Chapter #

ELICITING USABILITY FROM BLIND USER MENTAL MODEL FOR TOUCH SCREEN DEVICES

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Abstract: A novel mental model of born blind users for touch screen devices to aid software developers in designing and building better usability applications for blind users is presented. The work of Kurniawan was the basis to examine the mental model of blind users. A user case study was carried out to assess the subjective mental model of users in regards to application of usability. This revealed that two stages: listening and interaction are used to facilitate the development of the Kurniawan mental model. This paper also suggests twelve usability features that can be added to facilitate the design phase of the system.

Keywords: Blind User, Heuristics, Mental Model, Smartphone, Touch Screen, Usability

1. INTRODUCTION

In spite of the authority of the human sensory system, the insight of the person is supplemented and enriched by past experiences developed by relationship with others. Without this ability, s/he will lack understanding of a particular situation. In the field of cognitive science, these perceptual relations are referred to as “mental models” [12]. The field of Human-Computer Interaction (HCI) has adopted and adapted these concepts to further the study in the field of usability [6].

When software developers create new products or applications, they are articulating ideas that they deem will speed up specific end-user experiences. The idea is known as a “conceptual model” and when suitably utilized in the product construction, it will aid in complementing a mental model that typical end-users have and acknowledge [32]. Products that are not proficient to make this connection consistently and spontaneously are typically perceived by end-users as unwieldy or perplexing since the users have no means to associate or envisage the experience.

Usability is the extent to which specific users can use a product to their satisfaction in order to effectively achieve specific goals in a specific context of the user [10]. Usability is strongly tied to the extent to which a user’s mental model matches and predicts the action of a system [6]. By and large, accessibility and usability are addressed at the end of the construction process of the software which often involves major amendments to it. To evade this, it has been recommended that it should be dealt with positively at the preliminary stage instead of retroactively after testing [14]. Thus the usability features should be incorporated at the requirement stage of the software development cycle. For the novice developer, it will be difficult to analyze the usability functionalities for a blind user unless s/he knows the mental model of blind users in interacting with the touch screen device. The designing of a mental model for blind users is a challenging task. Some research has explored the blind users’ mental model and there is a necessity to give more focus on this area to ease the usability problems that blind users continue to face. As a result, we embraced a bottom-up approach based on fieldwork observation (for proposing a mental model) to depict a set of scenarios representing usability issues that have consequences on the final software architecture [2], [11]. Our research purpose is to derive possible usability features of the mental models of blind users of touch screen devices. Furthermore to explore and modify these models pertaining to the touch screen environment and their strategies in dealing with the device.

2. MENTAL MODELS

Kenneth Craik in 1943 was the first to invent the “Mental Model” theory [22]. He declared that the mind predicts the future action and reactions in advance by making a miniature dimensional model. The mental model can also be defined as how our mind represents an event/object to predict the future outcome (Davidson *et al.*, 1999), [17], [19]. [24] affirmed that the mental model is indeed indispensable for designers since it reflects the user’s insight of what the system is confined to, how it works and why it works in that way. In 2002, Puerta-Melguizo *et al.*, [25] asserted that the content and structure of the mental model spur on how users interrelate with the system application. It avoids the interaction problem arising between the user and the computer by removing the unconstructive feelings towards the system.

Little research has been conducted on the mental model for blind users. The work on mental model for blind user by [20] was focused on the challenge faced by the blind user using assistive technologies when browsing the web. The study found that the mental model of a blind user as a "vertical list" and that they perceive all information in a web page as single column like structure. In this case, the blind user will remember the sequence of interested items. The web page having huge information has to memorize a large set of items which is a burden for the blind user mental model. Furthermore, by converting 2-d information in a web page into a single columnar list, many navigational hints would be lost. Due to these factors, usability is achieved after spending more effort and time by a blind user as compared to the sighted user [3], [29]. Another study on the mental model by Takagi *et al*., [30] confirms that the blind user consider the information as a vertical list of online shopping web sites. They initiated the searching process based on their own scheme to speed up the process.

Some research has also been undertaken in the blind user model that required a more thorough understanding of the blind user's behaviour with the system. The standard model of Kurniawan & Sutcliffe [16] was studied because they investigated the blind user's mental model of the new window environment. He tested blind users in three processes, namely: exploration, task-action and configuration. In the exploration stage, the user first explored the desktop to see what applications are available. In the next stage, the user created another loop of planning how to interact with the system and executing the task. At the last stage, the user configured the system if needed when comfortable with the application.

Kurniawan *et al*.'s model [16] is modified by Saei *et al*., [26] to include more components such as: skill based, knowledge-based, domain user expert and system help to minimize the gap between the developer and the blind user. One of the important observations from our study is that neither Kurniawan nor Saei concern themselves about the action performed in each process of the mental model. Most of the traditional usability such as help, feedback, error prevention were based on what they think and how they handle each situation. No usability is elucidated for what action was performed for each stage of the mental model. Without understanding what action will be performed for the different stages, it will be difficult for developers to understand the exact functioning of the mental model. This is one of the major motivations for us to conduct this study.

3. TOUCH SCREEN USABILITY

The work of Kurniawan [16] gave an idea about how a blind user thinks and acts based on cues given by screen readers using desktop computers. Touch screen interaction differs from the interaction using a desktop screen reader in three ways. Firstly, it facilitates one to interact directly in a significant way than indirectly with a mouse or touchpad. Secondly, it can be held in the hand without requiring any intermediate devices. Finally, touch screen interaction can also be performed through voice-activated search tools such as Siri or Vlingo. The distinctive features and characteristics of touch screen based Smartphones that makes usability evaluation a demanding process are: (1) they have a small screen size despite the fact that they still have to display large amounts of information, (2) the buttons of the device generally have more than one function, and (3) the devices have limited processing and memory capabilities [18].

Another reason is that the interaction in touch screen between the sighted to blind user varies using touch screen. Generally, the sighted user uses dynamic layout and identify the items through vision. But the blind user uses static layout where s/he has to flicker to identify the items. As a consequence, usability changes for the blind user and therefore the mental model should be adopted to derive their usability.

From the literature, we found that the Kurniawan mental model for blind users [16] is based on a study carried out for screen readers only and not for touch based devices. Not only that, the processes studied concerned: exploration, task action and the configuration processes. However, our user study for blind touch screen users reveals that each process is not executed in a single step. It consists of multiple stages. Therefore, this study will extend the previous works by studying the stages available in each process to propose an updated, more universal and thus an enhanced mental model [7]. Subsequently, factors affecting these stages will be studied to elicit usability features to facilitate the design of the new system.

4. EXPERIMENT

The user study was carried out to elicit the mental models of the blind user when interacting with the touch screen based smart phone through audio and haptic feedback. We recruited around seven blind participants with an average age of 35 years. All participants have enough experience of using mobiles with screen readers. None of the participants, however, have experience of using a touch screen mobile. Since the cohort size is small, we conducted on average about 8.5 trials per participants. *All* users have English as a second language (L2). A Smartphone running our prototype generates the speech according to Android development code. The prototype was deployed on the Samsung Galaxy S2 running the Android Ice Cream Sandwich OS touch based Smartphone and tested with the blind users.

The mental model literature suggests that if the system is too complex such as web and touch screen devices without prior training, a mental model is elicited (Zhang, 2008). We adopted the same strategy.

We conducted Verbal and Hands-on Scenario in which the user is required to perform a series of tasks to achieve the target [28]. The user is prompted to think aloud during the experiment. The user has to answer several questions pertaining to hands on the task using the system. It helps the investigator to extract the usability problem they faced.

The blind users were given the target name. The audio cues were given to reach the target. The blind users used these audio cues in order to reach this target. On pressing each target chosen by the blind user, the audio cue informs the name of the target. The blind user has to repeat this task until they reach the desired target. The mental model and usability are elucidated based on observation and discussion with the blind user. Some of our findings are supported by the literature which is mentioned appropriately.

5. EXTENDED MENTAL MODEL

The study observed that a blind user for every exploration, task action and configuration process, adopted two stages of strategy to acquire the target: listening and interaction. In the listening stage, a blind user listens to the audio cues to navigate. Based on the listening comprehension, interaction took place. This activity is iterated until the target is reached. Each stage of the strategy based on our understanding, in a developer point of view is explained.

The process of listening is divided into: listening, hold in memory, build the images, search in their database, retrieved, compared, test the image and execute the task. The interaction technique will be faster if the image was already stored. Hence it is imperative for developers to use a common vocabulary for effective interaction between the blind user and the device [7].

The perception of the image may be different between the blind user to the sighted user. But it does not affect the quality of interaction. For instance, the image form for the word ‘tiger’ will be the same for all sighted users but vary for each blind user. Although it varied widely, based on their own individual perception, the blind user would proceed to the next level.

According to physics, interaction is a transfer of our energy from human to any device. In the exploration process and task action process, interaction is the next stage after listening. This interaction occurs through gestures such as touch and flickering in touchscreen devices. When a blind user has performed the interaction, he waits for feedback. If feedback is provided, the user proceeds to the next task. The unexpected feedback cause the user to be stuck from proceeding any further. If the user did not receive the feedback, the user will repeat the task. The application will be terminated if the user incorrectly presses the close button [7].

6. USABILITY ELUCIDATION

The user study reveals that the listening and interaction stage is either strengthened or weakened by many usability features. In this extended paper,more components are accommodated for listening in support of listening comprehension(LC). Thus, the listening stage is dependent on audio features, listener characteristics, speech synthesizer and text characteristics. The interaction stage is influenced by gesture, orientation, content and sub-content features. The other features such as user characteristics and environmental factors overlap both the stages if stimulated. The usability features are discussed with their metrics.

6.1 Audio

Audio is the main component for blind users to listen to. The source of audio may be from the environment or the device itself. While the ambient sound from the environment may hinder the interaction, the audio from the device, however, facilitates the interaction. Controlling the audio such as the volume [1] stop, pause and repeat what they listen to determines the effect of the listening.

6.2 Speech Synthesizer

The blind users receive the information aurally. While receiving the information, there is a chance of passing the erroneous message to the user through a speech synthesizer. Thus, choosing an intelligent speech synthesizer is a daunting task. This section deals with the usability problem that the blind user will face while listening to the audio due to the speech synthesizer.

6.2.1 Type of synthesizer

The type of synthesizer has substantial impact on the quality of the output speech. Natural speech is more intelligent than synthesized speech [23]. The compressed synthesized speech is more intelligible than uncompressed natural speech.

6.2.2 Speech rate

The L2 listener has more comprehension with a low speech rate compared to a higher speech rate.

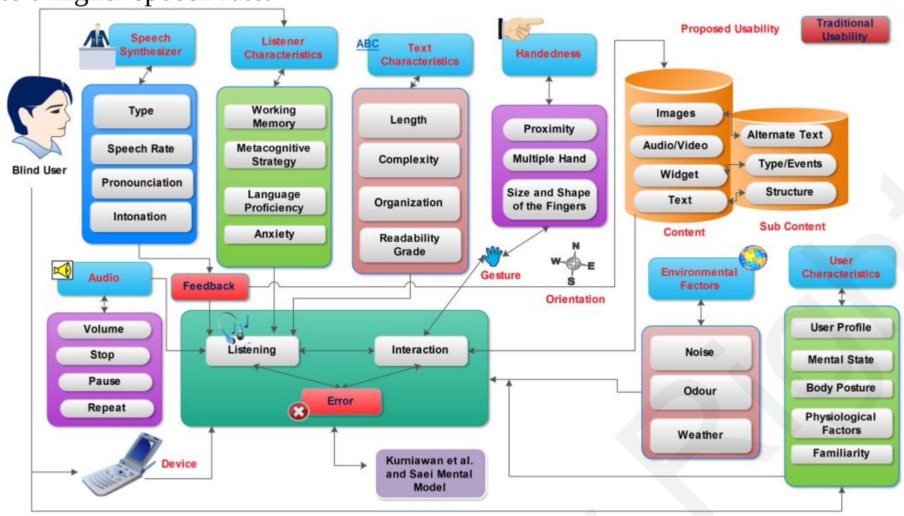

Figure #-1. Proposed mental model with elucidate usability and its metrics

6.2.3 Intonation

Accent: It identifies the person is from regionally or socially by the features of pronunciation [5]. Familiar accents are easier to understand than an unfamiliar accent. For instance, it may be difficult for an Arab user to comprehend a British or Amercian English accent than an accustomed Indian English accent.

Phrase: The natural speakers often break up sentences into several phrases, which can be articulated with pausing. Sometimes punctuation can be misleading (Table #1) and sometimes can serve as a guide.

Table #-1. Syntactic Phrases

Punctuation	Syntactic Parse
(A+B) * C	A plus B star C
We saw Peter, and Mary saw Scott	We saw (Peter and Mary) saw Scott

Melody: It refers to the patterns of tones with which a phrase, sentence or paragraph is spoken. The speech synthesizer has a small taxonomy of melodic patterns. It has the limitation of uttering only assigned patterns.

6.3 Listener Characteristics

While considerable individual difference factors may affect both native language (L1) and L2 listening comprehension, this review covers only the subset of factors deemed by our participant (L2) as relevant to the question of difficulty of listening passages on our prototype. The factors discussed here include working memory capacity, the use of metacognitive strategies, language proficiency and experience with the L2 and anxiety.

6.3.1 Working memory capacity

It refers to those who are most competent to the presence of mind, attentive and understand easily what they have listened to and have strong provisional storage. The comprehension correlates with greater working capacity [9].

6.3.2 Metacognitive Strategies

The L2 listener having good metacognitive strategies – those who are aware of and use effective strategies shows better listening comprehension [31].

6.3.3 Proficiency

It involves familiarity with non-native language's vocabulary size and phonology; amount of exposure to the language and background information about, scheme, structure, text and culture.

The listener's ability to correctly decipher the phonology and vocabulary improves with an increase in proficiency and experience. Prior experience in the relevant study compensates for mishearing or encountering unfamiliar words, which can increase comprehension.

6.3.4 Anxiety

When a listener feels the message is too complex or difficult to understand, concentration falters and comprehension declines. Anxiety mostly occurs when the listener is trying to sort conflicting information, listening to illogical passage(s) and also to new information. It causes a negative impact on comprehension.

6.4 Text Characteristics

Although there are many factors which influence the L2 listener, our study is based on the factors which influence the usability of the system. The factors discussed here include the passage: length, complexity, type, organization, authenticity and readability grade.

6.4.1 Passage length

The passage length has been defined by the researchers with a number of measures such as syllabus/second, duration, number of words or sentences. This section is classified into passage length, and redundancy.

Passage length: The research reveals that the longer length passage has some difficulty in LC, but the effect is weak. Since the user has to listen to the keywords of the sentences and then build-up the sentences on their own.

Redundancy: Repetition of information increases the LC consistently but it depends on the type of redundancy such as whether the sentence is paraphrased or an exact repetition. It is supported by Sasaki [27].

6.4.2 Complexity

Passage complexity is referred directly to dissimilar properties such as syntactic structure, pragmatic information and directness.

Syntatic feature: Newly listened to vocabulary have a detrimental impact on LC. Negatives (negative prefixes like '–un' and negative markers like 'not') have higher impact than positive keywords.

Pragmatic information: Inclusion of pragmatic information such as idioms and culturally specific vocabulary decreases the LC among L2 listeners which was proved by Sasaki [27].

Directness: The sentence with implied meaning is more difficult for the L2 low proficiency listener.

6.4.3 Organization

Passage type: The passages about familiar topics are easier for L2 listeners than the passages about unfamiliar topics.
Orality: It is the extent to which a passage contains more spoken words (non-academic) than written languages (academic) words [15]. The passages that are more oral are less difficult to understand for L2 listeners. Such passage have more disfluencies, greater redundancy and simpler syntax (not grammatical).
Coherence: It involves the appearance of logicality and relevance in a passage. The less coherence between the passage the more they seem off-topic or tangential.
Discourse Markers*:* Discourse markers such as *but*, *however*, increases the coherence of the sentences. Thus, it improves LC among L2 listeners as mentioned in [13].
Readability grade:
The reading scale is the ease in which the text can be interpreted and comprehended. This scale is used when the listening user are kids [4].

6.5 Handedness

Hand movements are very crucial for gesture based interaction such as touch and flick. Mostly a finger is used for interaction. Often, the index finger is used for interaction. Sometimes if the proximity of a finger to a device is narrow, there is a chance for other fingers to hit the surface of touch screen leading to execute unexpected events. Generally, a blind user seldom uses multiple hands for interaction.

The study reveals the size and shape of the finger also play a vital role in the exploration process. The bigger size finger will hit many targets simultaneously which will lead to mayhem during navigation. If the shape of the finger was not normal then it may hit the wrong target on the touch screen. As a result, developers should take care of the target size, avoiding the target to be placed in crowded areas and keeping the padding size normal to facilitate easy exploration.

6.6 Contents and Sub-contents

The contents can be classified into: text, images, audio/video and widgets. The structure of the text was already discussed in section 6.4. The image information was delivered to the blind user through alternative text. It needs the advice of a domain expert to deliver precisely [26].

Delivering video is identical to audio delivery which was discussed in Section 6.1. Widgets are the interaction point in the touch screen to operate the given kind of data or application. The interaction varies with the types of widget such as buttons, text input, list and menus. The orientation of the widget also causes an impediment for interaction for blind users. At present, blind users are able to interact only with the textbox and a button. Therefore, more study is needed possibly in the future for direct exploration of different classes of widgets.

6.7 User Characteristics

User characteristics determine the effectiveness of listening and interaction. User characteristic such as age affects the exploration process. The rate of hand movement and the preciseness of hitting the target were decreasing with an increase in age.

Mental state affects the rate of the exploration process. While positive mood enhances the process, negative mood retards it. At some posture, the body may assume a great variety of shapes and positions. If the body and mind are not stressed, comfortability can be achieved and hence the exploration phase will take place faster.

Physiological factors such as illness, stress and fatigue will cause discomfort during the interaction. A high level of exposure (familiarity) enhances the interaction level.

6.8 Environmental Factors

Environmental factors such as: noise [8], odour, or weather induced sweating reduce the speed of exploration with the devices. As environmental factors cannot be controlled, the developers can take cautious steps to minimize the accessibility burden.

7. DISCUSSION

The user evaluation of the obtained data strongly confirms the hypothesis that usability can be elucidated through the action performed on each process of mental model.

The proposed mental model is the extension of existing Kurniawan and Sutcliffe's [16] mental model for the blind users with respect to touch screen technologies. The proposed conceptual mental model includes listening and interaction components which support each stage in the mental model. These components are necessary in order to assist the developers to minimize the gap between the developers and the blind person.

The mental models are always unstable [21]. In addition, the added components such as listening and interaction are stable. The techniques used for these components are unstable. The interaction with the system differs with the advancement of technology. For instance, the keyboard is used in desktop computing to navigate through the items. On the other hand, swipe gesture is used in touch screen technologies. Below we discuss some findings derived from this study.

- **The usability elucidated with the mental model is less than 100 per cent of the most complex applications.** These differences are due to the fact that the complexity of usability calls for the proper identification of usable features in the affected parts of the system. The usability elucidated in this paper is universal in nature and can be applied for all the 'apps' (applications) if needed. Specific usability problems can be identified with stackholders and users.
- **Text characteristics are good. But users are not able to comprehend what was spoken**. This impediment is due to the speech synthesizer. The speech synthesizer used by the user should be evaluated based on the usability problem such as: what type of synthesizer is used, speech rate, understandable pronunciation and suitable intonation (see Figure 1). Another impediment is listener characteristics. If the user has poor working memory or less metacognitive strategy or poor proficiency in the spoken language or is anxious due to some reason (see Figure#1), the listener (user) has to be excluded from testing or to accommodate some features in the application to alleviate this problem.
- **Some of the elucidate usability features did identify the testing condition of usability.** For instance, developers need to think about the problems faced by blind users during the different types of weather and climatic conditions. For example, if developers feel that noise due to thunder will have an adverse impact on the interaction, than an audio control such as volume increase and/or decrease can be included in the software requirement.
- **Some of the usability features overlap with each other.** For instance, the developer felt that during a negative mood phase (mental state – user characteristics), the blind user may perform any of these undesirable two actions: firstly, the user can press the target forcefully, giving more pressure during the touch. It can lead to the non-execution of the touch event or the execution of a long click event; secondly, the user can hit the incorrect target, which may lead to the execution of an undesired event.

  To solve these, the developer can adjust the requirement to get the user to confirm before the event is executed.
- **Usability is the subset of accessibility. We cannot elucidate any major usability problems out of the inaccessible part of the system.** Currently, the blind user is not interacting with the content such as the widget except by button control. They navigate through the pages with the

swipe gesture in a static layout. Thus, the minor usability problem arises in a static layout where direct interaction with the content is not experienced.

Although our findings are specific to our prototype developed, it needs more checking based on the requirements of the target application. These findings give reliability in eliciting usability features to the knowledge warehouse that is beneficial in the process of asking the right questions by the novice developers to the stakeholders (blind users) and to confining accurate usability requirements for software development without an HCI expert on the development team.

8. CONCLUSION

It is highly important to define usability requirements at the earliest stage of software development process such as in the requirement stage. This is a difficult task as usability features are more difficult to specify as it requires a lot of discussion among stakeholders, especially the blind users or to approach HCI expertise to perform this. However, non-availability of HCI expertise or high cost to be paid to the HCI experts will cause the developer to find an alternative solution to elicit usability requirements. Our work takes a step in this direction, suggesting that usability features should be dealt with at the requirements stage. This paper has focused on eliciting usability based on the proposed mental model. This analysis will reduce the burden of novice developers to understand the mental model of blind users. The list of usability features suggested by the paper is not intended to be exhaustive; there are a number of confounding variables that need to be considered: metrics to measure listening load and complexity of interaction with the touch screen system. However, our future studies will address these factors and should help interpret the proposed metrics within these constraints.

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