Analysing the Mental Model of Blind Users in Mobile Touch Screen Devices for Usability

M. Fakrudeen, M. Ali, S. Yousef, and A. H. Hussein

Abstract—**Understanding the concept of mental models can help to make sense of usability problems in software design. Yet the software engineer and developer faces many difficulties in the proper understanding of the user behaviour during interaction with the system. This paper presents a mental model of born blind users for touch screen devices to aid developers in designing and building better applications for blind users. The work of Kurniawan was preferred as a 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 usability. Our research revealed that two stages, namely: listening and interaction are used to facilitate the development of the Kurniawan mental model. This paper also suggests eight usability features that can be added to facilitate the design phase of the system. As far as is known this is a novel suggestion.**

***Index Terms*—Mental-model, blind-user, usability, heuristics, touch-screen, smartphone**

I. Introduction

HUMAN beings have the aptitude to sense the world by means of vision, touch and other senses. In spite of the authority of the sensory system, insight of the person is supplemented and enriched by past experiences developed by relationship with others. Without the ability to relate with prior experience, he will lack understanding of a particular situation. In the field of cognitive science, these perceptual relations are referred to as "mental models" [10]. The field of Human-Computer Interaction (HCI) has adopted and adapted these concepts to further the study in usability [3].

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 utilised in the product construction, it will aid in complementing a mental model that typical end-users have and acknowledge [25]. 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 [7]. Usability is strongly tied to the extent to which a user's mental model matches and predicts the action of a system [3].

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 [16]. 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 analyse the usability functionalities for a blind user unless 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 [13], [9].

The purpose of our research is to derive possible usability features of the mental models of blind users of touch screen devices. The objective of the present study is to explore and modify the blind users' mental models pertaining to the touch screen environment and their strategies in dealing with the device.

II. Background

Kenneth Craik in 1943 was the first to invent the "Mental Model" theory [18]. He declared that the mind predicts the future action and reactions in advance by making miniature dimensional model. On other hand, the mental model can be

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defined as how our mind represents an event/object to predict the future outcome [3],[12],[21].

Later, Potesnak [19] 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 particular way.

In 2002, Puerta *et al.* [20] 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.

Another study on the mental model by Takagi *et al.* [24] experimented with the mental model using screen-reader users of a vertical list for 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 on the blind user's behaviour with the system. The standard model of Kurniawan & Sutcliffe [11] 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. He proposed three models:

- A structural model is that which is created such that the location of the application in the desktop in a two dimensional format such as icons is utilised,
- While the functional model is created with the shortcut keys.
- The hybrid model is a mixture of both.

Kurniwan *et al.*'s model is modified by Saei *et al.* [22] 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 Kurniwan nor Saei concern themselves about the stages in each process of the mental model. Without understanding the different stages used for each process, 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.

III. Touch Screen Usability Evaluation

The work of Kurniawan gave an idea about how a blind user thinks and acts based on cues given by screen readers. Touch screen interaction differs from the interaction using a 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 [14].

Another reason is that the interaction between the sighted to the blind user varies. Generally, the sighted user use dynamic layout and identify the items through vision. But the blind user uses static layout where 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 is based on a study carried out for screen readers only and not for touch 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. Subsequently, factors affecting these stages will be studied to elicit usability features to facilitate the design of the new system.

IV. User Evaluation

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.

A. Participants

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 on using a touch screen mobile. Since the cohort size is small, we conducted on average about 8.5 trials per participants.

B. Equipments

The prototype was developed and run on any Smartphone which supports the Android platform. 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 operating system touch based Smartphone and tested with the blind users.

C. Procedure

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.

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V. Proposed 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 understanding of listening, interaction took place. This activity is iterated until the target is reached. We explain each stage of the strategy based on our understanding, in a developer point of view.

A. *Listening*

Listening is the process of giving attention to the audio. Listening may be performed either at the starting or in the intermediate stage of interaction with a touch screen device. Without the listening process, interaction is futile for blind users. The interaction through listening depends on the process of listening, type of listening, environment and acoustics of the audio. The process of listening is divided into various stages, as shown in Fig. 1. At first, when a blind user listens to the audio, it is grasped and held in the memory. Secondly, the image was developed based on the storage. Thirdly, the image was searched. If the image was found, the existing image and the newly formed image were compared. Then it tests all the cues. If the image was not found then it was stored in the memory with necessary cues if possible. Finally it was generalised to proceed for further action [15]. The interaction technique will be faster if the image was already stored. Hence it is imperative for developers to use common words for effective interaction between the blind user and the device.

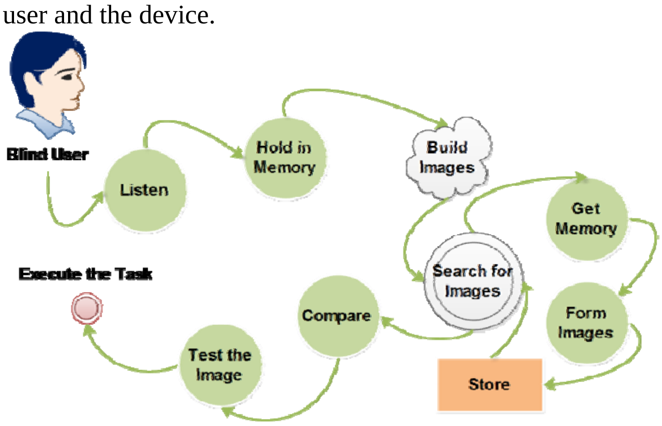


Fig. 1. Stages During Listening.

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 perception, the blind user would proceed to the next level.

The type of listening such as active listening or acute listening also affects the explorative process. Since they fully depend on audio instructions to proceed to the next level, the blind users were generally acute listeners. Thus interaction was affected by the quality of audio and the acoustic of the sound which are discussed in subsequent sections.

B. *Interaction*

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, see Fig. 2. If feedback is provided, the user confirms whether the expected feedback is received, only then may the user proceed to the next task. If an unexpected feedback is received which cannot be confirmed due to difficulty in understanding the cue or due to various reasons such as the screen orientation has changed, then the user will be stuck from proceeding any further. If the user did not receive the feedback due to wrong hand movements such as not pressing the correct target, the user will repeat the task. If the user incorrectly presses the close button, the application will be terminated.

We analyse the usability features in the existing mental model. We derive four usability feature: help, undo/modify, error and feedback. These features are recommended by HCI experts [17],[23]. The usability literature has provided an extensive set of guidelines for these features to help developers build usable software. Therefore, we feel it is beyond the scope of this paper. We also identify a list of other usability features during the listening and interaction stage. We summarize these features in the next section.

VI. Eliciting Usability Features

The user study reveals that the listening and interaction stage is either strengthened or weakened by many

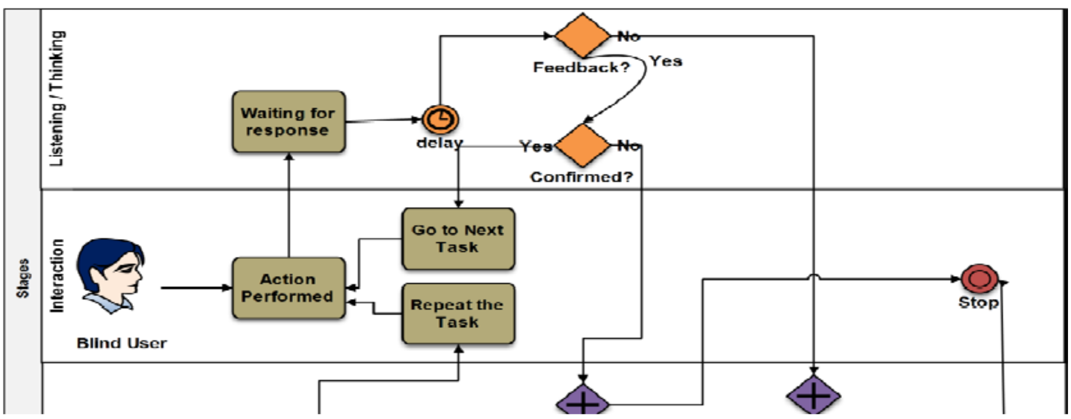
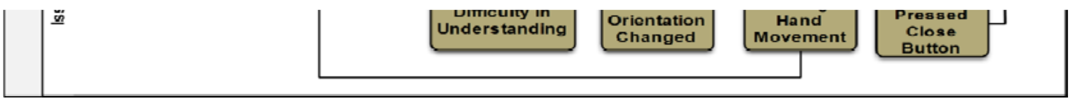


Fig. 2. Stages During Interaction.



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usability features. While the listening stage is dependent on audio features, the interaction stage is influenced by gesture, orientation, content and sub-content features. The other features such as user characteristics and environmental factors affect both the stages if stimulated.

A. 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. The quality of audio such as the volume [1], tone [5] and speech rate [2] determines the effect of the listening. Factors such as the spoken language may contain less lexical information than the printed language and these reduced forms have been shown to interfere with the listening comprehension for non-native listeners [8].

B. User Characteristics

User characteristics determine the effectivity of listening and interaction. They are:

1) User Profile:

Blind user characteristic such as age affects the exploration process. The rate of hand movement was decreasing with an increase in age. The pressure on the touch screen target was seen to increase with age which will render recurring execution of events. In addition, the preciseness of hitting the target decreases with the increase in the age among the blind.

2) Mental State:

Mental state here refers to the mood of the person. Mood affects the rate of the exploration process. While positive mood enhances the process, negative mood retard the rate of information being processed [26]. Partial sleep or sleep deprivation also affects the rate of interaction [4].

3) Body Posture:

Posture is the deliberate or habitually assumed position of the human body while interacting. It may be sitting, standing, walking and lying. During posture, the body may assume a great variety of shapes and positions thus affecting interaction. The problem can be overcome by the comfortability of the blind users. At any posture, if body and mind are not stressed, comfortability can be achieved and hence exploration will take place faster.

4) Physiological factors:

Physiological factors such as illness, stress and fatigue will cause discomfort during the interaction.

5) Familiarity:

Familiarity or intimacy refers to the feeling of closeness to the application and device. It is also the degree of desireness to interact with the application and device. The familiarity requires prior experience in related services, frequent exposure and recall rates. The level of exploration increases with familiarity.

C. Environmental Factors

Environmental factors such as noise [6], 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.

D. Handedness

Hand movements are very crucial for gesture based interaction such as touch and flick. Mostly a finger is used for interaction. Although each finger is divided into three segments, only the upper segment (distal phalanx) was mostly used by the blind users. The hand movements are affected by:

1) Proximity

It is the degree of closeness of the hand with the device. The observation during the user study found that the blind user uses the index finger for interaction. Sometimes accidently the middle finger also touched the surface of the touch screen. Thus a blind user may hit the surface leading to execute unexpected events.

2) Multiple Hands

Commonly, sighted user uses both hands during messaging to increase the rate of interaction. Since our application used in the study was not of the messaging type and interaction is only thorough the widget such as pressing the button - these interactions were performed only by the use of a single hand.

3) Size and Shape of the fingers

The study also 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.

E. Contents and Sub contents

The content was the information provided to the user. Based on the information received, a blind user will cut-out for the next plan of action. Unlike the sighted user, it was difficult for blind users to process the information they desired among the bunch of information. Hence the developers ought to give precise rather than vague information. The contents can be classified into text, images, audio/video and widgets.

1) Text

Text delivers the message to the user in the form of symbols. During interaction, textual information passed through the audio to the blind users were governed by the structure of the text such as grammar and linguistics.

Grammar

Grammar was complemented by phonetics (sound of a word), semantics (meaning) and pragmatics (intended meaning). Our research reveals that if the information provided was a second language to the blind users then the interaction will be delayed owing to the difficulty in understanding the information.

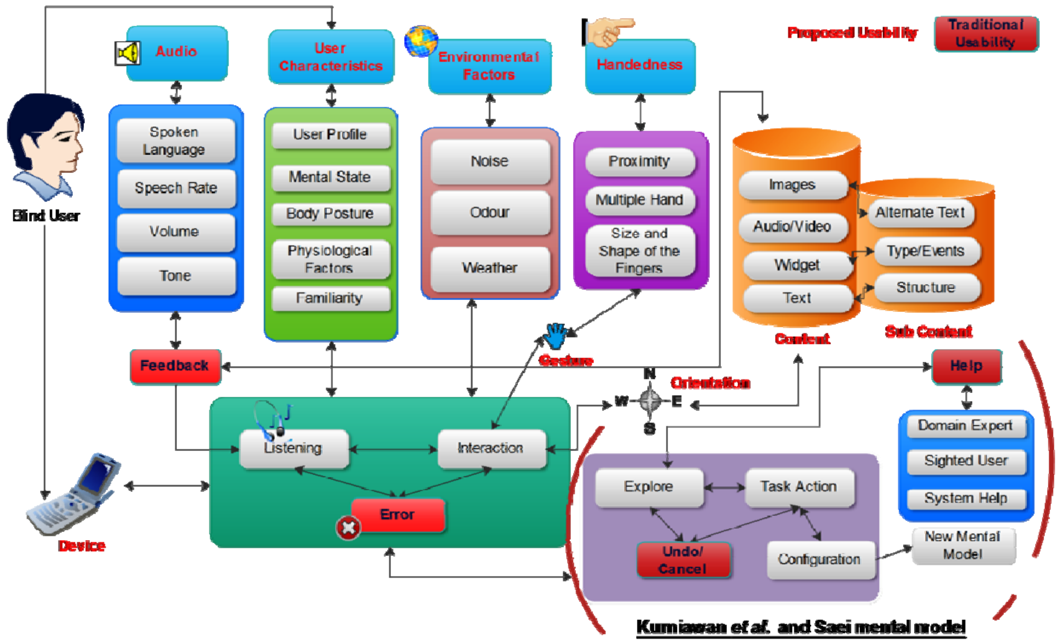

Fig. 3. Proposed Mental Model.

Much of the difficulty arises due to vernacular usage and grammatical errors. This may lead to erroneous navigation or interaction and failure to get the desired results. Therefore the essential information in a short and precise manner must be provided to use for an increased efficiency of interaction.

Linguistic

It refers to how the text is functioning in exploration with the device. For efficient communication to take place there must be interaction between cohesion and other standards of textuality. Additionally, if a blind user does not have prior knowledge of a relevant text, communication may break down because the understanding of the current text was obscured. For instance, blind users may find it difficult in understanding the word 'Eggplant' if the cue used the word 'Brinjal' or even 'Aubergine'. This may be due to whether they use British or American English or their vocabulary.

2) Image

The alternative text is the textual information delivered to blind users which are the information about the images, videos and animations. It was rendered through the ALT attribute in HTML based applications or through narration in non-HTML applications. The rate of exploration may be affected if the user was provided with the information which they do not know. As explained by Saei *et al.* [22], it needs the advice of a domain expert. The information in alternative text should be minimal and thus it must be given precisely.

3) Audio and Video

The information in the audio or video is delivered through the audio format for blind users. Hence both are the same for the user. The details regarding the audio were already discussed in the previous section.

4) Widget

It refers to the interaction point in the touch screen to operate the given kind of data or application. The interaction with the widget by blind users varies with the type such as buttons, text input, list, menus and containers such as dialogue boxes. The click or long click is the main interaction for many widgets.

At present, blind users are not able to interact with the widget except for a few types such as textbox and button. Hence more study is needed possibly in the future for direct exploration of different classes of widgets.

5) Orientation

The arrangement of the widget either in portrait or in landscape form in a page affects the interaction technique. The location of the widget changes with the orientation and hence it will be difficult to interact with it.

VII. Discussion

This paper has examined and suggested some improvements on the existing Kurniawan and Sutcliffe's mental model for the blind users with respect to touch screen technologies. The proposed conceptual mental model has additional components added to it compared with the existing models.

These added components are namely the listening and interaction process intermingled with the two stages of exploration and task action process. The current mental model contributes four usability functionalities namely: feedback, error, undo/abort and help, according to usability experts. However, the suggested mental model provides eight usability functionalities, such as: audio, user characteristics, environmental factors, handedness, content and sub-content, orientation, gesture and device.

These usability functionalities can be supplemented as non-functional requirements for software development. Some of the usability functionalities can be tested directly but others require specialised usability testing. For instance, developers need to think about the problems faced by blind users during 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.

In another instance, the developer felt that during a negative mood phase, the blind user may perform any of these undesirable two actions:

i. 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;
ii. 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.

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.

VIII. 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; these features are a starting point for identifying usability features. If these usability functionalities are appropriately depicted in the requirements specification, they are more liable to be built into the system. These will advance the system's usability and contribute to the usability levels recognized in the non-functional requirements.

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