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Sonification System of Maps for Blind

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1. Introduction

Creating, manipulating, accessing, and sharing information such as pictures, maps, charts and other visualisations as well as mathematical data and tables are fundamental skills needed for life. Visualisation is commonly used within almost every scientific field. Visually impaired people have very restricted access to information presented in these visual ways and it is currently very hard for them to create, manipulate and communicate such information.

For visually impaired people other information presentation ways must be found, which would replace visual information. The solution is to transform visual information to stimulus which could be perceived by other human sensor systems, which are functioning normally. A touch sense is used for a long time due to Braille reading system. Nowadays dynamic Braille displays are used for situations where more discreet communication is required. However, Braille displays are expensive and can not be widely used.

A sense of hearing is the other choice. It seems that exploitation of hearing doesn't require expensive hardware because a sound system is present in all new computers. One solution is to use a screen-reader and a voice synthesiser to access information on a computer. The screen reader extracts textual information from the computer's video memory and sends it to the speech synthesiser to speak it. Such technology generally only allows access in a linear manner (for example from the top left corner of the screen) and non-textual information such as pictures and diagrams are not easily displayed in this manner. It is difficult to present information where the spatial relationships between the data are important.

The term "sonification" comes from the Latin word "sonus" which means sound. Sonification is the method of information transfered by non-speech audio signals. By means of such signals a visually impaired user could explore computer screen if the sound output is related to area over which computer cursor currently is present.

The aim of this study is to create a model of system for map sonification. The system must use a cheap hardware, for example, usual sound system and tablet. The main component of the system is computer software, which enables sonification of an imaginable display. The term "map" must be understood in a wide sense –vector graphic picture divided to the relatively large area constant colour regions.

Shortly about the structure of the paper. The related works are analysed in the second section. The third section is devoted to the method. Firstly, non-speech sound characteristics most suitable for sonification are analysed. After that XML based maps presentation format is discussed. Finally, a model of sonification is presented and its functionality is described. The details of implementation are discussed in the fourth section. Finally, the fifth section is devoted to the discussion about sonification and the achieved results.

2. Related works

One of the first approaches of sonification signals used in human computer interaction is called earcons (Blattner et al., 1989). Sounds used for earcons should be constructed in such a way that they are easy to remember, understand and recognise. It can be a digitised sound, a sound created by a synthesiser, a single note, a motive, or even a single pitch. Rhythm can be used within earcons to characterise the sound and makes it more memorable (Deutsch, 1980). The guidelines were provided for the creation of earcons (Brewster et al., 1995; Lemmens, 2005). Example of their use is conveying of error messages, to provide information and feedback to the user about computer entities. Presentation of earcons can be accelerated by playing two earcons together (Brewster et al., 1994, McGookin & Brewster, 2004).

A method for line graph sonification invented in the mid 1980s was called SoundGraphs (Mansur et al., 1985). Movement along the x-axis in time causes notes of different pitches to be played, where the frequency of each note is determined by the value of the graph at that time. It was established by experiments with fourteen subjects that after a small amount of training, test subjects were able to identify the overall qualities of the data, such as linearity, monotonicity, and symmetry. The flexibility, speed, cost-effectiveness, and greater measure of independence provided for the blind or sight-impaired using SoundGraphs was demonstrated.

In the late 1980s a system called Soundtrack was developed (Edwards, 1989). It is a word processor for visually impaired people. The interface consists of auditory objects. An auditory object is defined by its spatial location, a name, an action, and a tone. One constraint applied was that objects cannot overlap. Their layout is, therefore, based on grid arrangements. Two forms of sound are used in the interface: musical tones and synthetic speech. Tones are used to communicate imprecise information quickly and speech is used to give more precise information more slowly. Speech is used to communicate die contents of documents being processed. An object's tone is sounded when the mouse is moved to point to it and the name of the object pointed to is spoken if the user presses the mouse button. The tones used in Soundtrack are simple square waves of differing pitch. The pitch varies with position, increasing from left to right and bottom to top. The edges of the screen are marked with another distinctive tone. Auditory objects are structured into two levels. At the upper level, the user interacts with an auditory screen comprising eight auditory windows. As the user moves the mouse across the window boundaries, their tones are sounded and their names can be ascertained, as previously described. To progress the interacting at the second level, the user activates a window, by double clicking the mouse button within that window. The same protocol applies within an activated window, so that each (sub)object has a tone and a name that are produced. Soundtrack demonstrated that a WIMP-style auditory interface could be designed for visually impaired users. Further improvements and experiments investigations are described in paper (Pitt and Edwards, 1995).

A diagram reader program for the visually impaired (Kennel, 1996) (called AudioGraph) enabled blind and visually impaired users to read diagrams with the aid of touch panel and an auditory output display. The experiments under the AudioGraph experimental platform described in this paper aimed to investigate whether structured musical stimuli can be used to communicate similar graphical information.

Invention of haptic devices leaded to design of multi-modal interfaces to access graphical information. An example of haptic system is Pantograph (Dufresne et al., 1995). The idea of multimodal access was realised in the research project PC-ACCESS (Martial and Garon, 1996). A similar technique was also used in the GUIB system in which graphics were communicated using sound and text using synthesised voice or Braille (Mynatt and Weber, 1994). There are known also later attempts to combine haptic and auditory (Jansson & Larsson, 2002).

Other approach is coding scheme based on a pixel-frequency association (Capelle et al,1998). The sensory substitution model can now be summarized as follows. According to model of vision, the acquired image matrix is first convolved by an edge detector filter and, second, converted into a multiresolution image. Then, coupling between the model of vision and the inverse model of audition is achieved by assigning a specific sinusoidal tone to each pixel of this multiresolution image; the amplitude of each sine wave is modulated by the grey level of the corresponding pixel. Finally, according to the inverse model of audition, the left and right complex sounds consist of weighted summations of these sinusoidal tones.

The experimental research (Rigas & Alty, 2005) indicated that the rising pitch metaphor can be successfully employed to communicate spatial information in user interfaces or multimedia systems. It was found that users interpreted better short sequences of notes (e.g., 6, 10 or 12). Longer sequences or groups of notes introduced an error in users' interpretation. Typically, 50–60% of the whole data was within +-3: Users successfully navigated an auditory cursor and recognised simple geometrical shapes. These results would enable the continuation of this work by introducing more shapes and enlarging the resolution of the 40 x 40 grid which was used as a basis for these experiments. The same research team (Rigas & Alty, 2005) carried out experiments of use of structured musical stimuli.

Tactile (embossed) maps were designed for this purpose. Until recently, the use of tactile maps has been very limited, as most of the maps have been produced by hand, for example using string and glue. Recent developments facilitated the production of cost effective maps. For example: printers, new types of papers and new types of ink.

An experiment found out that the tactile display did not improve performance when audio was present. The mouse appears to have some design deficiencies that means it is not useful on its own. However, as discussed above, when combined with other modalities it can be effective. Traditional methods of accessing diagrams use raised paper, allowing a teacher and student to work together by providing a visual representation of the diagram to the teacher and a tactile version to the student.

Providing accessible tactile diagrams through this method is not a trivial task. Is was noted that a direct translation of a visual diagram to a tactile diagram is in most cases not sufficient to provide accessible tactile diagrams. The data generated are static, and can be slow and expensive and error prone to alter and recreate. Further to this, for situations where the teacher and student are not collocated, this shared access to the workspace is not available through this method. For these reasons, there have been work examining computer-based technologies as an alternative to the raised paper.

In the TeDUB project (Technical Drawings Understanding for the Blind) (Horstmann et al, 2004) the system was developed, which aim is providing blind computer users with an accessible representation of technical diagrams. The TeDUB system consists of two separate parts: one for the semi-automatic analysis of images containing diagrams from a number of formally defined domains and one for the representation of previously analysed material to blind people. The joystick was used for navigation through drawings.
In the recent work (Zhao et al, 2008) sonification was used to convey data (plots) information to visually impaired user.

3. Method

3.1 Sounds

Humans can perceive a wide range of frequencies. The maximum range we can hear is from 20Hz to 20kHz. This decreases with age so that at 70 a listener might only hear a maximum of 10kHz.
Perception of sounds is characterised by three basic features: pitch, timbre, and loudness. They are subjective attributes that cannot be expressed in physical units or measured by physical means.
Pitch is the perceived frequency of a sound. In the case of a pure tone, its primary objective correlate is the physical attribute frequency, but the tone's intensity, duration, and temporal envelope also have a well established influence on its pitch (Houtsma, 1995). If a tone is complex and contains many sinusoids with different frequencies, which is usually the case with natural sounds, we also may hear a single pitch.
Our auditory memory seems to be particularly good at storing and retrieving pitch relationships, given that most people can easily recognize tones or melodies and sing them more or less correctly. This ability to recognize and reproduce frequency ratios is often referred to as perfect relative pitch. Some people possess the ability to identify the pitch of sounds on an absolute. This relatively rare ability is referred to as perfect absolute pitch.
Loudness may be defined as that attribute of auditory sensation that corresponds most closely to the physical measure of sound intensity, although, this definition is not accurate in all circumstances. Loudness is often regarded as a global attribute of a sound, so that we usually talk about the overall loudness of a sound rather than describe separately the loudness in individual frequency regions. Sounds of between 1kHz and 5kHz sound louder at the same intensity level than those outside that frequency range. Humans can perceive a very wide range of intensities.
The traditional definition for timbre used in ANSI standard is by exclusion. It is the quality of a sound by which a listener can tell that two sounds of the same loudness and pitch are dissimilar. This definition does not tell us what timbre is. The sense of timbre comes from the properties of the vibration pattern. Timbre is the attribute of auditory sensation in terms of which a listener can judge two sounds with the same loudness and pitch to be dissimilar. It is what makes a violin sound different to a piano even if both are playing the same pitch at the same loudness. Even though its structure is not well understood it is one of the most important attributes of sound that an interface designer can use.
The analysis indicates that non-trained people better rely on relative changes of sound than on absolute values.

3.2 Format of maps

Nowadays vector graphics format is widely used to store digitized maps. Often rich interactive maps are published in web using SVG file format (W3C, 2003). SVG is an XML markup language for describing two-dimensional vector graphics. It is an open standard created by the World Wide Web Consortium. The available fill and stroke options, symbols and markers enable higher quality map graphics.

As a XML based language, SVG supports foreign namespaces. It is possible to define new elements or add new attributes. Elements and attributes in a foreign namespace have a prefix and a colon before the element or attribute name. Elements and attributes in foreign namespaces that the SVG viewer does not know, are ignored. However, they can be read and written by script. Foreign namespaces are used to introduce new elements (e.g. GUI elements, scalebars) and for the attachment of non-graphical attributes to SVG graphic elements (W3C, 2003).

Most suitable software for browsing interactive SVG maps some years ago was plugin Adobe SVG Viewer, available for all major platforms and browsers (Linux, MacOSX, Solaris, Windows) which earlier could be downloaded free from the Adobe SVG homepage. Exist and commercial products as MapViewSVG from ESRI (ESRI , 2008).

```
<path id="Finland"
fill="rgb(128,255,128)" M140 76C139.82
70.67 133.284 62.11 127 63.46C119.30 65.11
117.69 71.50 109.00 66.48C98.81 60.59
100.58 49.34 93.58 41.11C86.38 32.65 83.01
40.97 83 48L77 46L96 75C105.89 76.76
118.67 89.71 120.09 100C121.01 106.62
117.20 113.69 116 120L123 127 .... C143.73
65.90 144.32 72.16 140 76 z"/>
```

Figure 1. Map with contour of Finland and example of contour description

Mapping represents a perfect application of SVG because maps are, by nature, vector layered representations of the earth. The SVG grammar allows the same layering concepts that are so crucial to Geographic Information Systems (GIS). Since maps are graphics that depict our environment, there is a great need for maps to be informative and interactive. SVG provides this interaction with very high quality output capability, directly on the web. Because of the complexity of geographic data (projection, coordinate systems, complex objects, etc.), the current SVG specification (W3C, 2003) does not contain all the

particularities of a GIS particularities. However, the current specification is sufficient to help the mapping community produce open source interactive maps in SVG format. Figure 1 is a example of represent map of Finland using SVG format.
The hierarchical structure of file for storing map is shown in Figure 2 (Daunys & Lauruska, 2006). There are shown only main elements. All map has text field with information about the map. This is information for presentation to user by speech synthesis. Other elements of the first level represent regions of maps. Actually, region is graphical tag of SVG, which describes contour of region. This tag has attributes related to sound, text and similar. Sound attribute allows to indicate sound file, which is played when cursor is over region. Text attribute is devoted to information about selected region.

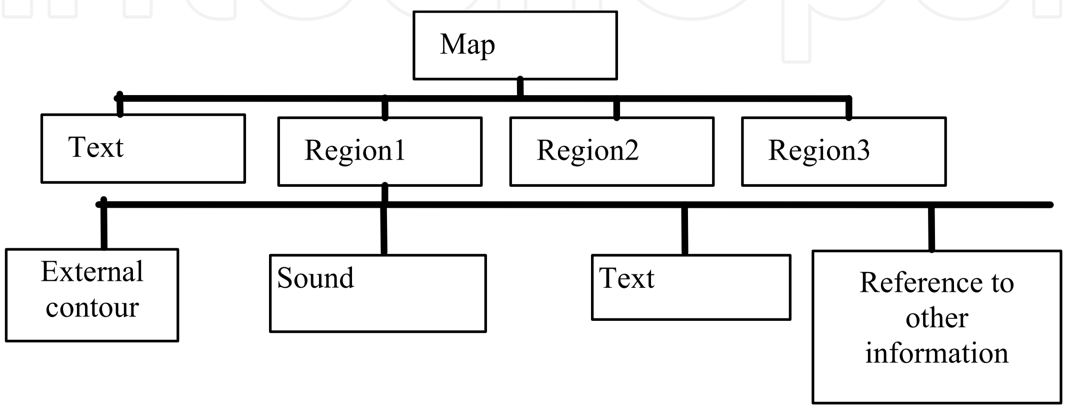


Figure 2. The hierarchical structure for maps information storage in XML format file

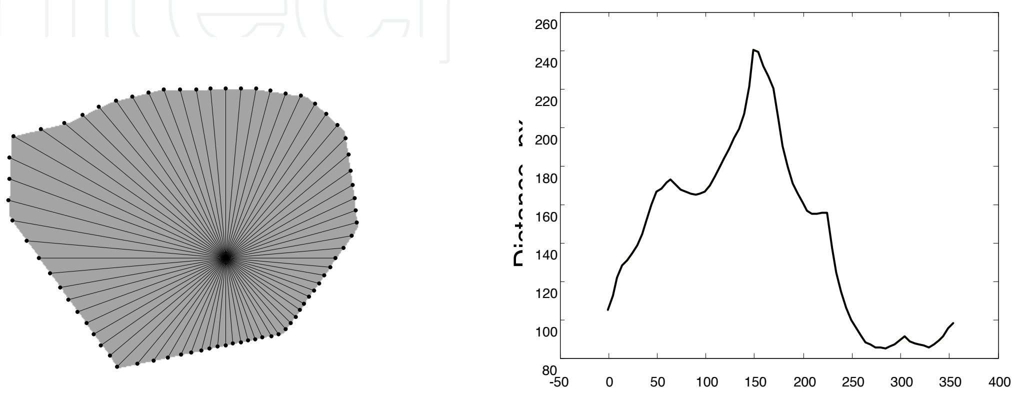
3.3 System model

First we consider the system hardware. Computer mouse is optional graphic-input device. The device use relative motion, so when the user hits the edge he or she needs merely to pick up the mouse and drop it back. It is convenient during usual work with computer applications, but maps exploration system is one of exceptions. In our application we need devices which give absolute coordinates. There are two choices: tablet and touchscreen. For graphical input on desktop or laptop computer we selected digitiser (tablet) as cheaper and more accurate device. PC computer have sound system and installed Microsoft Windows XP (Service Pack2) operation system.
Created sonification software without executable file has resources (collections of WAV and XML format files) and configuration file.
Software must implement these actions:

- loading default system configuration;
- selection of XML file;
- parsing of XML file;
- handling of mouse move events or menu options.

Moving of pen on tablet invokes mouse movement event in computer OS. Mouse events must initiate the generation of non speech sound. Mouse coordinates are defined and by them it is determined, over which region the mouse is present. If the mouse is on the same region as previously, now changes are done to played wav file. If the mouse goes to the new region, correspondingly, the old sound file is stopped and new file is started to play. Additionally, the distance of cursor point to the region boundary is measured to give alert signal if cursor is approaching the boundary of region.

The algorithm for determination of distance is next. The initial direction angle and the step for angle increase are selected. By default angle is equal to 0 degrees and step is equal to 5 degrees. We go from cursor point by the given angle while we reach boundary. Boundary is reached when pixel colour changes. Then we calculate Euclidean distance from cursor point to point on the boundary. The obtained value is stored in the array. Next direction is selected by adding angle step to current direction angle. And again point on boundary and distances is found (Figure 3 (a)). From the array of distances, which is plotted in Figure 3 (b), minimal distance is defined.



a) b)

Figure 3. Determination of minimal distance from cursor point to boundary of region: a) points on boundary detection in all directions, b) plot of distances between cursor point and boundary points

If minimal distance is lower than threshold then alerting signal is issued. The volume of sound is increased when distance decreases.

4. Implementation

In this section we will discuss implementation issues of the sonification system. For coding we selected C# language. We used the free Microsoft Visual C# 2008 Express Edition. The Windows application is based on ***System.Windows.Forms*** assembly.

The developed software must be very stable because it will be impossible for a disabled to solve a software crash and respond to unpredicted dialog boxes. Best guarantee for stability should be found in widely used technologies. In recent years the .NET Framework by Microsoft has brought the ability to write much more robust and secure code on the Windows platform. Furthermore, .NET Framework is not operating system specific; there exist some projects where .NET Framework is implemented in other OS. For example, one of the projects is Mono leaded by Novel.

One of the advantages of .NET Framework is its automatic memory cleaning, so called garbage collection. It is carried out when managed code is used. One of the simplest ways for managed code programming is the use of C# language.

.NET Framework promises good options for interoperability. It is easy to combine code written in different .NET languages because all code is first translated into CIL (Common Intermediate Language). CTS (Common Type System) also exists and ensures compatibility

of parameter types in functions calls. It is simpler to invoke methods on COM objects. There are also some choices for cross-machine communication between managed modules.
The parsing of SVG document was implemented using XLINQ library functions, other called as LINQ to XML library. The abbrevation LINQ stands for *NET Language-Integrated Query*. LINQ defines a set of general purpose standard query operators that allow traversal, filter, and projection operations to be expressed in any .NET-based programming language. The standard query operators allow queries to be applied to any **IEnumerable<T>**-based information source. XLINQ provides both DOM and XQuery/XPath like functionality in a consistent programming experience across the different LINQ-enabled data access technologies.
We used object-oriented programming technology. XLINQ allows parse data from XML file directly to classes of graphical objects.
Graphical rendering was implemented with Windows GDI+ functions. PictureBox control allows draw stable pictures. Included bitmap in it allows organise navigation plane.
For speech synthesis we used Speech library from NET. Framework version 3.0. It allows not only synthesize English speech but also some effects as emphasis of words or speech rate changes by 5 levels.
Only one software component was used outside .NET Framework. It was DirectSound library from Microsoft DirectX version 9c. Attractive features of DirectSound are advanced sound playing control: some files in the same time with independent parameters control.

5. Discussion

The differences of visual and auditory systems are pointed by Brewster (Brewster, 2002). Our visual system gives us detailed information about a small area of focus whereas our auditory system provides general information from all around, alerting us to things outside. Visual system has a good spatial resolution, while auditory system has preference in time resolution. So it is impossible to convey the same information by these two information channels.
In the sonification report (Kramer & Walker, 1999) it is stated that progress in sonification will require specific research directed at developing predictive design principles. There is also indicated about the need of research by interdisciplinary teams with funding that is intended to advance the field of sonification directly, rather than relying on progress through a related but peripheral agenda.
Analysis shows that there many different sonification efforts including solutions for visually impaired but they are more as project results and are not widely available.
The described sonification system can be easily implemented and easily integrated to bigger projects. The improvements mostly can concern selection of sounds.

6. Conclusions

XML format files were successfully used for preparing information for sonification. The developed model of sonification was successfully implemented using free software development tools: Microsoft Visual C# 2008 Express Edition and Microsoft DirectSound library.

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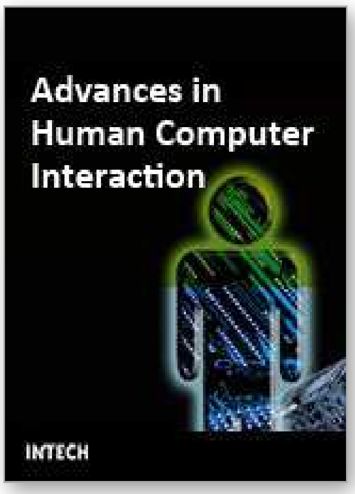

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In these 34 chapters, we survey the broad disciplines that loosely inhabit the study and practice of human-computer interaction. Our authors are passionate advocates of innovative applications, novel approaches, and modern advances in this exciting and developing field. It is our wish that the reader consider not only what our authors have written and the experimentation they have described, but also the examples they have set.

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