

Audio User Interface for Visually Impaired Computer Users: in a Two Dimensional Audio Environment

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Abstract—In this paper we discuss a set of guidelines which could be adapted when designing an audio user interface for the visually impaired. It is based on an audio environment that is focused on audio positioning. Unlike current applications which only interpret Graphical User Interface (GUI) for the visually impaired, this particular audio environment bypasses GUI to provide a direct auditory output. It presents the capability of two dimensional (2D) navigation on audio interfaces. This paper highlights the significance of a 2D audio environment with spatial information in the context of the visually impaired. A thorough usability study has been conducted to prove the applicability of proposed design guidelines for these auditory interfaces. While proving these guidelines, previously unearthed design aspects have been revealed in this study.

Keywords—Human Computer Interaction, Audio User Interfaces, 2D Audio Environment, Visually Impaired Users

I. INTRODUCTION

USER Interface (UI) designing for computer applications is now a matured field of study. At the beginning command line based user interfaces were used, which were not user-friendly for a typical computer user. With the emergence of Graphical User Interfaces (GUIs), computer applications became more user-friendly. Numerous problems were raised in optimizing them to suit human factors. Nature of Human Computer Interaction (HCI) methods may differ on abilities of the person who use it. Therefore, interfaces have to be optimized to fulfill requirements of various user groups.

It is a fact that visually impaired users have the minimum use of GUIs among the other users. Increased development of applications with complex GUIs would make it more difficult for them. Although these modern GUIs may ease the workload of sighted users, it may complicate the interactions for the visually impaired. According to Richard Schwerdtfeger [1], GUIs make it impossible for visually impaired people to use most popular software and they have limited chance to perform well in this graphic oriented world. A GUI provides spatial information for users in visual form to navigate to the exact position on interface. They could access functional elements which are spread throughout the interface using this spatial information. Visually impaired users cannot receive this information which is provided by GUIs. Current GUI interpreters such as screen readers are still not capable of providing this spatial aspect. Screen readers allow them to access all text based information in a sequential manner. Screen readers access a buffer of characters and orally present

the information [1]. It is acceptable that some components such as pictures, colors, videos, etc. are not accessible to the visually impaired. However, they use tables and grids to formulate data in Braille language [2]. If there is a way of presenting these complex structures and spacial information to them it would be more useful.

In this approach, an audio based interface with positional information is considered as a possibility for visually impaired persons. Following a thorough literature review, a prototype application is developed in order to test the concept. A controlled experiment is conducted between this prototype and current solutions. Both qualitative and quantitative approaches have been considered in the evaluation procedure. After analyzing the results, several guidelines are proposed in order to develop audio based user interfaces for the visually impaired.

II. RELATED WORK

World Wide Web (WWW) is a main source for seeking information nowadays. Visually impaired users find it difficult to surf the WWW because of the reliance of hypermedia on visual layout. In their study on mobility within hypertext resources, Goble et al. [3] have mentioned some issues with GUI for the visually impaired as listed below.

- Do not understand what is on the page
- Do not know the page length and where is he/she now
- Get confused and cannot figure out what to do next
- Difficulties on access frames, tables, spacer images, and large images
- Too much details on a single page makes it complex
- Experience of moving on the web is not satisfying or enjoyable

Similar set of problems are addressed in this approach in designing an audio based interface.

In the real world context, visually impaired people use auditory input to identify their surroundings. According to outcomes of the study by Mereu and Kazman [4], the accuracy level of identifying a target in a sound-only environment of visually impaired users is higher than of sighted users. Therefore, answers for most of the above mentioned problems may be solved with the use of spatialized sound.

Mereu and Kazman [4] have proposed a 3D audio based environment which can be used in applications like AutoCAD. That solution can enhance the user experience of depth perception in similar applications. The same concept could be adjusted to be used in a 2D environment to access desktop applications, websites, etc.

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Visually impaired users use the keyboard as their initial input method when using a computer. Mouse is not usable since a visually impaired person could not have a precise measurement about a particular point in the desktop environment. They use keyboard often to navigate sequentially, whereas they use shortcuts to navigate non-sequentially. However, there have been efforts to encourage the visually impaired to use mouse pointer as an input method. McKiel [5] has invented a solution for this purpose in his work towards the patent (Patent No: 6,046,722, USA). Positioning of sound according to the movement of the cursor was the main principle of his solution. Although this looks as a perfect solution, it is difficult to give a precise position of a particular object on the screen. There is a certain doubt if the auditory output is clear enough for the user to get a fine idea about the screen. This solution will not allow a user to locate multiple elements on a screen [5].

Scientific data visualization is somewhat different from presenting general information. Special visual objects like charts, graphs, tables, etc. are needed to illustrate the scientific information in an understandable manner for the reader. Inventions and developments in GUI technologies allow publishers to make scientific publications more comprehensive for the users by exploiting advanced and dynamic graphic utilities. In terms of visually impaired population, this representation is an added burden for them. It should be noted that charts, tables and graphs are much difficult for a visually impaired user to understand since they present complex information in multiple dimensions. Experts have tried to invent solutions which can aid the visually impaired to understand this specific information in a computer application or in a web site. In the study by Fritz et al. [6], two methods have been suggested to overcome this accessibility barrier. They have introduced a system called TACTICS which operates on the principle of "Tactile Imaging". It enhances the images which contain the scientific information to an extent which can be printed on a microcapsule paper using a general laser printer. These kinds of solutions are more time consuming and an additional effort is needed to print and understand the graph.

It is evident that there have been significant efforts to present spatial information to the visually impaired computer users. However, they still have an issue of lack of positional information in a computer environment. Two dimensional navigation is another factor which has not been addressed in a profound manner in these past studies.

III. RESEARCH PROBLEM

Presently, although there are various technologies to support the visually impaired in using computers, screen reading (JAWS, MS Narrator etc.) is the most used technology. The underlying quandary with the screen readers is the sequential nature. It reads a particular interface from top to bottom which gives no idea of spatial information to the user. This process makes it difficult for the user to properly grasp the application and it creates an overload of memory.

According to the background factors, it is clear that this nature of linearity affects the performance of the visually impaired user to a considerable extent, which prevents them

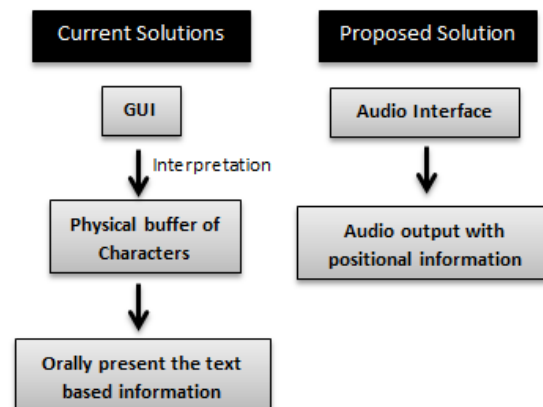


Fig. 1. Proposed solution vs. current solutions

from using complex applications. A novel interface is needed where they can receive spatial cues of interface elements. This interface should go beyond converting the typical GUI to the level of dening a new-fangled interface. Sound perception can be used to a good effect in this approach as it is a main sense used by the visually impaired population.

IV. PROPOSED SOLUTION: AUDIO USER INTERFACE (AUI) FOR THE VISUALLY IMPAIRED

Solution design was decided after some interviews and user questionnaires. In addition, the guidelines defined for the visually impaired under Web Content Accessibility Guidelines 1.0 [7] were also considered.

Following are some guidelines which have been decided to test and prove;

- Minimal number of interfaces required to complete a task
- Limited amount of key strokes to complete a task
- Elements should be in large sizes
- Less number of elements in a single interface
- Easily understood navigational layout

A. Audio Based Online Environment

As the target group is visually impaired, accessibility depends on the ability to listen. Figure 1 shows the difference of this proposed solution and current solutions. The interface is based on limited number of elements with captions/labels. The inaccessible components such as pictures and videos are eliminated. A common set of basic components, menu items or form items with captions are used instead of links, buttons, text boxes, labels, etc. Functionalities are limited and simple, therefore the system expected to be more comprehensive in nature.

These audio based interfaces have unique interface elements. They are specially designed for the visually impaired and can be introduced briefly.

1) *AudioForm*: AudioForms are comparable with java swing frames or windows forms. The entire form is segmented into cells. Each cell holds a position in space. By placing other objects (described below), they can be given the location

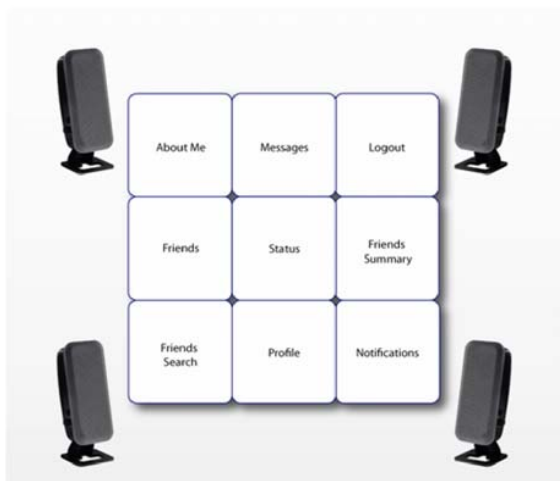


Fig. 2. Actual speaker setup with the home page of application

information of the cell. Predefined function keys are used to focus on text objects, read the entire page and traversing list objects.

2) *AudioText*: This is the first audio object, described in the AudioForm section. It holds similar characteristics to html text box which enables user input. The element speaks out the currently entered character and during space bar it reads the last word. When user clear letters using backspace the deleted letter will be read. These features are adapted from existing screen readers.

3) *AudioButton*: Finding a particular button to submit data can be tiresome to the user. Therefore, submission of data through directly accessing the Enter key on form itself is encouraged. In addition, AudioButtons perform complex tasks unlike typical button elements, such as holding selections. It may be argued that choice/selection objects are to be developed separate and such implementation would look similar in the work environment.

4) *AudioLabel*: - As the name suggests, the element is a simple container of characters which are read when focused.

Complex lists are handled by using a separate AudioForm partitioned with single column and multiple rows, or as non-responsive AudioButtons with multiple non-responsive child options. The former is mostly used in this AUI. An elaborate description of the elements will be found in later stage of the document. Considering visually impaired user's special ability to listen, it is possible to create a platform where they can listen and imagine a 2D environment through sound positioning. As an example, user remembers the login menu item is positioned in right-top corner because the sound comes from the same side. Figure 2 will illustrate the sound positioning in a 2D environment.

B. Prototype Implementation

For the purpose of evaluating the concept, a prototype implementation was carried out. The prototype scenario is based on current visual implementations of social networking. Development was completely based on the above mentioned

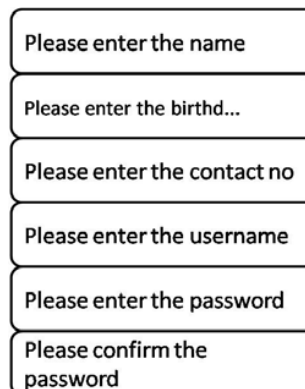


Fig. 3. Vertical navigational structure

core elements. A brief introduction to the features and functionalities of the prototype is presented.

C. Sample structures

The interfaces were balanced as users would encounter all possible layout structures. Structures such as vertical lists, horizontal navigation structures, navigation structures with both horizontal and vertical layouts, were taken into consideration. It is necessary to implement all the orientations in a natural scenario, to observe the user interaction capabilities in different orientation formats.

1) *Vertically oriented structures*: E.g.: Registration - Navigation in this page is purely vertical (Figure 3). Only up and down arrow keys can be used for navigation.

2) *Horizontally oriented structures*: E.g.: Login - Navigation in this page is purely horizontal. Therefore, only the right and left arrow keys can be used (Figure 4).

3) *Horizontal and vertical*: E.g.: Home Page - in this structure navigation in both orientations is possible where the user can use all the arrow keys for navigation. (Figure 5).

4) *Tables and grids*: E.g.: Summary of Friends - This is one of the important implementations of tables and comparison structures. The structure simulates a table with the column headers reading firstly, followed by subsequent rows (Figure 6).

5) *Complex interactions*: E.g.: Notification Status - this introduces some complex interactions. First, the user is able to enter his/her own status and save it. Then, he/she can view status messages of the others, indexed by their name. This structure can be easily traversed using the up and down arrow keys (Figure 7). If the user needs to read the comment on a particular status, he may enter it and view the comments by traversing in the same manner. Then, he/she can exit back to the main page. Entering into such sub-menu is possible through pressing the F2 key in our prototype. The existing systems such as JAWS have similar functionalities mapped to function keys, therefore it could be assumed that mapping actions to function keys will be adaptable to the intended audience.

V. EVALUATION

It was decided to conduct a controlled experiment between two objects: the proposed solution and a current application.

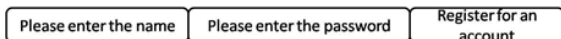


Fig. 4. Horizontal navigational structure

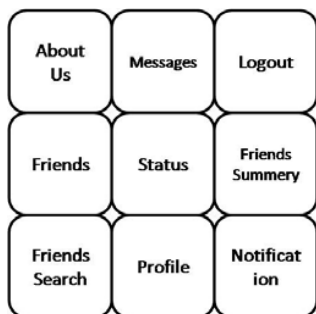


Fig. 5. Horizontal and vertical navigational structure

However, instead of using a current application like a screen reader, dimensional information was omitted from the proposed solution to create a similar application. Therefore, in this test object, elements were navigated in a sequential (linear) manner with only up and down arrow keys. This action has been taken to ensure the similarity of functionalities in both the test objects.

A. Performance Evaluation

One part of the quantitative approach was to compare performance of users in both the applications. Level of performance has been determined according to the time taken, number of errors encountered and number of assistance needed while completing a predetermined task set. Test subjects were asked to perform the same task set in both the applications. These tasks are listed as follows:

- Find “Register for an Account”
- Register with the system

Name	Contact no	Birth day	Username
Kanishka We..	0718204589	1987 3 25	kanishka
Ravihansa Ra.	0118388383	1987 4 3	ravi
Malshika Dia..	0718283838	1987 3 22	malshi

Fig. 6. Friend summary table

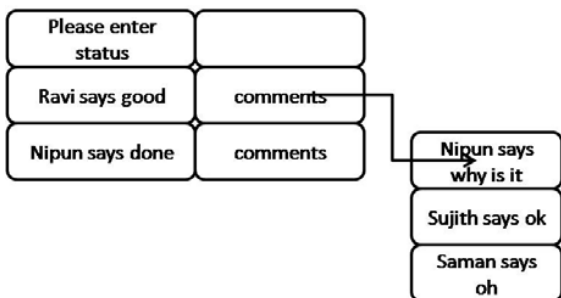


Fig. 7. Notification Status

- Login to the system
- Find friend search
- Perform friend search
- Check friend summary

B. Home Page Description

This can be considered as the second part of the quantitative approach. After completing above tasks, subjects were asked to describe the home page (Figure 5) as they could remember. It should be noted that they needed to visit this particular page several times while completing above tasks. They were expected to describe the home page through hand gestures (pointing) or verbally (top-right, top-left, etc.).

Then, they were given an opportunity to describe the same page while or after auto-reading (application reads the page automatically when the F1 key is pressed) the page. These two types of descriptions will be referred hereinafter as from memory and while reading, with respect to the home page description. Their responses were recorded during both these phases in a matrix as shown in Figure 8. Location of each interface element was recorded with regard to both horizontal (x) and vertical (y) directions. Accuracy of horizontal or vertical position was awarded a binary value: Correct or Incorrect (1 or 0). Interpreting and recording responses to determine accuracy values was the responsibility of the observer. Therefore, the accuracy values may be subjective to the judgement of the observer.

About Me	Messages	Logout
Friends	Status	Friend Summary
Friend Search	Profile	Notifications

Fig. 8. Matrix that has been used to record responses from the user in home page description

C. User Questionnaire

Initially, only the quantitative approach was considered to compare performance aspects of the objects. Qualitative approach was added in to the overall evaluation procedure, according the comments from users during pilot studies. It was noticed that there were some positive feedback from the pilot studies and there was no such organized method to collect them. Therefore, a user questionnaire was designed to gather feedback from the users with regard to the new solution. This questionnaire consisted of 14 questions which were focused at various HCI aspects. They are listed as follows:

- 1) I was aware of my position in the system at any given point
 - Whether the user has an idea of how deep is he/she is in the system at any given point
- 2) System structure was familiar with compared to the real world
 - Real world scenarios often involve directions. Closer the system to the real world, it would be more familiar to work with
- 3) Level of interactivity compared to the current applications is high
 - Amount of involvement needed by the user to accomplish the given tasks in the system
- 4) Provided interactivity encouraged me to positively involve with the system tasks
 - Has the provided level of interactivity eased the accomplishment of the given tasks?
- 5) It was easy to recover when I have encountered an error
- 6) It was easy to remember objects on the interfaces
 - To measure to what extent the user can remember objects on a particular screen on a re-visit
- 7) It was easy to distinguish among different functions on the screen
 - Identification of the positions of the elements
- 8) There were dedicated locations for particular functions
 - Identification of specific functions on uniform locations on a screen (E.g. "Logout" at top right)
- 9) It is important to have dedicated locations for particular functions on the screen
- 10) Navigational layout (arrow key navigation) has provided a better control over the tasks
 - Unlike the traditional applications which use mainly "Tab" and "Shift" keys to navigate, the proposed solution using arrow keys. Was this more helpful?
- 11) I have identified tabular structures for data representation
 - Some of the information in the proposed solution is presented as tables
- 12) Tabular representation was useful in identifying relevant information
- 13) It was easy to identify data comparisons in the application
 - In some cases, tabular representations were used to present data comparisons
- 14) Comparison of data is useful for better comprehension

Answers for these questions were ranked on a likert scale (1-Strongly Disagree to 5-Strongly Agree) from each of the users. These questions were presented and responses were received verbally during the evaluation procedure.

D. Sampling Plan

Ten (10) participants from the University of Sri Jayawardenapura, Sri Lanka were selected as the sample group. The

target group had to be computer users who use computers in their day-to-day academic or extracurricular activities. Therefore, it was difficult to receive a large user sample for the expected evaluation. There were 7 totally blind and 3 partially blind users among the group. There were 5 male and 5 female users in the whole sample. It should be noted that the subjects were asked 11 multiple choice questions prior to the whole evaluation procedure in order to gather general information.

Moreover, the sample was divided in to two groups, since they were presented with the same task set in both objects. For one group, firstly, the linear application was presented to record performance metrics - time taken, number of errors encountered and number of assistance needed. Then they were presented with the proposed solution for home page description and user questionnaire. The other group was presented only with the proposed solution for the entire evaluation procedure and they have not been exposed to the linear application. By following this particular procedure, the learning effect which could have been there in the performance evaluation has been mitigated. If a single subject had been exposed to both the systems knowledge from one system could have affected the performance level in the other, since they were presented with the similar tasks. Assuming that the subjects are in a same educational level, performance metrics from each group could be used as a controlled experiment. However, it should be noted that all 10 users were presented with home page description and user questionnaire, unlike the performance evaluation.

VI. RESULTS

Results from each of the above evaluation phases (performance evaluation, home page description and user questionnaire) could be presented in a separate manner.

A. Performance Evaluation

Averages from all the users from this particular evaluation could be seen in Table I. Here, the values from all the users in completing the task set have been summarized and then averaged.

	Time (s)	Errors	Memory Aids
Proposed Solution	1280	16	13
Linear Application	932	4.8	3.8

TABLE I
COMPARISON OF THE AVERAGE USER PERFORMANCE: PROPOSED SOLUTION AND LINEAR APPLICATION

B. Home Page Description

There are 9 elements in the home page in 9 equal cells on the screen. Users have been assigned a score out of 18 according to the correct responses for 9 cells with regard to x and y directions. Thereafter, an average score is calculated for all the users. Averages for this analysis from memory and while playing are respectively 5.1 and 16.5.

Further analysis was carried out to compare the accuracy of describing the positions of elements in horizontal and vertical directions. A cross-tab analysis was carried out to illustrate this comparison. When x and y positions considered separately, there are 90 readings for each of the directions (9 cells, 10 users), which creates the sum of 180 readings. Results and Chi-Square tests of this cross tab analysis are depicted respectively in Figure 9 and Table II.

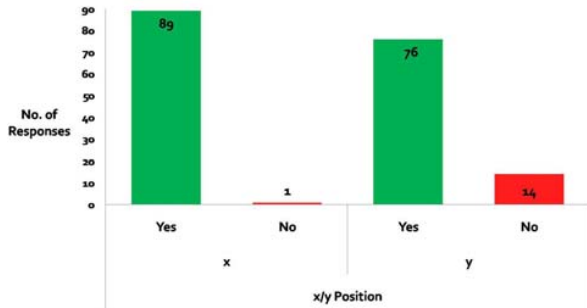


Fig. 9. Cross tab analysis of home page description: horizontal vs. vertical directions

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.291 ^a	1	.000		
Continuity Correction ^b	10.473	1	.001		
Likelihood Ratio	14.472	1	.000		
Fisher's Exact Test				.001	.000
N of Valid Cases	180				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.50.
b. Computed only for a 2x2 table

TABLE II

CHI-SQUARE TESTS OF HOME PAGE DESCRIPTION: HORIZONTAL VS. VERTICAL DIRECTIONS

C. User Questionnaire

Responses for each question from all the users according to each rank in likert scale (1, 2, 3, 4, and 5) can be depicted in Table III. Those responses have been weighted accordingly to get a total weighted sum. Then those sums have been divided by number of users (10) to acquire mean score for each of the questions. These results are also depicted in Table III and in Figure 10 as a bar chart.

VII. DISCUSSION

According to the results from performance evaluation, it is evident that the linear solution has outperformed the proposed solution in all 3 metrics: time taken, number of errors

Q NO	1	2	3	4	5	Total Weighted Score	Average Score
1	0	0	3	1	6	43	4.3
2	0	0	0	1	9	49	4.9
3	1	0	4	1	4	37	3.7
4	1	1	1	2	5	39	3.9
5	0	0	2	1	7	45	4.5
6	0	0	5	4	1	36	3.6
7	0	0	0	0	10	50	5
8	1	0	0	1	8	45	4.5
9	0	0	0	2	8	48	4.8
10	1	0	1	1	7	43	4.3
11	0	0	0	1	9	49	4.9
12	0	0	0	0	10	50	5
13	0	0	2	0	8	46	4.6
14	0	0	0	0	10	50	5

TABLE III

RESULTS OF THE QUESTIONNAIRE: DISTRIBUTION OF RESPONSES FOR EACH QUESTION

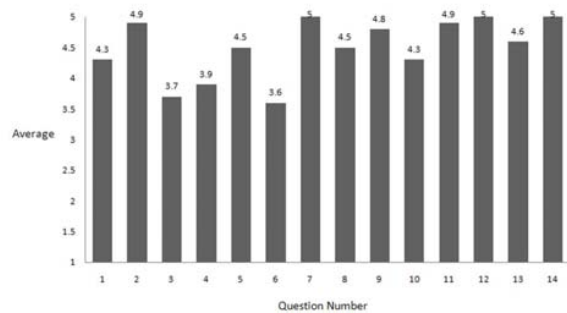


Fig. 10. Average score for each question in questionnaire: from all subjects

encountered and number of assistance needed. Main reason behind this particular result could be the frequent usage of linear interaction models in their current day-to-day activities. It is assumed that they have mapped this interaction nature in a short period of time to the linear solution used in the evaluation. However, most of the subjects have claimed that they would be more comfortable using the proposed solution if an extensive training was given. It should be noted that only one evaluation session was carried out with the subjects. One of the users has specifically mentioned that "Although this new arrow key layout is an excellent idea, I'm not much familiar with it." They mostly use "Tab" and "Shift" keys to navigate in their current applications, instead of arrow keys. Therefore, it could be stated that the difficulty in adapting to the new navigational layout may be the other main cause for this under-performance of the proposed application.

Results from home page description earned a low score (5.1 out of 18) with regard to recalling from memory. However, it has earned a higher average with regard to the responses while reading (16.5 out of 18). According to this analysis, it could be stated that the spatial identification of elements is a possibility for the visually impaired in a two dimensional audio environment. Previously unattended fact could be revealed

from this particular evaluation providing sufficient memory aids. Subjects have found it difficult when remembering the locations of the elements on a re-visit during the evaluation. They have claimed that more practise with the solution will enhance their memory. This particular result is consistent with the responses for question 6 in the questionnaire. It has earned an average of 3.6 which is the lowest average among all the questions. According to the observations, totally blind subjects were comfortable when compared with the partially blind subjects in identifying locations and reaching desired elements using arrow keys. Partially blind subjects had some confusion when identifying and reaching the desired locations. Adding some memory aids such as verbal cues in the initial stages of deployment would enhance the level of memory. Those memory aids can be made optional to be switched on or off. A new guideline could be devised from this particular observation:

Some memory aids should be incorporated in the early stages of deployment.

According to the analysis on vertical and horizontal positioning of elements, subjects have identified elements more accurately in the horizontal direction (x) than in the vertical direction (y). Number of correct responses for these two directions are respectively 89 and 76. Same tendency was observed during completing the given task set. Therefore, it could be stated that it is suitable to disperse more elements in the horizontal direction than in the vertical direction:

Placement of elements should be biased towards the horizontal direction.

In the user questionnaire, questions 1 and 2 were aimed at depth of the system and its similarity to the real world activities. Respective averages for responses for those questions are 4.3 and 4.9. Subjects have stated that this familiarity encouraged them to involve in application in a more natural manner. Therefore, it could be determined that it is suitable to incorporate dimensional information. However, subjects have pointed out that there should be sufficient "depth cues" to identify the current position in the application. It should be noted that although this fact has earned a higher average, the proposed application was designed without any depth cues. Another novel guideline could be devised from this particular observation:

There should be sufficient amount of depth cues to identify the current position.

Questions 3 and 4 have aimed respectively at the level of interactivity provided and attitude of the subject towards that level of interaction. Respective averages for these questions are 3.9 and 4.5. The proposed solution has been designed in a manner that the number of interfaces and number of key strokes would be minimal to complete a given task. According to the above analysis and user comments, level of interactivity provided in the proposed solution is low with compared to the current linear solutions. Moreover, this particular interaction level has encouraged the subjects to actively interact with the application. Therefore, previously mentioned guidelines could

be proved acceptable according to this result:

Minimal number of interfaces required to complete a task.

Limited amount of key strokes to complete a task.

Having sufficient error cues and error recovery options are generally accepted guidelines in any kind of an interface design. The proposed solution consists of set of error cues and they have earned a positive response (4.5) according to question 5. However, subjects have claimed it is still possible to incorporate more error recovery options in the solution.

Questions 7, 8 and 9 were aimed at distinguishing locations and identifying standard locations for particular elements in an interface. They have earned averages of 5.0, 4.5 and 4.8 respectively, which are of a higher range. Subjects have stated that main reason for this response is the less number of elements in an interface and the large size of a single element. Therefore, it was easier to identify and distinguish locations of the elements. As an example, the home page had only 9 elements and since all of them were equally dispersed in the screen, their sizes were larger than in a typical GUI application. Previously mentioned guidelines could be seconded:

Elements should be in large sizes.

Less number of elements in a single interface.

Question 10, which has been aimed at the navigational layout, has achieved an average of 4.3. This proves that the new layout is not difficult to handle, although it is difficult to adapt in a short period of time. Some of the users stated that it is interesting to work with arrow keys, since they can have a higher freedom of navigation. It could be stated that a simple key layout would assist a visually impaired user to actively involve with the system. Therefore, the following guideline could be seconded:

There should be an easily understood navigational layout.

Questions 11, 12, 13 and 14 have been aimed at identification of tabular structures, data comparisons and importance of having such data representations. They have earned very high response rates (4.9, 5.0, 4.6 and 5.0 respectively). It should be noted that identification of such data representation in current applications is a cumbersome effort due to linear nature of navigation. Spatial information of proposed application eases this effort, since a user could identify the differences among columns and rows in a table or a grid. This can be regarded as a significant feature in the proposed application:

Tabular structures can be interpreted easily with the assistance of spatial information.

VIII. CONCLUSION

In this paper, it was proved that a two dimensional audio environment is a possibility for visually impaired computer users. The basic social networking application which has been built using this concept has achieved positive feedback from the users, although the performance evaluation has shown a

negative result. With further investigations, this concept could be extended effectively to implement in various applications. However, when adapting this concept to a target user group, a novel set of guidelines should be followed unlike in a typical GUI application. Some of the existing guidelines should be altered dramatically to ease the nature of interaction. Limiting the number of elements, keystrokes and interfaces are main aspects to address. Elements should be in larger sizes than a typical application and the navigational layout should be designed in an easily understood manner. Placing more elements in horizontal direction than in the vertical direction yields more effectiveness. Incorporating sufficient amount of depth and memory aids is another important area to address. It is noted that tabular structures can be implemented easily with the assistance of spatialized sound. However, applicability of these guidelines may vary according to the application and qualities of the user group.

IX. FUTURE WORK

Guidelines which were presented in this paper are facts that arisen from a usability study. They could be further investigated to be developed to the level of globally acceptable standards. More experiments could be carried in diverse scenarios to validate the applicability of these guidelines. It would be beneficial for the visually impaired if more information could be incorporated in an application. However, this task should be done with a thorough analysis and a critical discussion with the user groups. It would be beneficial if the concept could be directly applied to current applications such as web sites, word processors, etc. Integrating dimensional information in application development environments would be an interesting future research. Although, it was mentioned that there should be sufficient memory and depth cues, it is still a contemporary area of research which could be exploited to yield positive results.

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