Geo-sonf: Spatial sonification of contour maps

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Geo-Sonf: Spatial Sonification Of Contour Maps

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Abstract—**Sonification is the use of sound to represent information. We have developed and evaluated a tool for interactive exploration of spatial data through the use of spatial sound and a spatial user interface. In this paper we describe two approaches for spatial sonification of spatial data: 1) person-centric spatial sonification and 2) space-centric spatial sonification. An evaluation of the designs is presented with the results.**

I. Introduction

Sonification is the representation of data in the sound domain using non-speech audio [1]. There is a growing interest in sonification both to provide an accessible interface for blind or partially-sighted users and to represent data that can be conveyed most effectively through sound (such as rapidly changing information or in an environment where visual input is not appropriate).

There has been a good deal of research on visualisation and the mapping of spatial data in Geographical Information Systems (GIS) is well developed and documented whereas sonification research is still in its infancy. Map creation has been around for thousands of years and developers know how to allocate the graphical components because they follow well-formulated design guidelines. Hence the GIS community does not focus their research effort on the mapping process but on the analysis, processing and management of multidimensional spatial datasets. Conversely, sonification of spatial data is not well developed; there are few guidelines and developers still focus on the mapping of data to sound parameters.

In addition, the mapping is implicit and accurate in traditional visualisation. While in sonification, although sound may be spatial, it is not inherent how to map the information, and the perception of the information is less precise. For instance, although sound may be mapped to a position in the azimuth plane, users are unable to accurately locate the position of the sound source as in an equivalent graphical visualisation [2].

Furthermore, spatial data in geographical visualisations is mapped to two-dimensional spaces while this need not be the case for sonification. For instance, someone explaining to their colleague the route from their workplace to their home is spatial information, but the communication medium is not.

This paper focuses on the design and implementation of two exploratory spatial sonification techniques that not only allow perception of contours on geographic maps, but also provide spatial information with sound. Contour maps provide more spatial information and can readily represent elevation information and distinguish different types of terrain. This makes contour maps suitable to be represented with the use of spatial sound.

II. Related Work

Bertin [3] states that a visualization developer should perform a component analysis: to analyze both the components of the data and those of the visual domain, and work out an effective mapping from one to the other. We extended this categorization to sonification. Location information can be used to enhance the sonification or can be used to represent qualitative information. Sounds can be localised through four methods as shown in Figure 1.

The taxonomy developed in [4] divides the research into four overarching categories for sound data mappings: spatial data with spatial sound, spatial data with non-spatial sound, non-spatial data with spatial sound and finally non-spatial data with non-spatial sound. We consider the four groups of spatial components of sonification:

Interaural Time Difference (ITD) is based on the principle that there is a phase difference between the sound arriving at the left ear compared with the right. Stereo speakers can communicate left-right perception and orientation information [5], [6]. Headphones or surround sound speakers convey location information generated through ITDs [7].

Interaural Intensity Difference (IID) is based on the principle that objects which are closer sound louder.

Together, these two effects give a listener the perception of sounds azimuthally and in elevation; see Figure 1 (D). Positional audio provides a listener the spatial perception of an azimuth plane and the elevation of the sound source. Some research has been done to combine ITDs and IIDs with geographical datasets [8], [9].

Doppler & Time Effects. Factors, such as Doppler or frequency changes, give a listener perception of source distance and movement from the listener's position perspective. The Doppler effect has been used for sonification [10], [11].

Non-spatial audible variables include pitch, loudness, attack and decay rates, timbre, tempo and brightness. Non-spatial motifs are higher order components that utilise the variables to communicate the information at a higher-level Earcons [12], auditory menus [13] and Pie Chart Sonification [7].

The non-spatial representations of sound enhance a sighted user's perception of the graphical and sonified representations of the dataset and provide the information to blind users that they are unable to see. For example, the Talking Tactile Tablet [14] and the sonified maps developed in [9].

There are various examples of path-based sonifications where a path is placed through the spatial data and sampled sequentially. The sampled points are then sonified [15], [16], [17], [18], [19], [20].

Research has shown that use of musical sounds gives the user an overview of graph sonification and the user is able to make a mental image of the sonified graphs [21], [22], [23].

Some researchers combine other spatial visualisation techniques to aid in the perception of spatial sonification, such as tactile feedback and haptics [23], [9], [24].

The scope of this paper covers the use of spatial sound to represent data, more specifically spatial data. There has been much research in the area of spatial sonification in virtual environments (VE) [25] where sound is used to enhance the sense of presence in the VE, or surround sound setups have been used to realise complex scenes or high fidelity realistic worlds. However, these latter examples are not included because they demonstrate acoustic renderings, rather than representing value information to the user.

Limitations of Existing Techniques

The overview demonstrates that researchers have not fully utilised the maximum potential of spatial sound. For instance, there are only two examples of researchers using Doppler and time effects to represent distance and no obvious examples of researchers utilising environmental effects to visualise data. The work by Hermann and Ritter [10] is an excellent example of how motion can realize two dimensional effects, but there is unquestionably more research to be done here. For example, echolocation or other factors such as reverberation and spatial occlusion could be used to visualise spatial information.

Auditory displays have been used to express aspects of information that are difficult to visualise graphically; this is certainly true of the multivariate information that was presented by Smith, Bergeron and Grinstein [5]. Auditory information also enhances visual information when used in conjunction with its visual equivalent or augmented with haptics or tactile.

There are definitely challenges with the perception of data through sound, and spatial sonification relies upon several models and assumptions. In the remainder of this paper we discuss possible designs and the implementations to represent spatial data with the use of spatial sound.

III. Spatial Sonification of Contour Maps

A. Ideas and concepts

Section II and a detailed review of existing work in [4] shows that there are areas in which sonification can be extended and adapted to form new and novel spatial sonification interactions. ITDs generate location information and IIDs give the listener a perception of sounds azimuthally and in elevation with the use of surround sound speakers. However, the mapping techniques of data variables to sound seem limited and there are few guidelines on sonification principles and design.

There are a number of possible implementations for a combination of ITDs and IIDs to give qualitative and location information. The listener's position is important for perception of this information. Positioning a listener in the centre of a sonification environment with the use of surround sound means the listener will be able to hear the motion of sound sources within the environment.

For our designs we were inspired by Hermann and Ritter [10] and Saue [11] for their sonifications based on Doppler and time effects. We used their ideas but extended them to use of pitch to represent change in distance.

We categorize our sonification designs by (1) person-centric where the user perceives distance by frequency and (2) space-centric where distance is represented by number of sounds (musical notes) playing. In both categories of design, the location information is given by the direction the sound appears to come from. In addition, the user can adjust parameters (such as the number of contours to be sonified).

The relationships we are most interested in exploring are visual and spatial relationships such as the number of contours and the distance of a contour from the users position on the map. These relationships correspond to a visual property mapped onto a sound attribute i.e. frequency or pitch.

The sonification techniques that we have implemented can be grouped into two categories: point and line. The listener can choose to explore the whole contour line, with the option to focus on specific points of interest on the contour.

This focus on point-based sonification exploration helped differentiate the specific points on the map. This was important location information for perceiving the shape of the map; changing from the front to the back of the listener.

The direction of explorative sonification depends on the starting point chosen by the listener. The sonification then follows the listener-selected exploration path, which can be clockwise or anticlockwise. In addition, the user can explore the sonified contours back and forth.

We used samples of piano notes played on a grand piano for our sonification system. The piano works well for this application because it combines a highly-directional initial click (which is a burst of lots of different frequencies) as the key is depressed with a reasonably pure sustained tone of an identifiable frequency.

We chose the frequencies noting that the range of frequencies should be reasonable for most people to hear, but individual frequencies need to be far apart enough to be distinct. In addition, we have selected frequencies that tend to have musically pleasing relationships.

B. Contour Maps

For the purpose of development and trial of a prototype for geo-sonification, we chose to generate contour maps based on mathematical functions in Gnuplot. Several different ranges of contour map data were explored and colours were chosen from the range of red to magenta, changing the RGB values at each contour line. Some maps were simple and only consisted

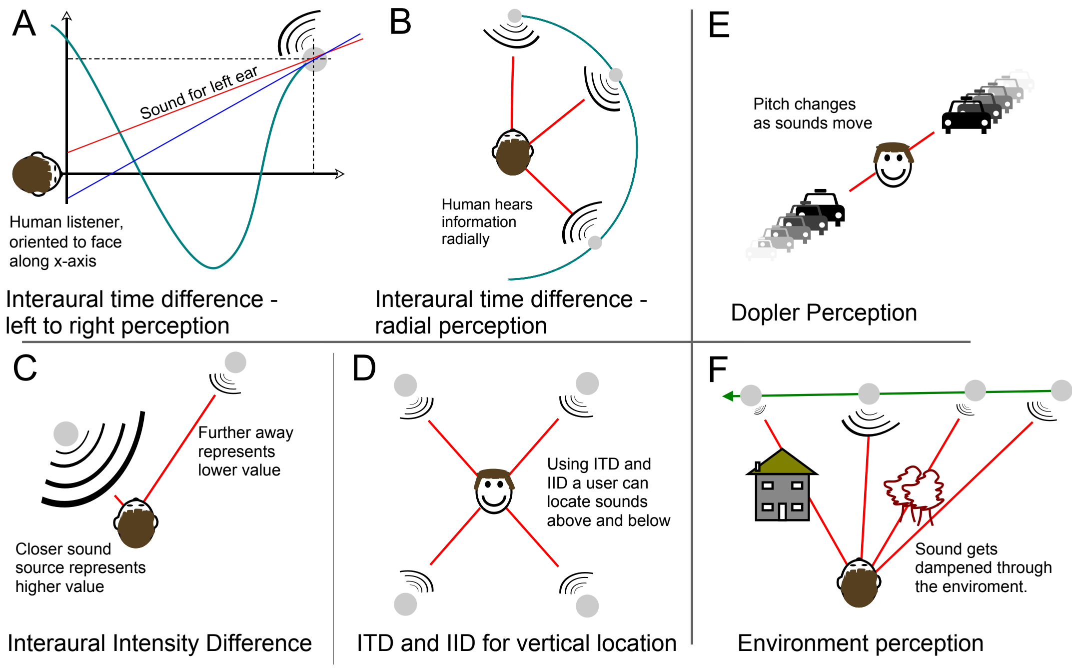


Fig. 1. A and B show Interaural Time Difference (ITD) to provide left right and radial information, C demonstrates the Interaural Intensity Difference (IID), D shows that through ITD and IID vertical positions may be detected, while E shows that location may be found through the Doppler effect and F through the environment. (From [4].)

of single contour lines, while others were more complicated and were laid out with several contour lines[1].

IV. Design I - Person-Centric Spatial Sonification

Person-centric spatial sonification is based on frequency changing over distance. The change in distance id represented by the pitch changing at each contour line. A single pitch represents one whole contour. We placed the listener in the centre of the contour map. The closest contour to the listener is represented with the highest frequency or pitch and the farthest with the lowest.

The user can select whether to sonify the entire map (all contours) at the same time or select a single contour to be sonified. The user selects the path to explore the sonification, which can be either clockwise or anticlockwise. In Figure 2 (I) we show the representation of the frequency of sound changing from high to low as the contours grow distant to the listener in the centre. This change is illustrated by the change in colour. Representing contours with in this way provides the listener with a clear distinction of the number of contours on the map. The shapes of the contours are indicated by the movement of the sound source within the soundfield.

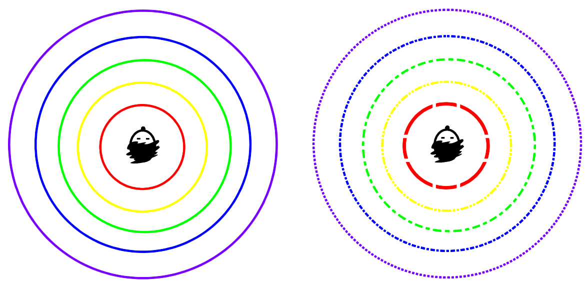
V. Design II - Space-Centric Spatial Sonification

Our design goal for space-centric spatial sonification is to be able to represent each contour in more detail. We achieved this by presenting every contour with a different set of frequencies. Smaller contours were represented with a smaller set of frequencies and larger contours represented with more frequencies.

As with design I, the listener is positioned in the centre of the map and the contour map sonification is laid out around the listener. With each contour growing in size and distance, more pitches are used to represent it.

The frequencies are interpolated so that the highest frequency starts at the highest point on the contour, which is always in front of the listener. As the user explores the contour

[1]These maps can be found at http://www.cs.kent.ac.uk/∼ tn37/geosonf/



(I) (II)

Fig. 2. Spatial Sonification Designs: I shows Person-Centric Sonification: the pitch of sound grows lower as the contours move further from the listener positioned in the centre of the map, II shows Space-Centric Sonification: the number of sound frequencies grows with the size and distance of contours from the listener positioned in the centre of the map

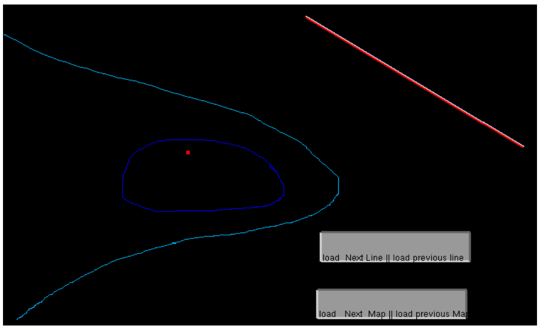


Fig. 3. The Exploration Line used to explore the Sonified Contours

map, the frequencies fall lower until the lowest frequency is reached on the farthest and lowest point on the contour, based on the listener position. The frequencies then start to rise up again as the listener continued to explore upwards and closer to the highest point.

The smallest contour, closest to the listener is represented by eight different pitches. The number of pitches grows by two octaves per contour and the biggest contour is represented with 88 pitches. The largest contour is farthest from the listener and requires higher resolution than the one that is smallest and closest to the listener Figure (2 (II)).

VI. Interface Design

The challenge in the development of a sonification system is not only to find a mapping of spatial data to spatial sound, but also to use an appropriate interface for exploring the data. Logically a spatial interface would be more appropriate for user interaction with a sonification system.

For our sonification system, we chose to use a graphics tablet as our interface. Exploring a sonification of a map on the graphics tablet provides additional spatial feedback to the user and aids in understanding of the map layout. The ridged boundary of the graphics tablet represents the edges of the monitor screen where the auditory contour maps are displayed, helping the users to locate the boundaries of the map.

Clicking the stylus pointer on the graphics tablet signifies the start of the sonification. Moving the stylus around allows a spatial exploration of the contour map. The user clicks the stylus on the graphics tablet and then moves it to create an *exploration line* as shown in Figure 3. With this line, a user is able to explore the sonified contour map. When this exploration line hits and crosses over a sonified contour, a sound representing that contour is played.

The user is able to go back and forth on the map, dragging and moving the exploration line to gain more understanding about the shape and layout of the sonified map. If the user wants to focus on a specific point of interest they can move the stylus around that particular point, to play it repeatedly.

VII. Empirical Study Design

We used contour maps to help us address our research questions. First, which spatial sonification design represents single contour maps more effectively? Second, which design represents multiple contour lines more efficiently.

In order to answer our research question, we ran an empirical study with forty-five test users. In the remainder of this paper, we discuss the empirical study and conclude with an analysis of the results obtained.

A. Empirical Study Structure

We generated a pool of contour maps of various difficulty levels, as discussed in section III. The contour maps were not displayed on the monitor, but were only presented with sound.

We chose a set of eight contour maps from our pool. Half of the maps in the set were maps with only a single contour line; the other half consisted of multiple contour lines.

We generated the possible combinations of the repeated measure so that each test subject has four contour maps per sonification design; with no maps repeated for one test case. We randomised the order in which the designs were presented to avoid bias.

We allowed all test subjects one hour in which to complete the whole test with eight contour maps presented using both sonification designs. Subjects were allowed to divide their time between the maps as they saw fit. The time taken by each test case, on every map and overall, was recorded in a log file.

It was important that the test users understood what sonification is and how it works. For this reason an initial training map provided a better understanding of what was required from the participant.

B. Metrics for Results Comparison

The test cases for the study required participants to draw the contour maps they had explored. These drawings were analysed against the original contour maps.

We considered several techniques to compare user-drawn maps against the original ones. We chose to measure the difference in the shape of the contours drawn by the user. This approach ignores the absolute position and size of the contours as these are not represented by our sonification. Measuring the difference in shape between the drawn contour and the original map is a reasonable compromise between simplicity and accuracy.

We developed a piece of software to compute a similarity measure between a user drawing and the original map. The user map is scaled and translated until the best fit to the original map is found, and then the difference in area between the two maps is computed in pixels. If a contour is missed out, the difference in area is taken as the area of the original contour and is included in the results.

VIII. Empirical Study Analysis and Results

We performed a 2x2 repeated measures analysis of variance (ANOVAs) with the independent variables of map type (multiple lines, single lines) and sonification type (person-centric, space-centric). The dependent variable was the degree of mismatch between the actual map and the map drawn by the user. Mismatch was calculated by rescaling user-drawn maps

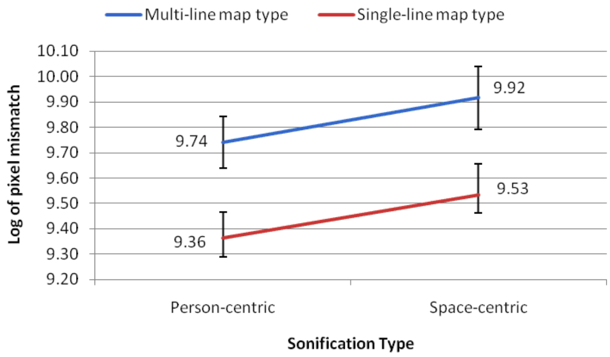


Fig. 4. The Analysis of variance (ANOVAs)

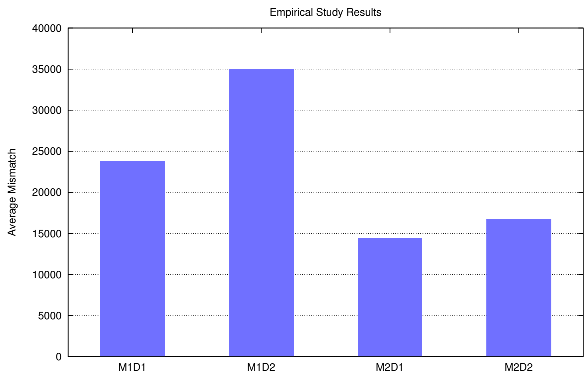


Fig. 5. Bar charts for empirical study results: x-axis represents Map type (M1: Single Contour Maps; M2: Multiple Contour Maps) and Sonification Design (DI: person-centric, D2: space-centric)

to the same size as the actual map and calculating the area difference in pixels. Raw data was log-transformed prior to analysis to meet the normality assumption.

Results showed a main effect of map type (F(1,65) = 16.56, p $<$ 0.001, ηp^2 = 0.20) with a significantly higher mismatch between the actual and user map for the map type using multiple lines (ln(M) = 9.83, ln(SEM) = 0.08) than for the map type using single lines (ln(M) = 9.45, ln(SEM) = 0.05).

Sonification type had a marginally significant effect (F(1,65) = 3.39, p = 0.070, ηp^2 = 0.05), with a lower mismatch for sonification type person-centric (ln(M) = 9.55, ln(SEM) = 0.06) than sonification type space-centric (ln(M) = 9.73, ln(SEM) = 0.08). The interaction between map type and sonification type was not significant (F(1,65) = 0.001, p = 0.971, $\eta p^2 < 0.001$).

From the analysed results, it is apparent that that overall, the task was much more difficult for maps with multiple lines regardless of sonification type and that person-centric sonification made the task easier regardless of map type. These results are illustrated more clearly in Figures 4 and 5.

IX. Discussion

This paper discusses spatial sonification of spatial data and investigates how sonification techniques (more commonly associated with spatial sonification) can be integrated with visualisation of a geographic map, more specifically a contour map. Our aim was to produce a set of interactive spatial sonification techniques that not only allow perception of contours on geographic maps, but also provides additional spatial information with sound.

Representing each contour with a different pitch gives the listener information about how many lines are actually on the map, while the directional sounds provide the listener with perception of shape. However, exploring each contour separately can be improved with more information than just a single frequency travelling within the environment with surround speakers.

The concept of space-centric spatial sonification is applicable to any image based data that requires a variable resolution or multi-modal representation in order to provide more detail to the user. Incorporating an appropriate increase or reduction in the granularity of sound frequency samples could improve this design further.

A. *Spatial Interface for Spatial Sonification*

For the spatial sonification prototype we used a graphics tablet with a stylus as an interface. Exploring a sonification of a map on the graphics tablet provides more spatial information to the user and aids in understanding of the map layout and the boundaries of the map. Moving the stylus around on the graphics tablet allows a spatial exploration of the contour map. The graphics tablet can be used as an exploratory interface for sonification of any scientific data, not only the line graphs or contour map sonification.

The question that arises here is whether the spatial exploration on the graphics tablet gave the user more information about their position on the map than the sound constantly changing in their environment? An empirical study designed specifically to test the effect of spatial exploration against spatial sound could provide interesting results.

B. *Findings*

Our research question concerned which spatial sonification design represents single contour maps more effectively and which design represents multiple contour lines more efficiently.

Space-centric design provides the user with more spatial information about the shape and the size of the contours. However, in the case where multiple contours are present on a map, it was occasionally difficult to ascertain the definite number of contours on the map. This is where person-centric design was reported to give the listener more information about the number of contour lines present on the map while providing information about the shape of the contour with the use of directional sound and surround sound speakers. This judgement of person-centric design was made by test users and was contrary to the results we computed.

Most of the study participants found person-centric design easier to use compared to space-centric design. The participants found it hard to tell the exact number of contours with space-centric design when there were more than two contours on a map. Almost all of the participants agreed that positional audio helped them to understand the shape of the maps, as they could easily relate the contours' position in space to their own.

X. Future Work

A. Improvements in the Existing System

In the previous section we discussed our findings regarding the representation of contour maps with our two spatial sonification designs: person-centric sonification gave the user more information about the *number* of contours, while space-centric spatial sonification provided the user with more information about the *shape* of the contours. A hybrid of these two approaches is likely to result in providing even more spatial information to the listener more effectively and efficiently.

Another possible improvement to the existing system could be achieved by incorporating more frequencies in a space-centric design. This would increase the information provided to the listener about each contour line.

B. Further System Designs

In this paper we presented two possible approaches to spatial sonification of contour maps. There are a number of other possible designs that could be implemented.

One such design could be based on the use of "continuous sound": one note representing each contour, but varying the tonal quality of the sound to distinguish between different parts of the contour. The spatial components can be represented with directional sound and surround sound speakers, as before. Exploring this design on the graphics tablet, like the other two spatial sonifications, would provide more information about the shape and location of the contour. This could also be a possible extension to the hybrid of our person-centric and space-centric approaches.

Person-centric design could be easily extended to support other spatial datasets, and used to conduct usability studies in spatial sonification with scientific data. This could also address questions such as "What kind of data could be explored with more ease and provide better perception with the use of spatial sound?" or "Which datasets are difficult to interpret with the use of person-centric spatial sonification?".

It would also be possible to use intensity variation for the sound components. The spatial components would still be represented with directional sound and surround sound speaker system. This design, however different to person-centric sonification, would represent the closest contour with a higher volume, decreasing it as the contours grow further away from the listener.

This is not an exhaustive list of possible designs for spatial sonification of spatial data. However, they are the next logical designs in continuation to the designs presented in this paper.

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References

[1] G. Kramer, B. Walker, T. Bonebright, P. Cook, J. Flowers, and N. Miner, "The sonification report: Status of the field and research agenda," NSF, Tech. Rep., 1999.

[2] A. W. Mills, "On the minimum audible angle," *Journal Of The Acoustical Society of America*, vol. 30, p. 237 246, 1958.

[3] J. Bertin, *Graphics and Graphic Information Processing*. Walter de Gruyter, 1981, (Translated by William J.Berg and Paul Scott).

[4] T. Nasir and J. C. Roberts, "Sonification of Spatial Data," in *ICAD'07 Proceedings*, The Schulich School of Music McGill University, Canada, June 2007, pp. 112–119.

[5] S. Smith, R. Bergeron, and G. Grinstein, "Stereophonic and surface sound generation for exploratory data analysis," in *CHI '90: Proceedings of the SIGCHI*, 1990, pp. 125–132.

[6] R. Minghim and A. Forrest, "An illustrated analysis of sonification for scientific visualization," in *VIS '95 Proceedings*. IEEE Computer Society, 1995, p. 110.

[7] K. M. Franklin and J. C. Roberts, "Pie chart sonification," in *Proceedings IV03*. IEEE Computer Society, 2003, pp. 4–9.

[8] A. Polli, "Atmospheric/weather works: A spatialized meteorological data sonification project," in *ICAD'04 Proceedings*, July 2004, pp. 31–36.

[9] H. Zhao, C. Plaisant, B. Shneiderman, and J. Lazar, "Data sonification for users with visual impairment: A case study with georeferenced data," *ACM Trans. Comput.-Hum. Interact.*, vol. 15, no. 1, pp. 1–28, 2008.

[10] T. Hermann and H. Ritter, "Listen to your data: Model-based sonification for data analysis," in *Advances in intelligent computing and multimedia systems*. Baden-Baden, Germany: Int. Inst. for Advanced Studies in System research and cybernetics, 1999, pp. 189–194.

[11] S. Saue, "A model for interaction in exploratory sonification displays," in *ICAD 2000 Proceedings*, 2000.

[12] M. M. Blattner, D. A. Sumikawa, and R. M. Greenberg, "Earcons and icons: Their structure and common design principles," *SIGCHI Bull.*, vol. 21, no. 1, pp. 123–124, 1989.

[13] P. Yalla and B. N. Walker, "Advanced auditory menus: design and evaluation of auditory scroll bars," in *Assets '08: Proceedings of the 10th international ACM SIGACCESS*. ACM, 2008, pp. 105–112.

[14] S. Landua and L. Wells, "Merging tactile sensory input and audio data by means of the talking tactile tablet," in *EuroHaptics Conference*, I. Oakley, S. O'Modhrain, and F. Newell, Eds., 2003, pp. 414–418.

[15] P. Meijer, "An experimental system for auditory image representations," *IEEE Trans. on Biomed. Eng.*, vol. 39, no. 2, pp. 112–121, Feb 1992.

[16] K. M. Franklin and J. C. Roberts, "A Path Based Model for Sonification," in *8th International Conference on Information Visualisation*. IEEE Computer Society, July 2004, pp. 865–870.

[17] S. Barrass and B. Zehner, "Responsive sonification of well-logs," in *ICAD 2000 Proceedings*, Atlanta, USA, 2000.

[18] L. V. Nickerson, T. Stockman, and B. J, "Sonifying the London Underground real-time-disruption map," in *ICAD'07 Proceedings*. The Schulich School of Music, McGill University, June 26–2 2007.

[19] A. Pendse, M. Pate, and B. N. Walker, "The accessible aquarium: identifying and evaluating salient creature features for sonification," in *Assets '08: Proceedings of the 10th international ACM SIGACCESS*. ACM, 2008, pp. 297–298.

[20] T. Stockman, N. Rajgor, O. Metatla, and L. Harrar, "The design of interactive soccer," in *proceedings of the 2nd International Workshop on Interactive Sonification*. University of York, February 2007.

[21] T. L. Bonebright, M. A. Nees, T. T. Connerley, and M. G. R., "Testing the effectiveness of sonified graphs for education: A programmatic research project," in *ICAD Proceedings*, Espoo, Finland, 2001, pp. 62–66.

[22] L. Brown, S. Brewster, R. Ramloll, M. Burton, and B. Riedel, "Design guidelines for audio presentation of graphs and tables," in *ICAD Workshop on Auditory Displays in Assistive Technologies*, University of Boston, MA, 2003, pp. 284–287.

[23] R. Ramloll, W. Yu, S. Brewster, B. Riedel, M. Burton, and G. Dimigen, "Constructing sonified haptic line graphs for the blind student: First steps," in *Proceedings of ACM Assets*. ACM Press, 2000, pp. 17–25.

[24] G. Weinberg and T. Thatcher, "Interactive sonification of neural activity," in *NIME '06 Proceedings*. IRCAM - Centre Pompidou, 2006, pp. 246–249.

[25] M. Gröhn, "Application of spatial sound reproduction in virtual environments experiments in localization, navigation, and orientation," Ph.D. dissertation, Helsinki University of Technology, 2006.