

Platform-Independent Implementation of 3D-Sound Computer Interface Icons for Subjects with Visual Impairments

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ABSTRACT

This paper describes a platform-independent system which adds spatial auditory feedback to the icons of a computer interface in order to assist visually impaired individuals during icon location and selection. In this enhanced system, icons have 3D sound properties, in addition to their graphical properties. Each icon has a specific sound associated with it. As the cursor is moved throughout the interface, the user is able to hear, spatially, in which direction and at what distance each icon is located, with respect to the cursor.

Keywords: Assistive Technologies, Human-Computer Interfaces, Universal Access, 3D Sound Auditory Icons, Spatial Auditory Icons.

INTRODUCTION

A Graphical User Interface (GUIs) takes advantage of the computer's graphics capabilities to make the computer easier to use. Well-designed graphical user interfaces can free the subject from learning complex command languages to control the computer. One form of control is the use of icons to launch programs. Users have to navigate throughout the "Desktop" of the computer and locate the icon associated with the desired software package. The user then can start the execution of the program by clicking on the corresponding icon. However, users with a variety of visual impairments may find it difficult to perform this task. Some systems, such as screen magnifiers and readers, presently exist to aid visually impaired individuals in the use of computers. Unfortunately, they are limited on the degree of assistance they can provide.

In order to use an icon-based interface, one must be able to distinguish the different icons and place the screen cursor on the desired icon. This requires acceptable visual acuity and contrast sensitivity, which allows images to be viewed sharply. However, individuals with visual impairments due to a variety of conditions may have difficulty with icon location and selection. Some conditions, such as Age-Related Macular Degeneration (AMD) and Retinitis Pigmentosa (RP), can reduce the field of vision. This will restrict visual perception to sub regions of the field of view [1].

It has been observed that visually impaired computer users require more time to identify, locate and select a target icon [2]. In that study, these individuals had a tendency to overshoot the target icon. This accounted for significant differences in the time required by visually impaired and normally sighted users for the completion of an icon selection task. Typically, visually impaired users would perform unsuccessful approaches to the target icon before finally selecting it. Furthermore, it has been proposed that the inaccuracy of locating icons is due, in part, to the lack of appropriate feedback regarding the relative position

of the target icon with respect to the screen cursor during the approach process. Hence, this paper proposes that the addition of spatial auditory feedback will enable subjects with visual impairments to more accurately locate and select icons.

METHODOLOGY

The following subsections outline the basic method used to achieve sound spatialization and the implementation methods considered for the development of the 3D sound icon system.

Sound Spatialization Through Interaural Intensity and Delay

With the use of digital signal processing techniques, a single audio signal can be separated into a pair of left and right audio signals. Hence, each signal can be individually manipulated in order to give the listener the illusion that the point source of the sound originated at a specific spatial location (see the following section for more detail on how Java 3D implements sound spatialization).

3D Sound Implementation Approaches

Spatialized sound requires significant amounts of computational power. Originally the use of dedicated hardware, such as a sound processor, was required. Our group has previously implemented the 3D sound icon concept in this context [3] [4]. However, it rapidly became apparent that limiting the implementation of this form of interface to computers with the corresponding dedicated hardware would significantly reduce the portability of the concept and its use by individuals with visual impairments.

In recent years, computational power in personal computers has increased dramatically. In addition to this, platform-independent programming languages, such as Java, have emerged and become popular. One variant of the Java programming language is Java 3D. Java 3D is an API for java that enables the programmer to develop scalable and platform-independent multimedia applications. In Java 3D, sound spatialization is achieved through the technique described below.

For each sound source, Java 3D calculates a separate left and right output signal. Each pair of left and right sound images include interaural intensity differences (differences in strength between the left and right channels) and interaural delay differences (differences in timing between the left and right channels). The calculation results are a set of direct and indirect (delayed) sound signals mixed together before being sent to the audio playback system's left and right transducers [5].

Experimental Program Functionality

The study uses an experimental program containing a prototype of the interface with spatial auditory feedback. This program, developed using platform-independent Java™, Java 3D™ and a MySQL® database, is designed to evaluate the performance of low vision subjects using icons with spatial auditory feedback. Testing protocols derived from the Jacko Low Vision Interaction Assessment (JLVIA) program [2] are employed in our experimental software.

Our experimental software has been developed to assess the level of interaction enhancement that can be achieved by adding 3D sound characteristics to the icons, under simulated conditions of visual impairment. In our experimental program each icon has a specific sound associated with it. The program maps the two-dimensional graphic user interface (GUI) on the computer screen to a horizontal plane where the screen cursor is the “listener” and each of the icons is a spatialized sound source. Accordingly, if a given icon is “above” the cursor in the GUI, its spatialized sound will be emulated as emanating from a position “in front” of the listener. An icon “below” the screen cursor in the GUI will have its sound emulated as if coming from “behind” the listener. Left and right relative positions of an icon with respect to the screen cursor, in the GUI, are mapped directly to left and right emulated sound sources, respectively.

Our experimental program used the icon sound spatialization approach described to provide supplemental information in a target acquisition task. Individuals experiencing simulated visual impairments are instructed to locate a target icon that is displayed at the beginning of each experimental trial. In each trial, the target icon is first presented to the subject, along with its associated sound for 5 seconds, in a “Target Icon” screen (e.g., Figure 1). To complete each experimental trial the subject is presented with the “Response” screen. In the “Response” screen, nine icons will be placed in a three by three grid, and the target will be one of the nine. The screen cursor is positioned at a fixed point at the bottom-center of the screen. The subject then attempts to click on the target with the screen cursor. An additional 440Hz sinusoidal tone is played when the screen cursor is in the clicking area of any of the icons displayed. Once the subject has clicked on an icon, the trial is completed.

Data on the subject’s performance is recorded during each trial. The identity of the target icon is recorded. The ordering of the icons in the grid is also stored. The search and click time (time elapsed between the display of the “Response” screen and the selection of an icon by the subject) is measured. Whether the subject clicked on the target or an incorrect icon is recorded. The screen cursor path from the starting point to the icon that is clicked is tracked. All the performance data, which is originally stored in a MySQL® database can also be exported to text files, which can be analyzed in MATLAB® at a later time.

For each a trial, a target icon is selected from the group of nine icons displayed in figure 2. The location of that target icon in the “Response” screen is selected from the nine grid positions. The number of unique pair combinations taken from the set of icons and the set of grid locations is 81. To ensure that a subject will be required to search for each icon at each grid location, the test sessions were programmed to consist of 81 trials, implementing all the possible icon-position combinations. To protect against biases in the ordering, the trials are randomized. When 81 trials are completed, the test is concluded.

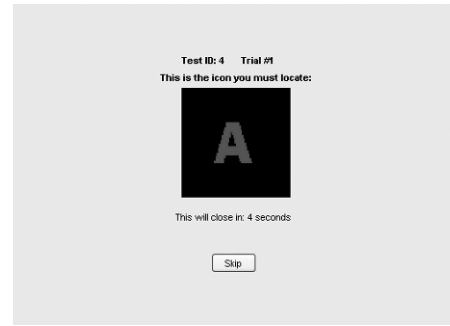


Figure 1: “Target Icon” screen of trial

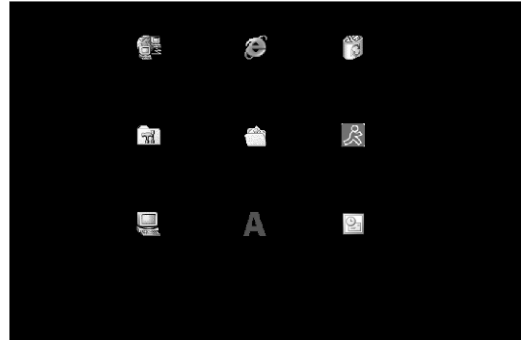


Figure 2: “Response” screen of trial

Simulation of Visual Impairments

To facilitate initial testing of the 3D sound icon concept, the protocol described above was applied to normally sighted subjects with artificial visual impairments imposed on them. Key visual impairments were simulated using reduced peripheral vision goggles and a blurring glass. The peripheral vision goggles are used to reduce the visual field and the blurring glass reduces visual acuity of the subject. To create the peripheral vision goggles, two washers were taped to the front of a pair of safety goggles. The goggles and washers are then covered with black electrical tape except for the two circular orifices in the washers. The subject was only able to see through the central orifices of the washers. Therefore the subject could only see a portion of the screen at any given time (see Figure 3), as is the case for individuals with significant reductions of their field of view. The blurring glass is placed 5cm in front of the monitor to blur the icon images so that the icons cannot be easily distinguished from each other. This emulates significant loss of visual acuity experienced by some computer users.

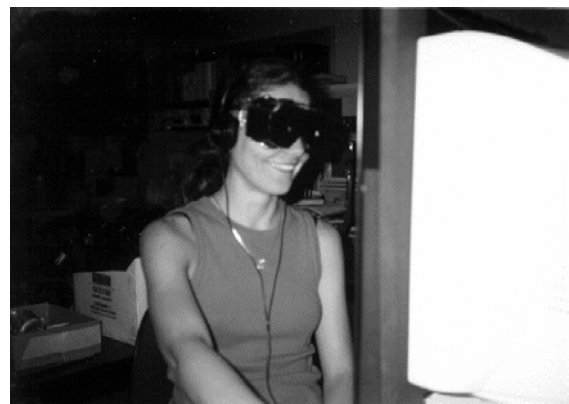


Figure 3: Subject wearing the reduced peripheral vision goggles

In each experimental session, the subject is first asked to perform a monocular visual acuity test, for each eye, using a Snellen chart (Figure 4). The blurring glass is placed 5 cm in front of the Snellen chart and the subject is instructed to stand 4 meters away. The subject then attempts to read progressively smaller lines in the chart, until he/she cannot correctly read a line. At that point, the visual acuity of the previous line read is assigned as the visual acuity of the subject (for the eye tested).



Figure 4: Example of a Snellen Chart [6]

The subject is then situated in the testing environment, sitting approximately 45 cm. in front of the computer monitor. With the reduced vision goggles on, the visual field test is performed. First, the visual field plotting paper (Figure 5) is aligned with the top of the monitor. The subject is instructed to cover one eye and to focus on the center of the plotting paper where the lines intersect. A pencil is moved slowly into the field of view along each of the lines from the endpoints toward the center of the paper. When the subject indicates that he/she can see the pencil then the corresponding location is marked on the paper. This process is repeated for each of the lines. The entire process is repeated for the other eye.

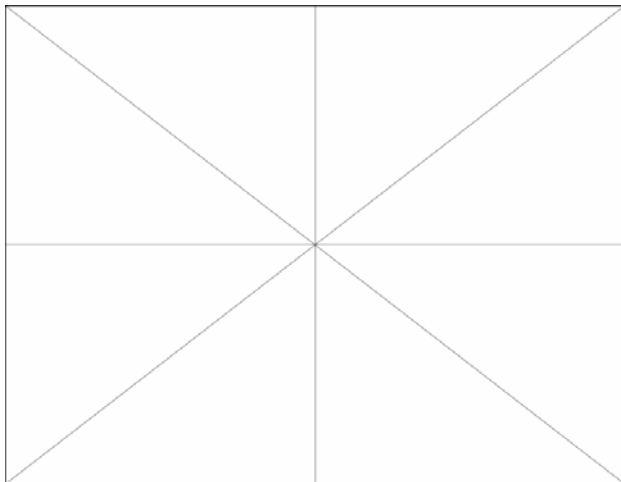


Figure 5: Visual Field Plotting Paper

After the visual impairment data is collected, the subject is ready to be tested by the software. The subject will perform two 81-trial tests: one without auditory feedback and one with auditory feedback. The order of the test is randomized in order to prevent biasing.

For the test without audio feedback, the reduced peripheral vision goggles will be placed on the subject and the blurring glass will be placed in front of the screen. A few practice trials will be performed to familiarize the subject with the interface. The trials are automatically saved into the database when the subject clicks the target icon on the “Response screen.”

The test with auditory feedback is similar. The procedure follows the same sequence, except that the subject will wear headphones. The headphones will allow the subject to hear the spatialized sound associated with each icon and the 440Hz sinusoidal tone indicating that the cursor is in clicking position for an icon.

Analysis

Since subjects tested are fully sighted, the significance of the artificial impairments imposed on their vision must be determined. The visual field plot is an indicator of the reduced peripheral vision. Once the points are collected, the smallest circle centered at the intersection, is drawn around the measured visual field limit points as shown in Figure 6. Since the holes in the goggles are circular, the encompassing circle represents the maximum visual field. The geometry to compute the effective visual angle, corresponding to the subject’s visual field, is shown in Figure 7. The visual angle α is computed in eq. (1) using the radius r of the circle and the distance d from the eye to the visual plane. In this experiment, the visual plane is the monitor. The simulated level of visual acuity loss is evaluated through the use of the Snellen chart, as outlined above. These visual measures are an attempt to quantify the effectiveness of the artificial visual limitations imposed on each subject.

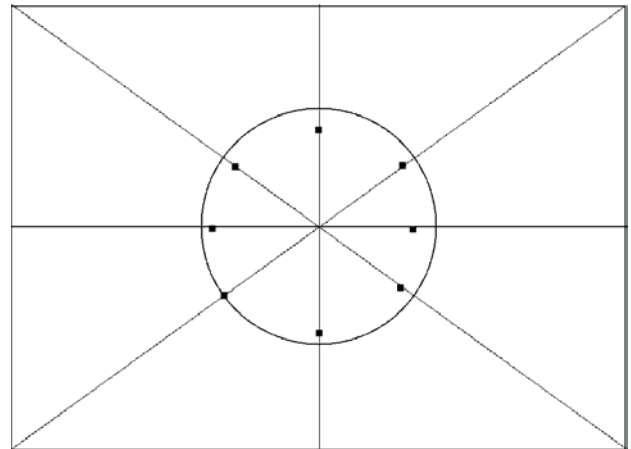


Figure 6: Visual Field Plot Analysis

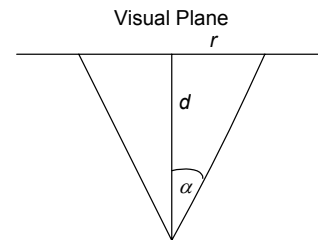


Figure 7: Visual Angle Geometry

$$\alpha = \tan^{-1}\left(\frac{r}{d}\right) \quad \text{eq. (1)}$$

The data gathered from the experiment is recorded to assess the performance of the subject in the search for the target. The analysis that follows focuses on the search and click average time and the hit-ratio (percentage of correct selections of the target icon in each trial) observed in the experiments. The search and click average time shows how long it takes the subject to select the target. The hit-ratio percentage represents the accuracy of the subject in the selection of the target. These two measures, when coupled, show the performance of the subject. The performance goal is high accuracy coupled with a low search and click time.

RESULTS

Table 1 shows the visual data recorded during the experiment. Subject 2 had a fairly large visual angle in the left eye. This deviation from the mean could be due to the subject's head shape and/or a particularly tight fit of the goggles on this subject during testing. Because of this, the mean visual angle will be used in the following analysis.

Subject	Left Eye Visual Angle (°)	Right Eye Visual Angle (°)	Left Eye Visual Acuity	Right Eye Visual Acuity
1	11.8	12.2	20/160	20/160
2	15.9	12.2	20/160	20/160
3	9.3	9.5	20/160	20/160
4	12.8	12.2	20/160	20/160
5	12.2	9.8	20/160	20/160

Table 1: Visual Data

	Mean	Standard Deviation
Left Eye	12.4	2.4
Right Eye	11.18	1.4

Table 2: Mean and Standard Deviation of Visual Angle (°)

The mean visual angle is 12.4°. The position of the subject is 45cm away from the screen in the experiment. The viewable screen surface, at that distance, and according to the average visual angle is 392 cm². The screen area of the monitor used in the experiment is 954 cm². Therefore, on average, only 41% of the screen is viewable by a subject with one eye. At the smallest visual angle of 9.3°, the viewable surface of the screen is 217 cm². This area covers 23% of the screen. These percentages indicate the degree to which the reduction of peripheral vision is implemented. Impairing the visual acuity is also effectively done. The best visual acuity score achieved in Table 1 is 20/160.

Experimental Program Results

In Table 3, the hit-ratios achieved by subjects during testing are shown along with their means and standard deviations. There is a noticeable increase in the hit ratio and a decrease of standard deviation for the icons with auditory feedback.

The search and click average time on an icon is shown in Table 4. The search and click time difference between the icons with auditory feedback and those without is insignificant.

Subject	Without 3D Auditory Feedback (%)	With 3D Auditory Feedback (%)
1	65.4	96.3
2	82.7	96.3
3	50.6	96.3
4	59.3	83.95
5	97.53	98.8
Mean	71.1	94.3
Standard Deviation	18.9	5.9

Table 3: Hit Ratios for Icons With and Without Auditory Feedback

Subject	Without 3D Auditory Feedback (Seconds)	With 3D Auditory Feedback (Seconds)
1	6.1	4.5
2	6.2	9.7
3	4.5	5.3
4	4.2	5.2
5	2.8	3.6
Mean	4.8	5.7
Standard Deviation	1.4	2.4

Table 4: Search and Click Average Times for Icons With and Without Auditory Feedback

DISCUSSION

It is apparent in Table 3 that there is an important increase in hit ratio for users using icons with spatial auditory feedback. Unfortunately, the results from the search and click average time do not show a similar improvement (Table 4). In fact, Table 4 shows that all the subjects took slightly longer to complete the trials in the test with spatial auditory feedback.

In retrospect, the simultaneous increase in accuracy (hit ratio) and in search and click time for the completion of the trials with spatial auditory feedback is congruent with the inclusion of additional guidance information provided by the 3D sounds of the icons in the interface navigation process. All the subjects were able to use the additional guidance information to achieve higher accuracy in icon selection. However, it seems that the incorporation of the additional information into the navigation strategy required additional processing, and time, from the subjects.

In order to gain a better understanding of how the subjects might have modified their approaches to the target icons when spatial auditory feedback was provided, the screen cursor traces under both conditions for all the subjects were studied. Figures 8 and 9 are representative samples of the screen cursor tracks for complete 81-trial sessions without (Figure 8), and with (Figure 9) spatial auditory feedback implemented for the icons.

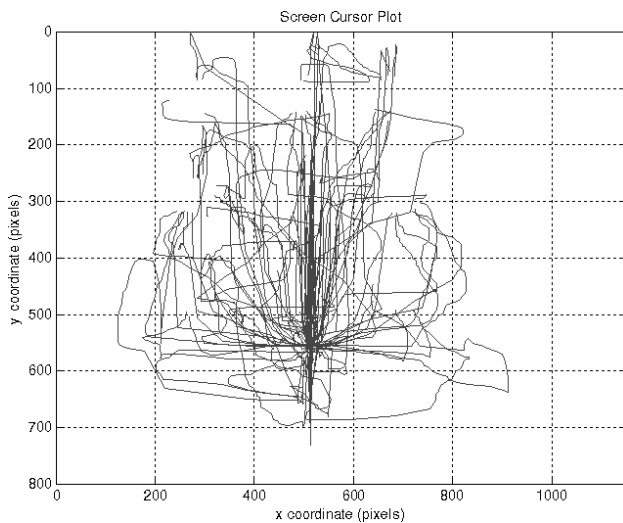


Figure 8: Screen cursor plot of all the trials in the Response Screen for Subject 2 using non-auditory icons

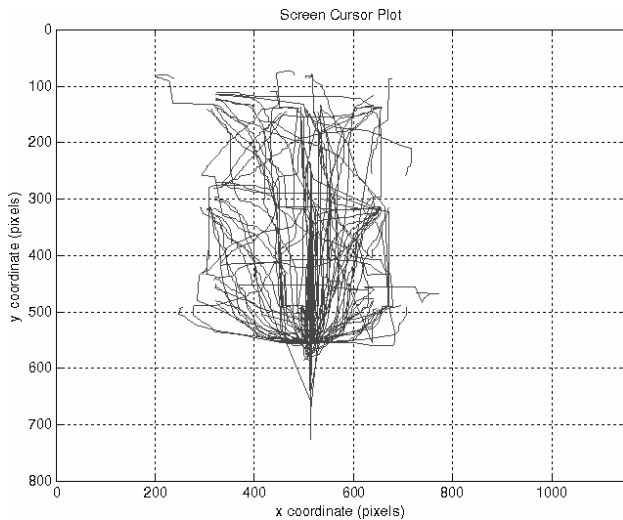


Figure 9: Screen cursor plot of all the trials in the Response Screen for Subject 2 using icons with spatial auditory feedback

Inspection of these figures reveals that without the help of spatial auditory feedback (Figure 8) subjects had trouble constraining the movements of the screen cursor to the icon grid and its immediate neighborhood. Subjects, indeed, reported intermittent inability to locate where the screen cursor was positioned when no auditory feedback was provided. Frequently subjects would attempt to regain knowledge of the cursor position in the screen by implementing movements not necessarily aimed at approaching the target icon. These movements likely contributed to the more “widespread” configuration of the cursor tracks under this condition. In contrast, when subjects had available spatial auditory feedback to help them locate the icons (Figure 9) the screen cursor movements were generally directed to approaching the correct target icon, with fewer instances in which the cursor would wander far away from the grid. This contributed to the more “compact” configuration of the cursor tracks under this condition (Figure 9).

CONCLUSION

The project presented paper has demonstrated the possibility of implementing spatialized auditory icons following an approach that is software-only and platform-independent. This form of implementation is likely to make the use of the spatial audio icons concept more generally applicable. The particular implementation described in the paper used the built-in sound spatialization mechanisms available in Java 3D, but other spatialization approaches, such as the use of Head-Related Transfer Functions (HRTFs), may also be considered.

The evaluation of the platform-independent spatial auditory icons interface in this project showed that the additional information available to the users enhanced their icon selection accuracy under simulated visual impairments. Our results indicate, however, that incorporating the additional information provided by the spatial auditory feedback might have required additional processing, and time, on the part of the users, during the icon identification and selection trials. In addition, it seems that the additional information available through spatial auditory feedback contributed to limit the spread of the paths in which the cursor traveled towards the icons.

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