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Designing a Multimodal Graph System to Support Non-Visual Interpretation of Graphical Information

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Abstract. While researchers have performed numerous studies to understand the human interpretation of visual graphs in reading, comprehending and interpreting displayed data; visually impaired (VI) users still face many challenges that prevent them from fully benefiting from these graphs. Thus, it influences their understanding of data visualization and in turn reduces their role in collaborating with their sighted colleagues in educational and working environments. We intend to develop a mobile application where visually impaired users can work together to build a collaborative graph that supported by data sonification in the mobile environment. The system properties were all tested by the task of identifying line trends in time series, which resulted in an accuracy of more than 80% for notes below 20 points. The usability testing has given result of 6.7 out 10 based on users' perception on the effectivity of the features.

1. Introduction

The utilisation of auditory graphs, which deals with the use of non-speech sound to display information, has received much attention in recent years in a wide range of application scenarios. AudioGraf was an early attempt to make graphs accessible by using a touch panel and an auditory display [1]. TeDUB project made significant efforts to achieve existing Unified Modelling Language (UML) to make graphs accessible to the visual impaired (VI) listener [2]. Another study has developed a system, called PLUMB, which was designed to support people with VI to understand graphs and data structures by using auditory cues [3]. While the recent study has developed further using the Graph SKetching tool to incorporate VI users in computing and other science, technology, engineering and mathematics (STEM) disciplines in which graphs are essential [4].

Meanwhile, audio in the interface is becoming more important as technologies get smaller and portable. By shrinking screen sizes, the amount of information that can be displayed is limited, placing more importance on the use of audio to communicate information. Despite these clear reasons to support research on mobile auditory graphs, little has been done to explore multimodal mobile

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graphing system on mobile device for collaborative work. To date, the closest work to our study has been developed by researchers from Monash University, GraCALC, as an approach for implementing numerical and statistical graphics to VI [5]. The system presents a graphic from a mathematical function as a line graph which then displayed on a web-based service. Graphics are displayed on a visual screen on the iPad. The interface has been intended to utilise VoiceOver screen reader and the standard iOS framework. As the user explores the display, the system determines a combination of speech, non-speech audio, and tactile (through vibration motors attached to the fingers) feedback to allow the users to explore the screen. However, it is not designed for collaborative work study.

To cover this gap, our study aimed to develop the app to help VI users to work collaboratively with their peers to estimate the trend in auditory graphs using real-time database in a mobile device. The designed app can serve as a good alternative for VI users instead of the portable traditional embossed graphs that is widely used in education for teaching blind student.

2. Related Work

Multimodal multi-sensor interfaces may connect one or multiple user input modalities and extract information from sensors (e.g., camera, microphone, touch screen, position, acceleration, proximity, tilt) [11]. Users can perform intentional actions when using sensor controls, such as tilting a screen to change its orientation. In addition, sensors can also serve as "backend control" for the interface to adapt automatically and without the user's intentional intervention (e.g., dimming the telephone screen when not in use). The purpose of sensor input is to make the interaction between user and system and the adaptation to the needs of the user transparent.

2.1. Non-Visual Mobile Multimodal Interaction

The navigation on a mobile device, which benefits both the sighted and the VI, has been investigated in a number of studies. Amar [7] designed the prototype handheld called ADVICE, integrating a Tactile Feedback and Acoustic Display on an embedded mobile device for the visually impaired. Sanchez [8] has designed desktop and mobile applications based on pointing gestures to help VI users travel on the city rail. The BlindSight system is based on the phone's physical keyboard, ensuring eye-free navigation through auditory feedback during telephone calls [9].

Slide Rule developed by Kane et al [10] enabling multimodal touch gestures in mobile device interaction. Also, using gestures on mobile touchscreen devices, Kane et al. considered a new set of rules to improve access to mobile devices. A pilot study was carried out by Metatla [11] to investigate menu navigation in an eyes-free manner related to execution times and mental stress. Their findings showed that users were considerably slower with a menu item search than with visual or audio-only displays based on a portable touch screen device when using a menu with an audio-haptic display.

To date, we did not find any related study aiming to implement the auditory graph for collaborative work in mobile device as we present in this study.

3. Prototyping Methodology

The prototype was developed based on the Android Operating System on Google Nexus 7 tablet, which runs the TalkBack screen reader and on a Samsung 9.7-inch Galaxy Tab S2 with a larger screen and haptic feature. This screen reader is a feature that helps blind and VI users receive the data by using loudly spoken text when touching, selecting or activating objects on the screen. Iterative Prototyping is the approach used in this project, in which the design of the prototype was iteratively generated and evaluated by potential users. The feedback and the evaluation of the last iteration is the prerequisite for the subsequent iteration.

The first iteration was the low-fidelity prototype for sharpening the goal and checking the significance of the collaboration graph. Two participants were involved and gave many suggestions for the next extensible development of the application. The idea was to share the role between teacher and student analogues and let them work collaboratively. The second iteration focused on extending the functionality of the application to implement the analogies of teacher and student into the system. The Publisher and Subscriber model was used as shown in Figure 1. The teacher acts as a publisher who can create a diagram and share it with other publishers or students. The Subscriber role is almost identical to the Student Analogy role, where they can access all available diagrams without editing

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them. Second, this iteration explored the concept of managing workgroups and multiple graphs. In this way, users can group and share all diagrams with the same group member. To achieve the goal of this iteration, only the low fidelity prototype was used in this iteration. The participants also saw participants to evaluate the interface.

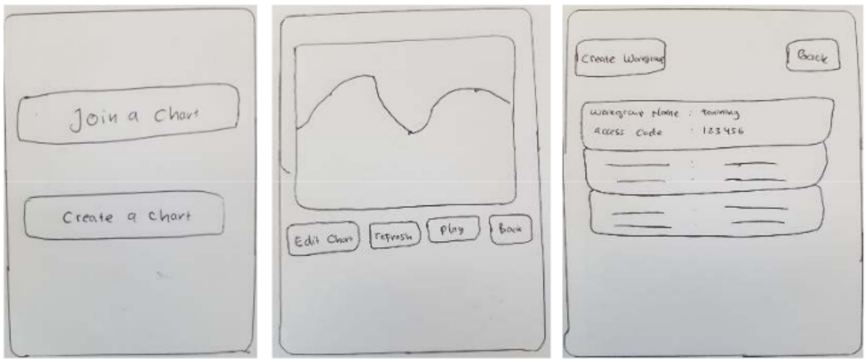


Figure 1. Paper low-fidelity prototype of subscriber and publisher

The third iteration was the high-fidelity prototype to allow the participants virtually complete evaluation. The sighted and visually impaired participants were shown difficulty when entering the forms into the system, but overall the system was consistent with the objective of the project. Sighted users, on the other hand, found many errors such as lack of registration unexpected shutdown of the system, and the inconsistent elements of the layout, such as key texts and key positions. The final iteration covered all full functions focused on completing all system functionalities and measuring the usability of the application. This iteration introduced the real-time update functionality.

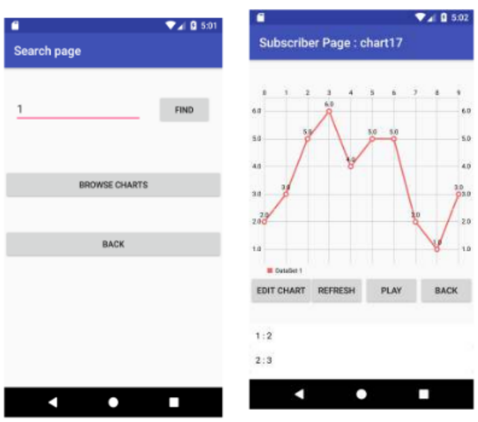
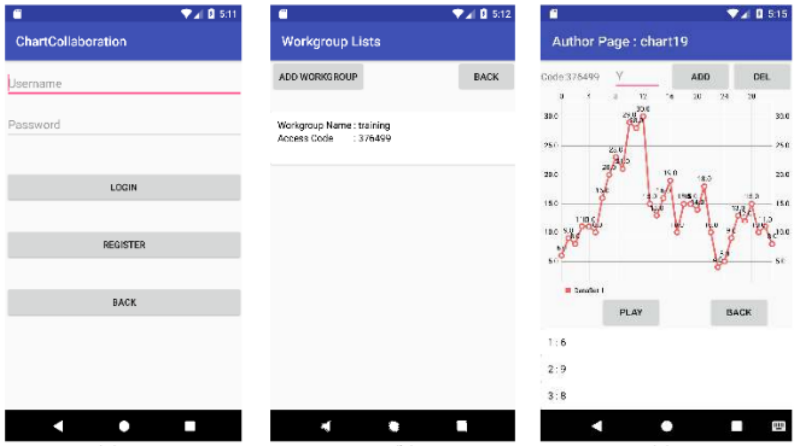


Figure 2. Subscriber interface for login (left) and graph display (right)



(a) (b) (c)

Figure 3. (a) Interface for publisher for login, (b) interface of workgroup management, and (c) the graph display interface.

Each time a publisher updates a graph, the graph on the subscriber page is automatically updated without pressing the Refresh button (see figure 2 and 3). Figure 2 and 3 above respectively shows the additional table appended at the end of the page as mentioned in the previous iteration. Therefore, both pair VI user are able to read and display the values of the graph sequentially in tabular format. The visual impaired participants evaluated the system profoundly and, for overall, gave positive feedbacks for this application.

4. Evaluation Method

Five (5) VI participants, aged 19-64, are involved in this iteration. The number was minimal as it is difficult to recruit visually impaired people to test this application in London. Although the number of participants is noticeably small, Nielsen [12] argued that five participants are sufficient to detect these real problems in a usability test.

A brief explanation of the mobile auditory graph was given and a 10-minute listen to the auditory graph to introduce themselves to the sound. As all participants were visually impaired people, the instructions for this evaluation were detailed to let them run the test smoothly. The password and username were only suggested with the number for efficiency when they enter the login or registration form. The task is divided into two sections, the first is the user acts as a subscriber / student. Second, he or she will be a publisher / teacher.

5. Result and Discussion

The first testing is aiming to measure the usability for the role of the subscriber. Participants are given a set of instruction to find the graph by inserting the graph_id number. Improvement over the previous iteration, the format of the keyboard has been changed to the keyboard for the telephone interface, therefore only the number is displayed without further characters. This helped the participants to fill in the form quickly and easily.

The observation did not reveal any noticeable problem for the participant. Participants are asked to answer how many rising and falling trends there are in the graph. The total note on the graph for the first task was only 10, followed by 20 notes on the second task and 30 notes on the third task. The accuracy of the participants' trend identification during the usability test had revealed that the participants were able to estimate the trend with less than 20 points representing a percentage of more than 80, but it dropped significantly to 40% when they were asked to estimate the trend in 30-point graphs. The findings confirms Harrar [13] research that adding complexity to auditory graphs could drop the performance of graph identification. Further, Nees and Walker [14] confirmed that more trend reversal also led to performance drops.

The second aspect concerned the application features such as navigation, page, graphs, workgroup and so forth as participants have to answer questionnaire and gave their feedback. Starting with the question about the performance of the screen reader in the application, the result was relatively low with 5.8. In fact, one participant was not familiar with the Talkback. Norman [15] pointed out that a user's understanding of a new user interface is based on prior knowledge. Therefore, it is reasonable that the participant had difficulties using the application and gave negative feedback in the questionnaire. However, other participants said that the screen reader worked well with the application.

The next aspect was clarity, which notes how accessible the presentation of working groups, graphs and points is. The result was 6.0 out of 10, which means the interface was acceptable to the users. Together with the evaluation of the navigation used in this application, the result was 6, which means that the navigation is sufficient.

The most important evaluation in this study is the sonification performance that reached the higher score of 7.4. This means that the sonification technique worked well to help the user to perceive the graph. The feedback was also validated to ensure that users have full control over the application and know what is happening in the system. The result was 6.4 that it meant the users were satisfied with the feedback. The next point is the usability of the graph and the entire application. The results were 6.8 and 7.4, respectively that user consider the system is very helpful not only to display the graph but also to help users work collaboratively. The result shows that locate a graph, creating a workgroup, creating a graph, adding or deleting a point was very acceptable to the participant with the average number was between 6.6 and 7.

Finally, the changing role was also tested. In the beginning the participants were slightly disoriented about the role differences. Although there are several suggestions from participants to bring roles together, it is important to distinguish the roles, considering in real scenarion, the participant may basically be a student who receives only the final graphics from the teachers. The average rate result was 7.2, which means that the mechanism seemed to be acceptable.

During the test period, a number of feedback messages were summarised. Some participants said they were confused with the role's function and suggested using only one role in the application. However, this may be because participants were unfamiliar with the function of the different roles and thought they would merge them. Also, a constructive suggestion to implement pause function to control the playback sound. It is reasonable, because the performance of trend detection decreased with increasing number of points in the graph.

6. Conclusions

In this study, we performed a test employing five VI participants to confirm how well the mobile auditory graph could help them for collaborative work. This study aims to develop an application to support visually impaired people in creating a collaboration graph. The prototype was built by four prototype iterations. The first iteration focused on extending the objectives and aggregating the requirements. The second iteration was a low fidelity prototype that examined the system adaptations with the specifications. The third was the high-fidelity prototype, where almost all features were present in this iteration. In this iteration, a synchronization button was also introduced to aggregate the updated graph. In the last iteration the real-time function was added. All functions were tested by conduction trend identification task, resulting accuracy more than 80% for notes less than 20 points. The usability test was performed with the result 6.7 out of 10, means that the systems' usability was effective and efficient. This is a best alternative instead of the portable traditional embossed graphs which is more time-consuming to produce and harder to replicate.

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