# Understanding, Evaluating and Analyzing Touch Screen Gestures for Visually Impaired Users in Mobile Environment

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**Abstract.** Smartphones usage among visually impaired users is growing in prominence and mobile phone providers are continuously looking for solutions to make touch screen interfaces more accessible to them. Key accessibility features for vision related impairment includes assistive screen reading applications like Voiceover (https://www.apple.com/in/accessibility/ios/voiceover/) in iOS or Talkback (https://support.google.com/accessibility/android/answer/6007100?hl=en) in Android which supports a variety of touch gestures for performing basic functions and commands. Our preliminary interactions with users from this community revealed that some of these existing gestures are ambiguous, difficult to perform, non-intuitive and have accuracy and detection issues. Moreover there is lack of understanding regarding usage of these accessibility features and existing gestures. In this paper, we address these challenges through set of three experimental exercises-*task based comparative evaluation, gesture elicitation and gesture performance* done with a group of 12 visually impaired users. Based on experimental evidences we pinpoint the exact problems with few existing gestures. Additionally, this work contributes in identifying some characteristics of effective and easy gestures for the target segment. We also propose design solutions to resolve users pain points and discuss some touch screen accessibility design guidelines keeping in mind different type of visually impaired users - *fully blind, extremely low vision and low vision.*

**Keywords:** Accessibility · Gestures · Assistive technologies · User centered design · Mobile user interfaces

## 1 Introduction

Touch based interfaces are extremely visually demanding and visually impaired users face difficulty in locating on-screen object in these phones. Absence of tactile feedback and physical buttons also plays a major deterrent for such users. Hence all smartphones currently provide assistive screen reading software as a prime accessibility solution to locate and read items on touch screen. These applications have inbuilt gestures to perform a given set of useful commands. However there are major challenges and issues with these screens reading software especially with the existing set of gestures. Some of these gestures are inconsistent and vary widely across platforms. For e.g. Talkback in Android uses mostly single finger swipe or circular gesture for a given


M. Antona and C. Stephanidis (Eds.): UAHCI 2015, Part II, LNCS 9176, pp. 25–36, 2015.
DOI: 10.1007/978-3-319-20681-3_3

function while Voiceover employs multi-finger gestures for same set of commands. This high inconsistency makes it difficult to develop consistent interaction language and gesture vocabulary for these users. Secondly, few of these existing gestures are highly ambiguous, non-intuitive and difficult to learn. Our initial interaction with some of the visually impaired users indicated that most of them were not using a large set of useful commands as they found gestures for those commands to be extremely difficult to remember and non-intuitive. The third major issue observed for the existing set of gesture was performance, accuracy and detection. For instance, gestures like circular movement for quick navigation in Talk back and two finger press hold in Voiceover were found complex to be performed by the users efficiently. Similarly, L-shape angular gesture in Talkback have poor detection due to high variation in angles and action speed, while some multi-finger gestures in Voiceover had finger detection issues by system because of difference in finger sizes or lifting of fingers. Apart from these challenges, few research work have been done to understand the accessibility and usability issues for such users and there is still lesser understanding regarding the usage of touch based phones by different segments of visually impaired users. Considering these challenges the following research questions were under exploration in this study –

- How effective are the existing touch phone gestures in terms of performance and intuitiveness for the users?
- Which are the most common errors that users commit while performing touch gestures and how can the gestures be designed to avoid those?
- What are the criteria for designing effective touch phone gestures for visually impaired?
- To what extent the visually impaired users rely on the haptic, sound and also partial visual feedbacks?

In this paper, we try to address these questions through a set of three experimental sessions done with a group of twelve users.

## 2 Related Works

Researchers in past have tried to work on improving interaction for *non-sight and non-visual browsing* of touch interfaces. Talking finger technique [5], Talking tactile Tablet [6], Touch ‘n Talk [7] were some of the earlier solutions which involved exploring touch screens through touch and providing feedback through speech. However these solutions were visually demanding as they required users to remember layout of the screens. Then there were few *eyes free interaction* methods been proposed which employed gestures to improve exploration of screen and performing basic functions. Sánchez and Maureira [8] developed a subway assistant for visually impaired users on desktop system which involved using directional gestures to perform basic operations. Shiri et al. [9] developed a gesture based accessible authentication method for visually impaired which used multi-tap gestures sequences as a password. Kane et al. [10] used accessible multi-touch interaction techniques for non-visual browsing which consisted of four basic gestures -single finger click, a second finger tap, multidirectional flick and L-select gesture for touch screen interfaces.

Researchers in the past have also tried to identify accessibility issues with the assistive screen readers. McGookin et al. [3] investigated the accessibility of touch screens for visually impaired people in which they revealed problems on the use of buttons as well as gestures. Leporini et al. [4] investigated the usability of Voiceover in IPad and pointed issues with gestures involved. Kane et al. [2] compared and identified the differences in preferences and performances of touch gestures among blind and sighted users.

Past research by Morris et al. [11] showed that gesture generated by user being more effective and preferred than those designed by designers. So, it is imperative that users are made part in the process of designing gestures. Our methodology is inspired from referent based elicitation technique suggested by Wobbrock et al. [1] and slightly modified by Kane et al. [2]. In this approach users are shown the outcome of the action and are asked to invent gesture if they want to execute that action.

## 3 User Study

The main objectives for designing the user study were

- To gain deeper understanding regarding performance and intuitiveness of existing gestures in assistive screen readers.
- To evaluate performance of new gestures as well as explore intuitive gestures for current and new set of command.
- Understanding the usage of current touch screens accessibility features among different types of visually impaired users-*mainly extreme low vision, low vision and fully blind.*

Based on our objectives, we conducted three different exercises with our target users. We started with an observation based exercise: *task based comparative evaluation* between two prominent assistive screen readers *Voiceover* in iOS and *Talkback* in Android. Based on insights regarding issues with existing gestures, next we conducted two experimental exercises: *Gesture Elicitation and Gesture Performance*.

**Participants.** All the experiments were conducted at three different computer training centers for visually impaired users. A total of 12 participants (2 female and 10 male, Mean Age = 31, S.D. = 9.56) were part of the overall study. All the users considered were computer literate and have the experience of using screen based reader application like JAWS, NVDA. 8 of participants had experience of using touch based smartphones and 4 of them used keypad based feature phones.11 of the participants were right handed while 1 was left handed. The duration of blindness also varied among participants with 3 being birth by blind, 5 early blind and 4 late blind(blind for 6–8 yrs.).

## 4 Task Based Comparative Evaluation

The key motivation behind this exercise was to observe and gather insights of two popular assistive screen readers: Voiceover and Talkback with regards to issues with existing gesture and other accessibility functions. It was a qualitative exercise and thus observations were made while users performed tasks and unforced errors were noted. Participants performed four representative tasks-*Opening an application (Navigation Task), Opening phonebook and making a call (Navigation task), Scrolling through messages and reading a particular message (editing task), Composing a message,* using Talkback in Samsung Galaxy S4 Device and Voiceover in IPhone 5S. A custom background application was developed to capture user's trails and measure gesture speed. Post these tasks, the participants were asked to answer a qualitative questionnaire based on their experience during the session to gather feedback and understand the issues faced.

### 4.1 Observations and Insights from Task Based Evaluation

*Performance of angular gestures:* Talkback in android uses nine shortcut angular gestures for a given set of commands in which we observed few performance issues. On several instances the gesture performed by users were not identified by the system. In one particular instance, a user performed the L-gesture for nine times to activate global context menu and an inverted L gesture five times before being finally recognized by system. The major reason was the flexibility system had for the angles of these gestures. Another reason was the speed of performing gesture. Many users felt irritated and mentioned the need for relaxation in angle detection.

*Need for Gestures for important function:* The current user interface is highly driven by visual metaphors and icons. It becomes very difficult for visually impaired users to interact with the overall interface through these iconic metaphors. A lot of difficulty was faced by users in performing some of the frequent tasks like calling or picking up a call, sending a message, selecting and deleting an item, cancelling an action, searching an item etc. For e.g. to pick a call in talkback user first has to locate the call icon and then do swipe gesture, for sending a massage user has to locate the send icon and then double tap. Users also mentioned the need for shortcut gestures of useful functions like controlling of speech rate, frequently used punctuation marks etc. Based on these insights we identified some of the commands which could be executed through set of gestures and these commands were included for gesture elicitation exercise conducted later.

*Errors and Ambiguity within Existing Gestures:* As part of the task based observation few major unforced errors were observed. For e.g., there were lot of instances where two finger swipes got recognized as single finger double tap action which resulted in opening of random application by the user unintentionally. One of the users mentioned how he locates a blank space on screen and then double taps to avoid his double taps getting recognized as single tap and corresponding undesired event. There was another conflict found between the single finger double tap which is used for opening an application and single finger triple tap which is used for magnification for low vision users.

## 5 Gesture Elicitation and Performance

The second exercise done with the users was *command based gesture elicitation*. As part of the experiment protocol users were asked to invent 2 different gestures to execute the given command. Afterwards we asked users to perform each gesture they

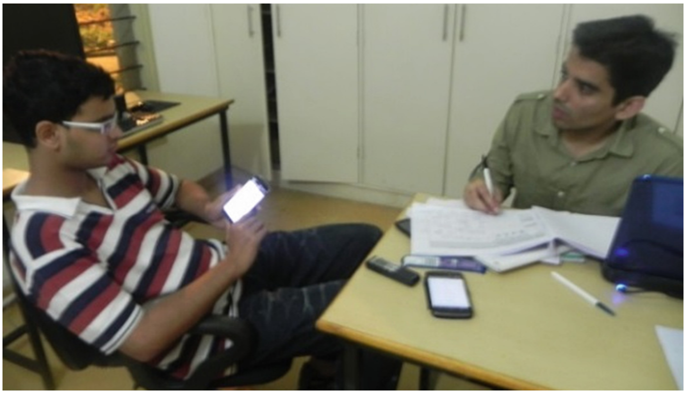


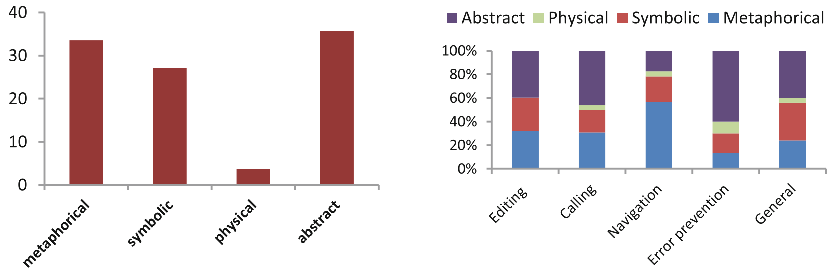
**Fig. 1.** Experimental setup

invented thrice. A custom recording application on Android was developed with a blank screen for drawing gesture on which users' trails were recorded and gesture speed was measured. The haptic feedback was provided to make users aware of the area in which they need to perform their gesture. A Bluetooth client application was built to run on another device which helped experimenter in capturing screenshots for each of the user trials. List of twenty five commands including both the existing and new set was selected for elicitation. Commands were divided into five different contexts: Editing (*cut, copy, paste, save, select, enter, read from top*), Error prevention (*cancel, back, delete, undo*) Navigation (*open, close, next/previous, scroll, pause/play, search*) Calling Functions (*make a call, reject, accept, put on hold*) and General Actions (*go to home screen, recent apps, show, unlock*). After each trial users were asked the reason behind inventing each of the two gestures. Through the gesture elicitation we tried to answer questions regarding intuitiveness and easiness of gestures. To measure these variables user were asked to rate the two gestures they invented on scale of 1 to 7 (with 1 = strongly disagree, 7 = strongly agree) in terms of easiness (The gesture I invented is easy to perform) and intuitiveness (The gesture I invented is good for its intended function) (See Fig. 1).

The third experiment was *gesture performance*. This exercise aimed to answer questions related to ease of performance of existing and new gestures, and identify characteristics of effective and easy gestures for visually impaired users. We included set of different shapes, symbols and characters for evaluating the gesture performance. As part of the protocol [1, 2] users tried the gesture once for training and they repeated each gestures thrice and screenshots were captured. After each category trials users were asked to comparatively rate gestures in a given category. We tried to measure the ease of performance of the gesture user performed (the gesture I did is easy to perform) scale of 1–7 (with 1 = strongly disagree, 7 = strongly agree).

### 5.1 Results from Gesture Elicitation

Each participant invented 2 gestures for each of the 25 commands. We collected a total number of 300 gestures from the six users. In terms of easiness user rated the overall




a) b)

**Fig. 2.** (a) Percentage of gestures in each nature category as defined by Wobbrock [1] (b) Percentage of each gestures type in the given context of commands

gestures as [mean = 6.39, S.D. = 1.1], while for good match users rated their gestures as [mean = 6.12, S.D = 1.09].

**Nature of Gestures:** Wobbrock [1] has defined the gesture taxonomy based on the nature of the gesture. According to his definition a gesture could be divided into four different categories based on its nature: *Metaphorical, Symbolic, Physical and Abstract*. For grouping our gestures we took into account the user rationale behind each of the invented gestures. Most of the gestures elicitated belonged to abstract, metaphorical and symbolic categories (Fig. 2a). Extremely less gestures belong to physical category as touch gestures doesn't give freedom for the user to perform real world physical actions which is more in case of the air and motion gestures. Most abstract gestures included lot of characters suggested by users for performing a given command. As observed from Fig. 2b users preferred more metaphorical gestures for navigation commands which could be due to large set of users preferring swipes, taps for frequently used navigational actions. A large number of abstract gestures and symbolic gestures were part of general context commands (like going to home screen, read notifications etc.) as they had less frequent usage and were of specific and complex nature. So users might find difficult to comprehend metaphors for these actions.

**Easiness and intuitiveness.** User rated the metaphorical gesture they invented highest both on easiness [mean = 6.49, S.D. = 1.01] and good match [mean = 6.52, S.D. = .74] while symbolic gestures were rated lowest on easiness [mean = 5.68, S.D. = 1.5] and physical gestures lowest on intuitiveness [mean = 5.71, S.D. = 1.38]. However it was interesting to note that user rated the same symbolic gestures good on intuitiveness [mean = 6.17, S.D. = 1.43]. The reason could be since these gestures were derived from mental imagery they felt highly intuitive to them but they could have faced the difficulty while drawing the symbols and representing them. For abstract gestures user rated equally well both on intuitiveness [mean = 6.38, S.D. = .82] and easiness [mean = 6.42, S.D. = .94].There was also significant difference found in terms of easiness ($p < .05$, $n = 178$) between metaphorical and symbolic gestures.

**Role of user's Cognition for Elicitated gestures:** Gestures suggested by users were based on visual imagery, alphabets, braille characters, abstract metaphors etc. For e.g. in case of editing commands many users suggested drawing letter V for pasting (inspired from Ctrl + V paste command), X for cutting (inspired from Ctrl + X cut command) etc. Many of the users also suggested using the first letter of command name as gestures. For e.g. some users suggested using letter H for hold function, letter D for delete, letter N for reading notifications etc. One of the reasons behind the abstract nature of gestures suggested could be result of user being able to think more analytically than metaphorically. Role of cognition could also be understood from differences in gesture suggested by people blind by birth and late blind. People who were late blind suggested many symbolic gestures driven from visual imagery and symbolic learning while people who were early blind suggested mostly metaphorical or abstract gestures like swipes, taps, flicks etc. Less amount of symbolic gesture by former could be attributed to their lack of visual imagery formed because of their early blindness. Some users also suggested using *braille characters* as gestures for few commands. This was also relevant as early blind users were unaware of the forms of roman characters.

**Agreement Scores.** An agreement score, *At*, reflects in a single number the degree of consensus among participants. Wobbrock [1] provides a mathematical calculation for agreement, where:

$$A_t = \sum_{Pi} \left( \left| \frac{Pi}{Pt} \right| \right) \tag{1}$$

In Eq. 1, $t$ is a task in the set of all tasks $T$, $Pt$ is the set of proposed gestures for $t$, and $P$i is a subset of identical gestures from $Pt$. The range for $A$ is [0, 1]. Figure 3, illustrates the agreement for the gesture set developed by our participants.

In general there wasn't any influence of the context of commands on user's consensus for gestures. There was more consensus for few general actions commands (notifications and home screen) and navigation commands (open, next scroll etc.) while very little consensus for error prevention commands (cancel and delete).

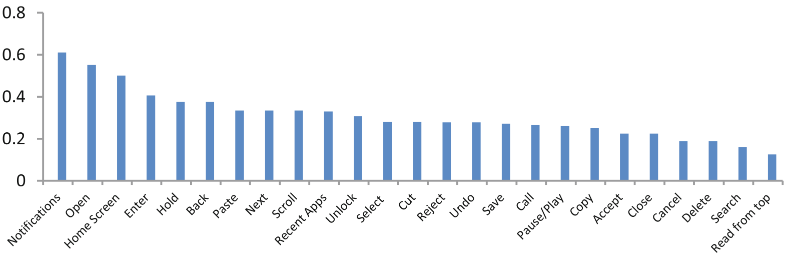



**Fig. 3.** Agreement scores for all the 25 commands

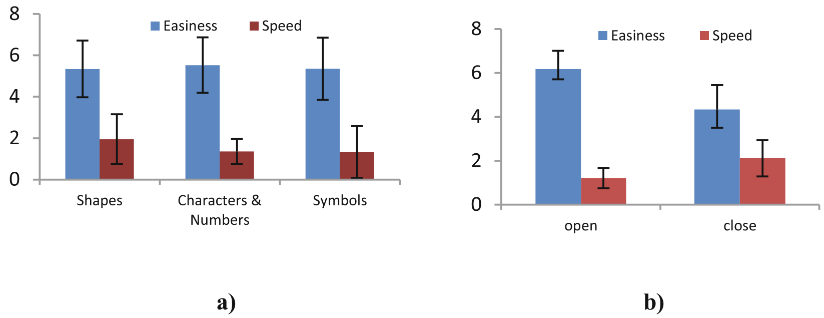



**Fig. 4.** a) Participants' easiness and speed ratings of shapes, characters and symbols. b) Participant average easiness and speed ratings of open and closed gestures. Error bars indicate +SD to - SD

### 5.2 Performance Evaluation of Gestures

Six users were part of the gesture performance study. A total of 19 gestures (including all shapes, symbols and characters) were evaluated for gesture performance. Some of the characters and symbols were unfamiliar for two participants who were birth by blind. Total number of gestures collected from 6 users was 318. Overall users rated all shapes, characters and symbols equally on easiness ratings with average being 5.34{S. D = 1.36},5.53{S.D = 1.33} and 5.35{S.D = 1.49} respectively (Fig. 4a). However there was difference in terms of gesture speed with user taking more time in drawing shapes [mean time = 1.96 s, S.D. = 1.2] than characters [mean time = 1.36 s, S. D. = .603] and symbols [mean time = 1.32 s, S.D. = 1.25] (Fig. 4a).The high standard deviation for gestures speed for symbolic gestures could be because some blind users taking more time to learn and draw few symbols with which they were not familiar. Based on the instances collected we evaluated the performance of gesture in terms of openness, continuity and curvature.

**Open V/s Closed.** For our comparison we considered open gestures as those where the initial starting point and end point doesn't meet for e.g. an arc, greater or less than symbol, letter S. We considered closed shapes as those where staring and end points meet together e.g. a square, circle, 8. Mean easiness for open gestures was 6.17 (S. D. = .84) and for gesture speed 1.214 (S.D. = .46) while for closed shape gesture mean easiness was 4.33 (S.D. = 1.11) and for gesture speed 2.12 (S.D. = .83).The independent t-test between both factors (easiness and speed) sets confirmed the significant difference ($p < .001$, $n = 80$) between them. This confirmed that closed gestures are indeed difficult in comparison to open shapes for a visually impaired person and should be avoided to be used as gestures.

**Continuous V/s Discontinuous:** During our qualitative discussion some users mentioned that they find drawing gestures where they need to lift their finger extremely difficult as they could lose track of reference point from where they need to restart drawing. Based on these statements we considered comparing discontinuous gestures in comparison to continuous gestures. For our comparison we considered continuous gestures as those where user could draw the complete gesture without lifting their finger e.g. letter N, S etc. We considered discontinuous shapes as those where user need to lift their finger for drawing the complete gesture e.g. letter A, E etc. Mean easiness for continuous gestures was 5.64 (S.D = 1.45) while for discontinuous gesture mean easiness was 5.1 (S.D. = 2.09).However the independent t-test didn't indicate the significant difference between the two data sets.

**Angular Gestures:** We considered all the L shapes, greater and less than symbols as part of evaluation of angular gestures. The mean easiness score for these gestures was 5.98 {S.D. = .95}.while average gesture speed was 1.17 s {S.D. = .338}.These results showed that these gestures are extremely easy to perform. We also analyzed all sets of gestures through MATLAB analysis which clearly showed the large variation in angles and sizes of these gestures.Thus the problem doesn't lie in the performance of these gestures but in the recognition of these gestures. Hence it is important that system model the large variations that are possible in these angular gestures for effective implementation of these gestures.

**Multi-finger Gesture Evaluation.** We evaluated the performance of multi-finger swipes, taps etc. in comparison to same gestures performed with single finger. Our results indicated that there was no significant difference found between the easiness of multi-finger gestures and the single finger gestures. Mean easiness score for multi-finger gesture was 5.47{S.D. = 1.2} while mean easiness score for single finger was 5.68{S.D. = .96}.One of the users mentioned multi-finger gestures sturdier than single finger gestures. However some performance issues were observed with multi-finger gestures like lifting of fingers, some finger not being detected because of differences in heights of the fingers. Thus one of the key insights was that though multi-finger gestures are easy to perform there are accuracy and detection issues as number of finger increases. So, one should prefer avoiding multi-finger gestures for frequently used commands.

## 6 Discussion

The three experimental studies discussed has helped us in gathering lot of insights regarding the use of assistive screen readers in case of touch based smartphones. We have discussed some of these insights that we gathered below:

### 6.1 Location of Gestures

We performed MATLAB image analysis on the user screenshots gathered from gesture performance to understand the preferred gestures location for drawing gestures by the users. The analysis indicated the user preference tending towards left top portion and all edges of the screen (which could be attributed to most users being right handed).The reason behind preference for edges could be due to the hard tactile cues the sharp edges of the smartphones provides from which these users can draw some reference. Another insight that we gathered was the user preference for performing gesture in particular location of screens. For e.g. one of the user suggested tapping in left and right corners to perform a given command. These insights could be really helpful in positioning visual elements on screens for the visually impaired users.

## 6.2 Gesture and User Type

*Duration of Blindness:* The duration of blindness had an impact on both gesture performance and elicitation. During gesture performance most users who very early blind couldn't draw many symbols or characters. They even faced difficulty in drawing one or two shapes. In gesture elicitation users who were blind by birth mostly preferred gestures like swipe, taps, flicks etc. and very less gestures influenced by visual imagery as it was difficult for them to imagine different visual shapes. Contrary users who were late blind came out with gestures inspired from lot of visual imagery which was easy for them to visualize. These insights provide pointers while deciding a uniform gesture vocabulary for the target segment.

*Low Vision V/s Fully Blind:* Most of the current assistive applications cater to fully blind situation or eyes free interactions and ignore how extremely low vision users uses them. The current user interface (UI) for most of the applications has smaller fonts, bad visual contrast and lot of small visual icons which makes difficult for low vision users to use them. During our exercises with extreme low vision users who could slightly make out difference in elements on screen it was observed that accessing and interacting with the UI was extremely difficult for them because of high visual demands. Thus it becomes imperative that designers understand these issues and build simplified UI with minimal visual demands for these users to access them easily.

## 6.3 Design Suggestions

*Effective gestures for visually impaired users:* Gestures which require users to come back to the starting point or lift their fingers should be avoided. One should consider gestures with open shapes and which are continuous in nature. Designers should avoid gestures which require some particular angles to be made by user as there could be performance and implementation challenges. Otherwise system should be modelled such that it allows large variation in sizes and angles.

*Customizable gesture sets:* Designing a uniform gesture vocabulary for visually impaired users would be an ideal solution but not seems feasible because of large variation in terms of easy and intuitive gestures among types of visually impaired users. Therefore one needs to build a customizable set of gestures which could cater these differences and would allow users to be able to choose gestures based on their preferences.

*Use of corners and edges for positioning UI element:* Since the edges and the corners of screen are easily accessible because of strong tactical cues, one should use them for positioning essential UI element while designing touch screen applications for visually impaired. This would actually allow exploring and skimming contents quickly without unforced errors.

*Quick and Easy navigation:* The current navigation and exploration in touch screens is sequential in nature which could be unnecessary tedious and irritating for users. The problem is more prevalent in case of interacting through web pages. Thus need for the designers is to device a system of non-sequential ways of navigation and shortcuts for skimming content quickly for touch based smartphones.

*Designing touch applications for extreme low vision and low vision:* The new challenge for designers is to make their applications accessible to extreme low vision and low vision. The accessibility features need to provide flexibility with regards to change of UI for making it more accessible to these users. Large target sizes, simplifying the UI by removing unnecessary functions, replacing small icons with large buttons, high visual contrast to differentiate between elements etc. are some of the ways designers could try to make their application more accessible to these users.

## 7 Conclusion and Future Work

This research started with open ended discussions with the visually impaired users to understand their pain points in using various features of smartphone. We received few direct feedbacks from these users such as their difficulties in accessing the UI elements on the screen, speed of talk back responses etc.. They also suggested including few gestures for certain task that they perform very frequently. Based on the evaluation study, we proposed the design suggestions for few existing gestures as well as suggested new gesture for certain commands. We also made touch screen accessibility design guidelines keeping in mind different types of users - fully blind and extremely low vision. As part of the next step in research we have already implemented few prototypes of the proposed gestures. The plan is to perform the comparative evaluation of these new gestures and modified gestures through experiments. We would plan to report the improvements in terms of accessibility for the target user group through use of our solutions.

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