Physical Sonification Dataforms

Stephen Barrass

University of Canberra, Canberra, ACT, Australia

ABSTRACT

Physical Sonification Dataforms are physical objects constructed from digital datasets to produce sounds. This paper reports on a series of three experiments that establish and verify the theory of Physical Sonification. This experiments use the HRTF data provided as a sonification challenge at ICAD 2011. The dataset is a spatial array of spectral filters measured from the left and right ears of a dummy head. The proof of concept is a coin-like metal disc cnstructed from the data that can be struck or scraped to produce a sound. The second iteration is shaped like a bell to produce a more sustained and pitched sound. The third experiment compares a Control with Test Bells constructed from left and right HRTFs. The timbre of the Control is categorically different from the Left and Right Bells which are strangely dissonant. Spectrograms of the Left and Right Bells show a superposition of doubled harmonics. These results suggest that the sound of the Bell could characterize a HRTF dataset in a way that could be useful for classification and recognition of HRTF datasets from different people.

1. Introduction

Recent advances in the printing of 3d objects in Computer Aided Design have made it possible to produce physical objects from digital datasets. The range of materials that can be printed include stainless steel, glass and ceramics. This technology has been driven by the need to prototype models and parts in industrial design, automotive engineering, architecture and other fields where the 3D shape of an object is important for functional and aesthetic purposes.

These materials also have acoustic properties that can be shaped by digital processes. This opens the door to the production of sonic objects from digital data sets. The ecological theory of hearing is that the human ear has evolved to hear information in the physical acoustics of everyday objects. Taking a further step in this direction leads to the idea that specially designed acoustic objects could be physical sonifications of digital data they are constructed from. Up until now Sonification has relied on the artificial synthesis of sounds using electroacoustic circuits, signal processing algorithms and computer programs. Physical Sonification Dataforms will only need air to work.

2. Background

The sonification challenge has become a regular component of the International Conference on Auditory Display since the Listening to the Mind Listening Concert of EEG Data at the Sydney Opera House in 2004, the Global Data by Ear concert at the ICA in London in 2006, the DNA Sonification contest in Copenhagen in 209, and the Embodied Sounds concert in Washington DC in 2010. This year in 2011 Gyorgi Wysernyi has organized a challenge to sonify a spatial HRTF dataset.

The Sonification contest is an opportunity to express yourself and your creativity on the field of Sonification. A data set will be provided with a detailed description that has to be sonified. This year the data set is some two-channel (left ear-right ear) recording of a dummy-head containig the Head-Related Transfer Functions. These transfer functions describe the transmission from the free-field to the eardrums, and are the directional dependent filters for the outer ears. The data set and instructions can be downloaded below. It contains horizontal and median plane HRTFs. Your task is to sonify these „raw numbers". You are welcome to use any software and idea, artistic or musical performance. [Wersényi, 2010].

Many data visualizations are rendered in a 3D view to appear like a physical object. This can be particularly beneficial for understanding datasets that are spatial or 3d in nature. The development of 3d printing has allowed researchers to render 3D visualizations in a 3D physical form. The manual manipulation and feel of the dataset may allow different perceptions and deeper understanding of the data than the screen version. A broad spectrum of these "data sculptures" are described and analysed in theoretical terms of metaphorical distance and embodiment in [Zhao and Vande Moere, 2008].

3D CAD tools have also been used to design 3D acoustic forms. The Federation Bells in Melbourne is a public installation of 39 bells of up to 1.2 tonnes in mass that were designed using computer simulations in order to produce specified just-tuned harmonics [MacLachlan, 2003].

Drawing these threads together lead to the idea of printing a 3D version of the HRTF dataset and then physically striking it to produce a sonification of the entire dataset in a single tone. The rest of this paper describes the process of producing this object, and the insights that have been gained along the way. The next section describes the three experiments that have established and verified the hypothesis of Physical Sonification Dataforms. This is followed by an analysis and discussion, then conclusions and further work.

3. Experimental Method and Process

3.1. HRTF Dataset

The HRTF dataset was measured by recording a white noise excitation using microphones in the ear canals of a dummy head. The dataset for the horizontal plane contain files at 1 degree intervals for both the left and right ear. The first three digits indicate azimuth from 0 to 359 degrees and each file contains 2*2048 *float* numbers that describe the spectral FFT from 0 Hz (DC value) up to 25 kHz.

3.2. Data Medallion

The first prototype called the Data Medallion is a coin-like disc made from stainless steel that produces a sound when struck or scraped. The Data Medallion was inspired by a paper on visualizations of HRTF provided with the dataset [Wersényi, 2010].

The polar plot of 360 HRTFs for one ear, shown in Figure 1., arranges the FFTs as spokes at 1-degree spacing, with the DC component at the centre and higher frequencies radiating outward. The spokes are coloured by amplitude at each point of the spectral envelope, to form a disc as shown in Figure 1a. Complete HRTF datasets are difficult to compare as a whole. This problem has been addressed with a second polar visualization of the difference between left and right ear called a HRTFD.

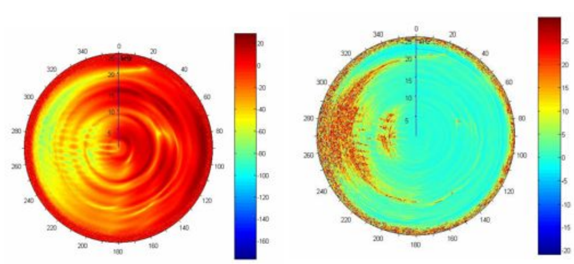

Figure 1. Polar Visualisations of HRTF data

A 3D visualization, shown in Figure 2. was also proposed to help auditory researchers comprehend and analyse the details of these large and complex HRTF datasets

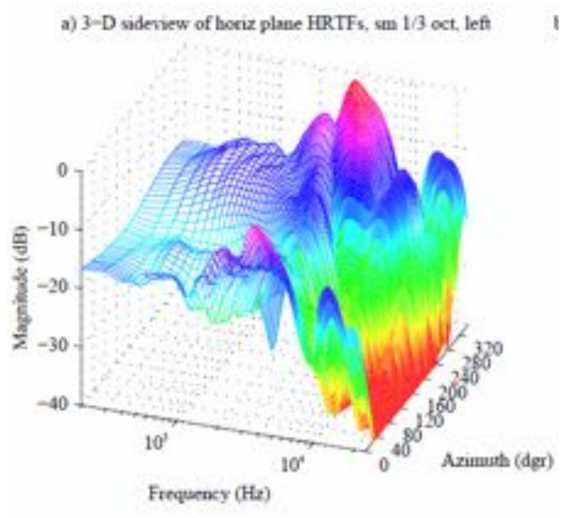

Figure 2. 3D visualization of HRTF for one ear

The combination of these visualizations inspired the idea that the left and right ear HRTFs could be presented as opposite sides of a physical coin. The idea was explored by constructing a 3D mesh in a CAD package as shown in Figure 3. This mesh was then laser printed in stainless steel to produce a physical object, as also shown in the figure. This object, called the Data Medallion is 5cm in diameter and ranges from 2 to 6 mm in thickness. The left and right ears are present as opposite sides that can be felt at the same time. The object produces a short sharp metallic sound when struck, and the surface roughness can be heard by scraping it with a metal rod. The capability to produce sounds from the HRTF dataset in this way is a proof of concept for Physical Sonification Dataforms.

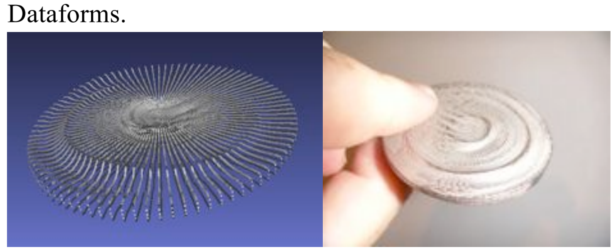

Figure 3. Data Medallion – a proof of concept

3.3. The Golden Bell of Hearing

Although the Data Medallion produces sounds from physical interactions, most of the information is related to the size, shape and material of the disc, and the effects of the dataset on the sounds is unclear. In experiments it was necessary to hold it with pointed pliers to prevent the sounds being damped. These observations led to a second iteration of the concept designed to enhance auditory perception of the characteristics of the dataset. The Golden Bell of Hearing was constructed by applying the HRTF spectral profiles to alter the exterior thickness of a bell shaped object, as shown in Figure 3. A handle was manually modeled and attached in a CAD program, and the object was again 3D printed in stainless steel as shown in the Figure. The physical acoustics of the bell-like shape produce a longer pitched ringing tone that produces small changes in timbre when struck in different locations. The metaphor of a bell also provides a cue for interacting with the object in an acoustic manner. The Golden Bell of Hearing demonstrates the application of acoustics and affordances to design and develop a Physical Sonification Dataform.

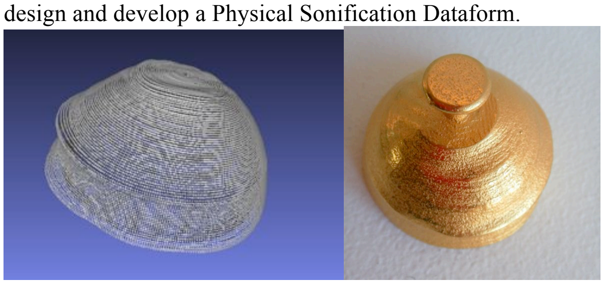

Figure 4. The Golden Bell of Hearing – an application of acoustics and metaphor to the concept

3.4. Test Bells

The hypothesis of Physical Sonification is that a physical acoustic form can allow the auditory perception of useful information about a dataset. The third experiment tests this hypothesis by comparing Bells constructed from the left and right HRTFs with a Control. Based on observations from the previous experiment the Bell form was made larger with a bigger handle and an internal loop for hanging a clapper. The Control Bell consists of this template without any data applied to it. The Left and Right bells were constructed by applying the spectral envelopes on the outside as previously. However this time a more complex shell was constructed by inverting the spectral envelope on the inside to follow the exterior, as shown in Figure 5. This more complex shaping was designed to increase the effect of the dataform on the acoustics of the object.

Figure 5. Forming the Left Bell from the Data.

As before, the three Test Bell dataforms were 3D printed in stainless steel, as shown in Figure 6.

Figure 6. Left, Control and Right Test Bells

3.5. Results

The Control Bell produces a 1.4s tone with fundamental at approximately 3kHz, and two main harmonics at approx 7.5kHz and 14kHz, when it is struck with a metal rod. Although the harmonics are not evenly spaced the tone is distinctly bell like.

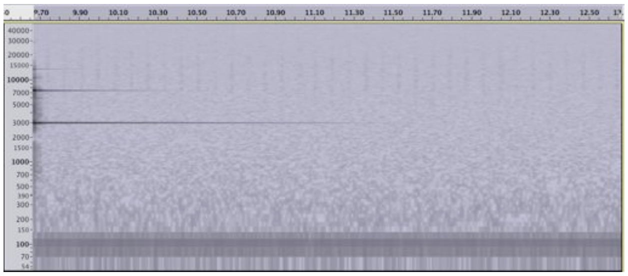

Figure 6. Audio spectrum of the Control Bell when struck.

When the Left Bell is struck it also produces a fundamental at approximately 3kHz with a duration of 2s, and major harmonics at 7kHz and 12.5Khz as shown in Figure 7. Although the spectrum appears similar both the Left and Right Bells have a dissonant tone that is distinctly different from the Control.

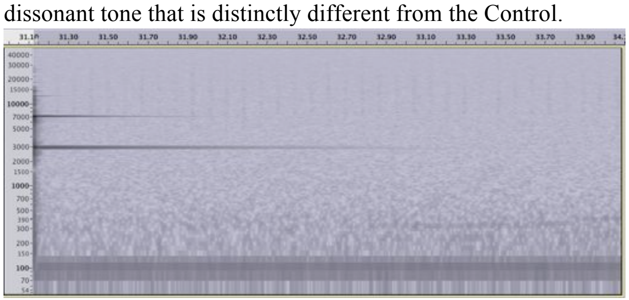

Figure 7. Audio spectrum of the Left Bell when struck.

The reason for the dissonance is evident from a closer inspection and comparison of the spectra in Figure 8. The Left Bell has a fundamental at 2.9 and 3.0 kHz, and second harmonics are at 7.0 and 7.1 kHz, with a repeated pattern of doublings in higher harmonics. The Right Bell has double fundamentals at 3.0 and 3.1 kHz, a set of doubled second harmonics at 7.2 and 7.3kHz, and a different pattern of higher harmonics.

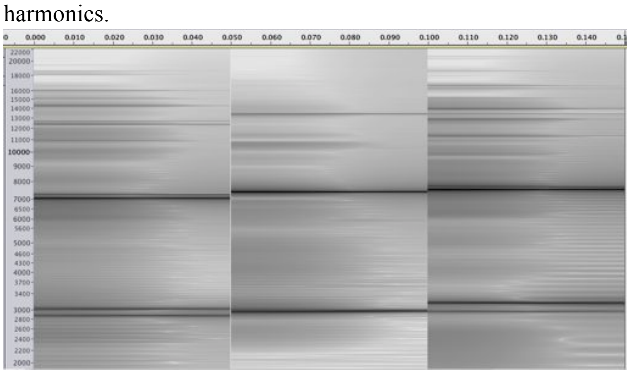

Figure 8. Spectra for Left, Control and Right Bells.

4. Discussion

The Left and Right Bells are distinctly in timbre and duration from the Control bell. The difference in timbre is due to a superposition of two harmonic series separated by about 100Hz in fundamental frequency. This produces a beating and dissonance that is unusual in a bell sound. The Left bell is slighty lower pitched than the Control, while the Right is slightly higher pitched. So although the Left and Right Bells have categorically similar timbres that distinguish them from the Control, they have a distinct difference in pitch that distinguishes them from each other. This pitch difference may be due to the yellow/red highlight in the visualization of the HRTFD in Figure 1. The Left and Right also have subtle differences in timbre due to the different patterns of upper harmonics.

5. Conclusion

This series of experiments has developed a proof of concept, a design process, and a validation for a theory of Physical Sonification Dataforms. In the first prototype the data was used to shape a coin-like medallion constructed from stainless steel, with the data from the left ear on one side and the right on the other. The Data Medallion produces a sound when struck or scraped, but the sound is damped by being held. The Medallion also allows you to see and feel the left and right ear HRTFs as features on both sides of a physical object you can put in your pocket for further contemplation at your leisure.

The next iteration was a small bell made of gold coloured stainless steel in which the HRTF filters of the left ear are rendered by the thickness of the curved sides. The Golden Bell of Hearing produces a more sustained and pitched bell like sound when rung. The design of the bell demonstrates the application of acoustics, metaphor and interaction affordance to the concept. The third experiment tests the hypothesis that the physical acoustics of the Bell can characterise the HRTF dataset of 360 spectral profiles as a single tone. The sounds produced by a control, left and right ear datasets were compared perceptually and spectrally. The Left and Right ear bells sound categorically different from the Control bell, and different in pitch from each other. The spectrograms from each bell show differences in the temporal development of harmonics caused by differences in the shape of each object. These observations support the proposal that Physical Sonification Dataforms can provide useful information about the dataset. The auditory differences between the Test Bells demonstrate the plausibility to distinguish HRTF datasets measured from different people by listening. These differences could be used to classify entire datasets in terms of similarity and difference from a single tone, and perhaps even to remember and associate datasets with different individuals

5.1. Further Work

In further work we will continue to explore the psychoacoustic effects of different shapes and forms, with different types of data. We will also explore design issues of metaphor, affordance and functionality with different tasks, contexts, and users.

6. References

[1] Zhao, J. and Vande Moere, A. (2008) Embodiment in data sculpture: a model of the physical visualization of information. In *Proceedings of the 3rd international*

conference on Digital Interactive Media in Entertainment and Arts (DIMEA '08). ACM, New York, NY, USA, 343-350.

[2] McLachlan, NM. Keramati Nigjeh, B. and Hasell, A. (2003) The Design of Bells with Harmonic Overtones, *Journal of the Acoustical Society of America*, **114 (1)**, p 505-511.

[3] WERSÉNYI, GY. (2010) Sonification Contest, International Conference on Auditory Display, Budapest, Hungary, 20-24 June, 2011, http://icad2011.com/the-sonification-contest.html, retrieved 28 May 2011.

[4] WERSÉNYI, GY. (2010) Representations of HRTFs using MATLAB: 2D and 3D plots of accurate dummy-head measurements. Proceedings of the 20th International Congress on Acoustics (ICA), Sydney, Australia, 2010 Aug. 23-27.