Multi-listener sonification:
A team approach to Interactive Auditory Display

Paul Lunn

School of Digital Media Technology
Birmingham City University
Millennium Point, Birmingham, UK

Paul.Lunn@bcu.ac.uk

Andy Hunt

The University of York
Heslington, York, UK

andy.hunt@york.ac.uk

ABSTRACT

When interactive sonification occurs in the real world – i.e., in a busy office environment, the listener is exposed to a wide range of sensory information. If the listener is distracted by their environment this reduces the effectiveness of the sonification, since a distracted listener will not interact with the data. The effect of localized distractions can be reduced when multiple listeners interact with the same data. This position paper discusses the merits of a team approach to sonification: sonifying in ensembles and in a distributed collective. In order to demonstrate this, a short pilot study of a group based sonification of listeners detecting signals in white noise whilst distracted is included.

1. INTRODUCTION

"The current enthusiasm for team working in organizations reflects a deeper, perhaps unconscious, recognition that this way of working offers the promise of greater progress than can be achieved through individual endeavor"

(West and Markiewicz, 2008) [1]

There are disadvantages to a single user listening to a sonification;

- The individual may not have perfect hearing
- They may have missed important information due to fatigue or distraction
- Everyone's individual perception of sound may be unique, so what one listener perceives as a signal may not be obvious to another, and
- The environment that the sonification may not be conducive for listening.

Utilizing multiple listeners can resolve some of these issues.

Multi-listener sonification involves two or more listeners interacting with a common data set. A team approach to sonification can provide several advantages. When dealing with a large data set, subdivision of the work amongst several listeners will reduce the overall time taken to listen to the data – a "many hands make light work" distributed approach. Multiple users independently listening to the same data will provide a more rigorous verification of any results obtained. Having users interact with a common data set in different environments will reduce the impact of localized environmental factors – such as distractions or intrusions.

2. MULTI-LISTENER SONIFICATION

Multi-listener sonification could be broadly subdivided into two approaches: ensemble sonification and distributed sonification. Ensemble sonification is when a sonification team works together in the same environment and at the same time, whereas in distributed sonification the listeners work on a common data set in isolation from each other.

2.1. Ensemble Sonification

There are several examples of sonifications that have utilized a multi-user approach. Cloud Bridge [2] is a multi-user interactive tool where several users simultaneously explore data as an ensemble. A tool was described by Tunnermann et al [3] where a multi-touch interface could be operated by an ensemble to interact with data via model-based sonification. EMOListen [4] is a multi-user platform that enables a group of listeners to interact with bio-signal data.

The above could all be classified as examples of ensemble sonification, where a group of listeners synchronously interact with a common data set in a shared environment. The advantages of this approach are that the group can interact with both the data and each other. However, a shared environment means that the group is collectively influenced by the same stimuli. This adds another level of interaction as the members of the ensemble will interact with both the sonification and each other. Figure 1 illustrates an individual listener who is placed within an interactive control loop.

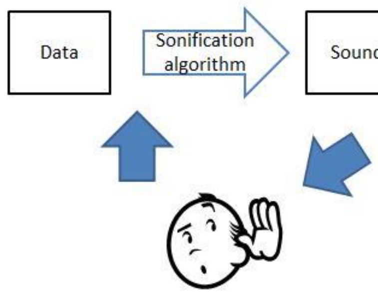

Figure 1. *A listener within an interactive control loop*

The user listens to the sound and through an interface is able to adapt the sonification algorithm. Figure 2 summarizes the effect of having additional listeners within this control loop.

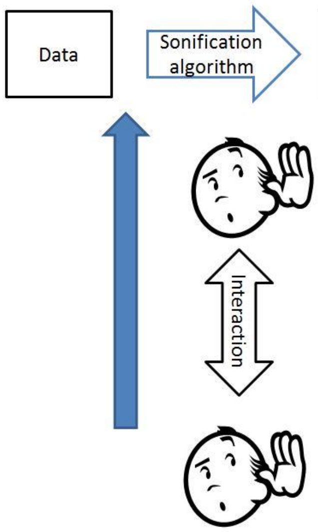

Figure 2. *Two listeners within an interactive control loop*

The addition of a second listener enables the team to interact with each other and the sonification (data and algorithm). It should be noted that there may be a limit to the maximum number of members of the ensemble, since an excessive number of listeners may only distract each other.

2.2. Distributed sonification

Distributed sonification is where a group of users interact with a common data set in isolation, each listener in a separate environment. Each individual forms part of a collective of sonifiers, and each member of the collective brings their own individual qualities to the group. Multiple users may interact with the data in separate environments and at different times. This approach to sonification shares many characteristics of a grid computing system, where a task is implemented on several separate computers. Parallels can also be drawn with a project such as Eric Whitacre's Virtual Choir [6], where thousands of singers separately record their own voices, which are then combined separately to form a choir. Like Whitacre's Virtual Choir, it is anticipated that distributed sonification will require a central administrator or conductor to co-ordinate the collectives' activities. A major benefit of this approach is that because each user is isolated, the effect of environmental influences on the sonification is reduced. For example, one listener may be distracted by a telephone call, but a collection of separate listeners would not be all distracted at the same time.

A distributed approach to sonification will be advantageous where there is a large amount of data to listen to. For example, a data mining task may result in a 20 hour long sonification. A solo sonifier would have difficulty in listening to this in one sitting; they would naturally experience fatigue and distractions which would reduce the efficiency of their work. If this was listened to by a community of 40 sonifiers, each only interacting with 30 minutes of data, the influence of listener fatigue would be reduced. Confirmation of any results could be achieved by multiple sonifiers listening to the same data. The use of a distributed collective, when dealing with large amounts of data, can lead to more accurate results.

3. ENVIRONMENTAL ASPECTS OF MULTI-USER INTERACTIVE SONIFICATION

3.1. Real world interactive sonification

Listening to sound in the real world is more challenging than listening under laboratory conditions. The listener is exposed to sights, sounds, tastes, smells and a gauntlet of additional day to day distractions, such as hunger, noisy neighbors, demanding work colleagues and the internet. Vickers [5] discusses how distraction and fatigue are challenges facing the designer of process monitoring auditory displays. The listener who is placed within an interactive control loop is exposed to multiple sensory stimuli (Figure 3). Some of this sensory data may interfere with the user's ability to perceive sound – for example, a listener with a toothache may be too distracted to effectively interact with the system.

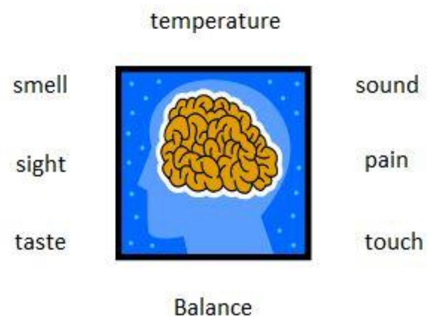

Figure 3. *Stimuli which may distract from effective listening*

The environment that the listener is placed in can have a substantial effect upon listening quality and thus can affect the listener's ability to interact with the sonification system. Interactive sonification is a field of sonification which places emphasis upon the listener interacting with the system that is producing sound [7]. The listener is placed into a control loop which responds to the user's input; Figure 1(which was displayed earlier in this paper) shows a control loop as found in interactive sonification.

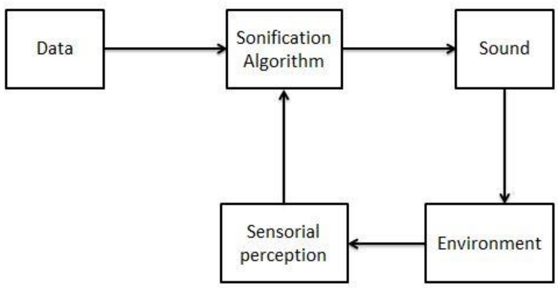

Figure 4. *A perceptual/environmental model of interactive sonification*

A model of interactive sonification that incorporates the environment and the listener's perception is illustrated in Figure 4. The environment that the sound is played in will influence the perception, and as any interaction is caused by sensory input, the environment will influence interaction. For example a noisy environment will diminish the listener's ability to perceive sound, and they may not interact with the system in the same way that they would if listening under ideal conditions.

3.2. Attention and Distraction

Ideally the listener would be placed into a quiet, distraction-free environment; in practice this may be difficult to achieve. This real-world environment will usually contain a level of background noise and disturbances which will distract the listener from interacting with the sonification. It is clear that the environment the sonification takes place in will have some effect upon the listener's attention. The environment provides a rich set of stimuli that is immersive: sights, sounds, tastes and smells all compete for attention. Although people are constantly stimulated, they have the ability to focus upon one set of stimuli at a time, they can pay attention to a single aspect of their environment. For example, when reading one may not be aware of background sounds. However an important characteristic of our attention system is the ability to refocus or move our attention to another stimulus. In the previous example we would stop reading when we heard a loud noise and then pay attention to its source. This is similar to the recognized psychoacoustic phenomenon, the "Cocktail Party" effect [9], where the listener's attention is diverted when they hear their name in noisy environment. Recognizing their name focuses the listener's attention upon conversations that they weren't aware of before. The brain must be subconsciously monitoring sounds in the background all the time.

It has been suggested that the human brain constantly monitors sensory information subconsciously; the brain scanning information in a low-level manner that has been described as a pre-attention phase [8]. In this pre-attention phase the brain may parse aspects of vision into objects, and amalgamate sounds of similar characteristics to form an auditory scene [9]. After this pre-processing, the attention given to the stimuli can be attributed to several factors. There are two forms of attention: automatic and selective [10]. Selective attention is when there is focus upon a stimulus, and a conscious choice is made to focus the attention on one area. Automatic attention is caused either by a change in stimulus, a stimulus that is considered important, or a stimulus that alerts the individual to danger. This is an instinctive response to changes in one's environment. When something triggers automatic attention, there is distraction from the selective attention activity.

4. EXPERIMENTAL WORK ON MULTI-USER SONIFICATION

An experiment was set up to explore if a distributed approach could be applied to a large data mining problem. This problem was related to the audification of radio astronomy data produced by the Search for Extra-Terrestrial Intelligence (SETI) [11]. This project audifies SETI data, as the default background data is generally random Brownian noise, and so the audified version has similar characteristics to white noise. Any potential candidate signals would be heard as glitches, tones, pulses or chirps within the noise. As the data is noise-based in nature it is presented to the listener as background white noise. Many listeners are familiar with noise-masking, and several internet sites such as [12] and apps, such as [13] now exist to mask environmental noise. For example, people in open-plan offices often report an improvement in productivity if they mask out distractions using white noise [14].

In this system, if a listener hears a candidate sound within the noise-like background data they can press a button on an interface that reports this information back to a centralized database. The user interface will include interactive controls to allow the listener to repeat sections of the data, which is important to enable them to confirm if there was a signal.
A single SETI observation generates a large amount of data, and once audified will generate 35 hours of audio. This is impractical for solo listening; however a distributed listening methodology would be beneficial. The audio is broken down into smaller packets and then distributed to a team, who individually interact with their own data. After the team has listened to this data, the incidents of button presses are collated; a number of hits from several individuals at the same time would indicate the presence of a signal, whereas false positives (where individual listeners have pressed the button in error) would not show a similar grouping.

4.1. Experiment

The objective of this experiment was to establish whether a team of listeners would be able to detect sinusoid signals mixed into white noise whilst taking part in a distraction activity.

An audio file, 14 minutes in duration, was created containing noise at -30 dB, generated from a SETI radio observation of the Moon [15], and which has Brownian noise characteristics. Mixed into the noise are 5 test tones that are 10 seconds in duration. These tones occur at various times throughout the test, and details of their frequency, amplitude and start times are shown in table 1. Start times listed are the number of seconds from the beginning of the test file that the signal starts.

Signal start time(seconds)	Frequency	Amplitude (dB)
56	200Hz	-30
137	200Hz	-50
251	1Khz	-40
446	1Khz	-30
788	200Hz	-54

Table 1. *Signal frequencies, amplitudes and start times*

These listening tests took place in an acoustically isolated room, where each listener was fitted with a pair of DT 100 Beyerdynamic headphones and asked to read a section of the novel The War of the Worlds [16] whilst listening to the audio file containing noise and signals. Listeners were asked to concentrate on the reading activity. If they perceived a signal, they reported this to the examiner by pressing a button, whereupon the examiner would log the time. The button was not connected to any devise but acted as an indicator that the listener had heard something. After the audio file was played, each listener was asked to complete a short questionnaire on the reading material, which was intended to establish if each listener was taking an active part in the reading task. All resources for this are available to download from the sonicSETI website [17].

4.2. Results

There were 9 participants, aged between 29 and 61, 8 males and 1 female. A table has been collated of the times that each candidate registered a signal and pressed the button (Table 2). The leftmost column (ID) is the candidate number and each time in seconds that the listener reported a signal is listed in the rows to the right (for example candidate 4 indicated 5 signals at 59, 140, 250, 447 and at 789 seconds. Several candidates reported more than 5 signals, with candidate 7 reporting nine signals.

	Time of report (seconds)								
ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	59	147	253	448	790				
2	57	60	140	172	252	447	792		
3	59	145	252	449	790				
4	59	140	250	447	789				
5	57	140	227	253	450	800			
6	57	141	254	450	793				
7	54	60	140	254	449	611	729	784	791
8	57	140	253	449	792	838			
9	58	140	253	310	448	789			

Table 2. *Times of signal detection reports for each candidate*

Table 3 indicates the number of correct reports per candidate. A report is identified as being correct if the candidate presses the button during the time that the signal was present. The correct column indicates the number of correctly identified signals, and the false column is the number of false positives – button presses when the signal was not present. The data appears to show some anomalous data – candidate 2 appears to identify signal 1 twice, candidate 4's identification of signal 3 is before the signal started, this could either be a false positive or an error when the time was written down. Candidate 5 identified signal 5 after the signal ended.

There is a high incidence of correct detection of the signals mixed in with white noise; the majority of listeners correctly detected all 5. Out of the 59 signal reports, 11 of these were false (18%), this would indicate that listeners are able to detect the presence of signal mixed into white noise whist distracted by a reading activity.

Evaluating these collated results as a group, it is clear to see that the real signals can be identified. When a listener falsely reports a signal, they do so in a random manner. A histogram which plots the number of reports against the time of report is shown in Figure 5.

ID	Sig 1	Sig 2	Sig 3	Sig 4	Sig 5	Correct	False
1	1	1	1	1	1	5	0
2	2	1	1	1	1	5	2
3	1	1	1	1	1	5	0
4	1	1	0	1	1	4	1
5	1	1	1	1	0	4	2
6	1	1	1	1	1	5	0
7	1	1	1	1	1	5	4
8	1	1	1	1	1	5	1
9	1	1	1	1	1	5	1

Table 3. *Table of correctly identified signals per candidate*

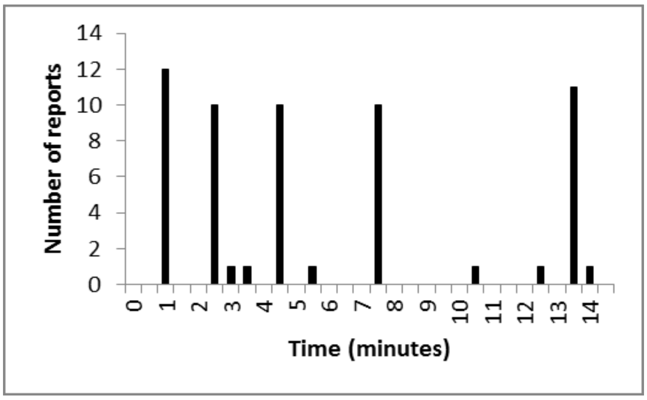

Figure 5. *Histogram showing incidence of reports against time*

Figure 5 shows that this team of sonifiers were able to correctly identify the presence of the five test signals presented; this is demonstrated by the five peaks on this histogram. The single points on the histogram are erroneous reports. By inspection of the graph it is easy to distinguish between clustering of hits when a signal occurs and the low incidence of errors.

5. CONCLUSIONS

In the real world, a listener in an interactive control loop is subject to a variety of stimuli – all vying for the listener's attention. The listener may become fatigued or distracted by their environment. There are other considerations such as the individual's hearing ability or competency to interact with the sound. A multi-user approach to sonification can help resolve some of these issues. Distributed sonification in isolated environments should reduce the effect of distraction. As demonstrated in the sonicSETI case study, individual errors can be ignored when plotted against a majority of results. Any results gained from a team of sonifiers are confirmed by a majority of listeners. When dealing with large amounts of data, where solo sonification would be time prohibited, a team of sonifiers could be a workable solution.

6. FURTHER WORK

As mentioned in the opening paragraph – this is a position paper which presents the novel concept of sonification in groups to this conference. This work in progress is expected to continue into several distinct areas.

The pilot study on distributed sonification was conducted under acoustically isolated conditions. The study's results suggest that collectively a group of sonifiers can accurately detect these signals, but further work needs to be undertaken to establish the effect of real-world conditions. This test needs to be repeated in a distracting and noisy environment to clarify whether distributed sonification can reduce the impact of the environment.

This work requires further study on ensemble sonification, with a particular emphasis upon the interaction between team members during a sonification experiment.

This team intends to conduct a live interactive ensemble based sonification during the presentation of this paper at the conference, which will incorporate live feedback of results obtained during the test, a technique that was suggested by Penelope Griffiths [18].

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