration system*. in *Information and Communication Technologies and Development (ICTD), 2009 International Conference on*. 2009. IEEE.

[18] Kalra, N., et al. *Iterative design of a Braille writing tutor to combat illiteracy*. in *Information and Communication Technologies and Development, 2007. ICTD 2007. International Conference on*. 2007. IEEE.

[19] Lahiri, A., S.J. Chattopadhyay, and A. Basu. *Sparsha: A comprehensive Indian language toolset for the blind*. in *Proceedings of the 7th international ACM SIGACCESS conference on Computers and accessibility*. 2005. ACM.

[20] Lee, K.-F., H.-W. Hon, and R. Reddy, *An overview of the SPHINX speech recognition system*. Acoustics, Speech and Signal Processing, IEEE Transactions on, 1990. **38**(1): p. 35-45.

[21] Krajnc, E., et al., *A touch sensitive user interface approach on smartphones for visually impaired and blind persons*, in *Information Quality in e-Health*. 2011, Springer. p. 585-594.

[22] Preece, A., *An Evaluation of the RAY G300, an Android-based Smartphone Designed for the Blind and Visually Impaired*. 2013.

[23] Yong, R., *"VisionTouch Phone" for the Blind*. Malaysian Journal of Medical Sciences. **20**(5): p. 1-4.

[24] Borodin, Y., et al. *The HearSay non-visual web browser*. in *Proceedings of the 2007 international cross-disciplinary conference on Web accessibility (W4A)*. 2007. ACM.

[25] Mahmud, J.U., Y. Borodin, and I.V. Ramakrishnan. *Csurf: a context-driven non-visual web-browser*. in *Proceedings of the 16th international conference on World Wide Web*. 2007. ACM.

[26] Borodin, Y., G. Dausch, and I.V. Ramakrishnan. *TeleWeb: accessible service for web browsing via phone*. in *Proceedings of the 2009 International Cross-Disciplinary Conference on Web Accessibililty (W4A)*. 2009. ACM.

[27] Chu, C.-N., *Two dimension interactive voice browser for the visually impaired*. 2004: Springer.

[28] Ghose, R., T. Dasgupta, and A. Basu. *Architecture of a web browser for visually handicapped people*. in *Students' Technology Symposium (TechSym), 2010 IEEE*. IEEE.

[29] Wu, M. and R. Balakrishnan. *Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays*. in *Proceedings of the 16th annual ACM symposium on User interface software and technology*. 2003. ACM.

[30] Pirhonen, A., S. Brewster, and C. Holguin. *Gestural and audio metaphors as a means of control for mobile devices*. in *Proceedings of the SIGCHI conference on Human factors in computing systems*. 2002. ACM.

[31] McGookin, D., S. Brewster, and W. Jiang. *Investigating touchscreen accessibility for people with visual impairments*. in *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*. 2008. ACM.

[32] Nesbat, S.B. *A system for fast, full-text entry for small electronic devices*. in *Proceedings of the 5th international conference on Multimodal interfaces*. 2003. ACM.

[33] Guerreiro, T., et al., *From tapping to touching: Making touch screens accessible to blind users*. IEEE MultiMedia, 2008. **15**(4): p. 0048-50.

[34] Gamecho, B., et al., *Automatic generation of tailored accessible user interfaces for ubiquitous services*. IEEE Transactions on Human-Machine Systems, 2015. **45**(5): p. 612-623.

[35] Gajos, K.Z., J.J. Long, and D.S. Weld. *Automatically generating custom user interfaces for users with physical disabilities*. in *Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility*. 2006. ACM.

[36] Romero, M., et al. *BrailleTouch: designing a mobile eyes-free soft keyboard*. in *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*. 2011. ACM.

[37] Buxton, W., R. Hill, and P. Rowley, *Issues and techniques in touch-sensitive tablet input*. ACM SIGGRAPH Computer Graphics, 1985. **19**(3): p. 215-224.

[38] Kane, S.K., J.O. Wobbrock, and R.E. Ladner. *Usable gestures for blind people: understanding preference and performance*. in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2011. ACM.

[39] Shneiderman, B., *Designing the user interface-strategies for effective human-computer interaction*. 1986: Pearson Education India.

[40] Niranjan. *show-java*. 2015; Available from: https://github.com/niranjan94/show-java.

[41] Norman, D. User Experience (UX) 2017; Available from: https://www.nngroup.com/articles/definition-user-experience/.

[42] Park, D., J.-H. Lee, and S. Kim, *Investigating the affective quality of interactivity by motion feedback in mobile touchscreen user interfaces*. International Journal of Human-Computer Studies, 2011. **69**(12): p. 839-853.

[43] Park, Y.S. and S.H. Han, *Touch key design for one-handed thumb interaction with a mobile phone: Effects of touch key size and touch key location*. International journal of industrial ergonomics, 2010. **40**(1): p. 68-76.

[44] Plos, O. and S. Buisine. *Universal design for mobile phones: a case study*. in *CHI'06 extended abstracts on Human factors in computing systems*. 2006. ACM.

[45] Boren, T. and J. Ramey, *Thinking aloud: Reconciling theory and practice*. IEEE transactions on professional communication, 2000. **43**(3): p. 261-278.

[46] Bevan, N. and M. Macleod, *Usability measurement in context*. Behaviour & information technology, 1994. **13**(1-2): p. 132-145.

[47] Kaiser, H.F., *An index of factorial simplicity*. Psychometrika, 1974. **39**(1): p. 31-36.

[48] Shneiderman, B., *Designing the user interface: strategies for effective human-computer interaction*. 2010: Pearson Education India.

[49] Lewis, J.R. and J. Sauro. *The factor structure of the system usability scale*. in *International conference on human centered design*. 2009. Springer.

[50] Oliveira, J., et al. *Blind people and mobile touch-based text-entry: acknowledging the need for different flavors.* in *The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*. 2011. ACM.

[51] Akiki, P., *Engineering adaptive model-driven user interfaces for enterprise applications.* 2014, The Open University.

[52] McCarthy, J. and P. Wright, *Technology as experience.* interactions, 2004. **11**(5): p. 42-43.

[53] Holzinger, A. *Finger instead of mouse: touch screens as a means of enhancing universal access*. in *ERCIM Workshop on User Interfaces for all*. 2002. Springer.

[54] Buzzi, M.C., et al. *Exploring visually impaired people's gesture preferences for smartphones*. in *Proceedings of the 11th Biannual Conference on Italian SIGCHI Chapter*. 2015. ACM.

[55] Sandnes, F.E., et al., *Making touch-based kiosks accessible to blind users through simple gestures.* Universal Access in the Information Society, 2012. **11**(4): p. 421-431.