REVERBERATION FOR AMBIENT DATA COMMUNICATION

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ABSTRACT

We propose an ambient communication system that modulates the reverberance applied to music with a single variable in order to communicate non-musical information to the listener. In order to assess the effectiveness of such a system, psychoacoustic tests of four subjects' ability to discriminate changes in reverberant decay time (RDT) were conducted. Results indicate that human listeners are able to accurately detect changes in RDT from a reference value of two, five, and ten seconds when the RDT increases by more than 60% or decreases by more than 30%. The rather large change in RDT required for accurate perception limits the dynamic range of the information that can be communicated when the variable is used to linearly change the RDT.

1. INTRODUCTION

Most people, when outdoors on a sunny day, are able to discern the approximate time of day by absorbing the ambient information surrounding them – the position and intensity of the sun, the length of shadows cast by objects and the colour of the sky and horizon. We need only to look at a wristwatch if we require a more accurate understanding of the current time. Similarly, we can use other forms of ambience to communicate data. Ambient communication – communication with minimum sensory and attentional overhead – is a relatively new area of research. An ambient communication system allows the user to monitor a small number of variables, without demanding the user's full attention and leaving the user free to concentrate on other activities. Two notable visual ambient displays, which are currently under preparation, use computer generated trees or computer generated human faces to reflect trends in stock market prices [Eades et. al.] [1].

In the related area of sonification, a significant amount of research investigating methods to generate sounds directly from data has been undertaken. However, such direct sonification is not always practical for ambient communication and in many cases the resulting sounds cannot be used as background music [2] [3] [4]. This paper presents an ambient communication system which changes the reverberation decay time (RDT) of any arbitrary music source as a function of the data being monitored.

When a listener listens to a sound source, wave-fronts from that sound source reach the listener either directly (the direct sound) or after reflecting one or more times from surfaces within the surrounding space (the reflected sound). Each time a sound wave reflects off a surface, the reflection order increases and some of the sound energy is absorbed. Low order reflections can give rise to distinct echoes and higher order reflections influence the over all reverberant quality of a space. Furthermore, the less absorbent the surfaces and the larger the volume of the space, the longer it will take for the sound energy to decay. Sound energy decays exponentially following an impulsive sound burst with a characteristic decay time – the reverberation decay time (RDT).

Reverberation provides important cues to the listener regarding the surrounding environment. More specifically, the late reverberation energy can indicate the volume of the surrounding space [5]. By modulating the reverberation, we change the listener's environmental context.

2. METHODS

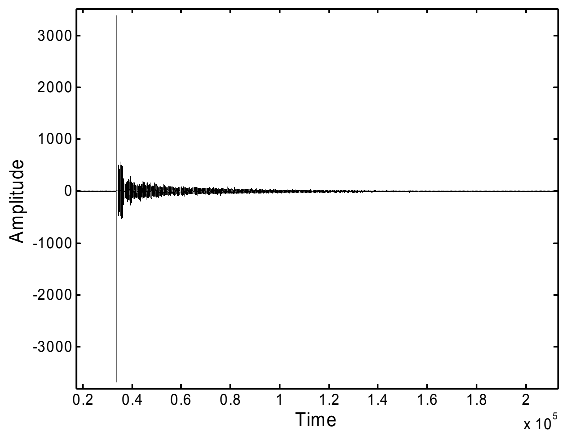
2.1. Ambient data communication system

We have developed an ambient data communication system for the PC which modifies in real-time the reverberation of the music/sound being played based on a single, external data signal. The software was written for the Windows XP platform using C^{++}, DirectX for sound/music playback, and Creative Labs' Environmental Audio Extensions (EAX) to control the reverberation. The external data signal can be sent to the PC system from a variety of sources including standard input, a file or more commonly through a TCP/IP socket. The system has been designed so that it can be connected to a live data stream, such as from the stock market.

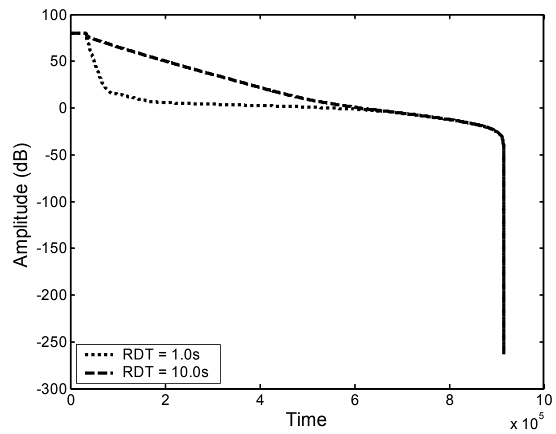
2.2. Psychoacoustics

In order to assess the sensitivity of human listeners to changes in reverberance, we conducted psychoacoustic tests. A two alternative, forced choice (2AFC) paradigm was used in which four test subjects used headphones to listen to the same music signal presented twice (choices A and B), but with the RDT modified using EAX. The music signal was an 8 second clip from a classical piece of music that was recorded in 16 bit stereo at 44.1 kHz [6]. In each trial, one presentation had a reference RDT (2s, 5s, or 10s), which was identical for all the trials in a particular test, and the other presentation had an RDT which varied between 0.1s and 20s. Each presentation of the music signal had the sound level normalised so that the RMS energy was identical for all presentations. The signal with the reference RDT was presented randomly as either choice A or choice B for each trial. The subjects were instructed to select the more reverberant music signal (A or B). Each test consisted of 120 trials and was typically completed in about 30 minutes. Each subject completed three tests in total: Test 1 had a reference RDT of 2.0s, Test 2 had a reference RDT of 5.0s, and Test 3 had a reference RDT of 10.0s.

Figure 1a shows an example of the EAX impulse response used to create sounds with a 10s RDT and Figure 1b compares the reverberation decay time (Schroeder plot) of the impulse responses corresponding to an RDT of 1s and 10s. The impulse response was measured using the log-sine sweep method [7] in which the sweep was played through the sound card and EAX was used to add reverberation to the sweep sound. The sound generated by the sound card, after EAX filtering, was recorded digitally from the soundcard's output buffers. The log-sine sweep was 20 seconds in duration, recorded in 16 bit mono at a sampling frequency of 44.1 kHz, and had a frequency range from 20 Hz to 22 kHz. The Schroeder plot, figure 1b, shows that the EAX RDT parameter modifies the decay time of the reverberation.



(a)



(b)

Figure 1. *(a) Impulse response for the 10s decay time; (b) Schroeder plot for the 1s and 10s decay time.*

3. RESULTS

Test 1 used a reference RDT of 2.0s. A curve was fit to the psychoacoustic data (with outliers removed) using probit analysis [7]. The results (Figure 2) indicate that subjects were able to detect the difference between an RDT of 2.0s and an RDT of 5.0s or greater, but there was a 15% error for RDTs of 1.0s and below. Similarly, Test 2 used a reference RDT of 5.0s and the results (Figure 3) show that subjects were correct more than 85% of the time for RDTs greater than 9.0s and less than 3.5s. Finally, for Test 3 with a reference RDT of 10.0s, the results show that subjects were correct more than 85% of the time for RDTs greater than 15s or less than 7s, but that performance was around chance in between.

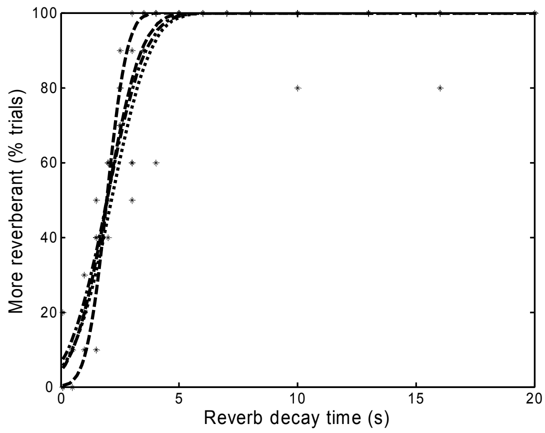


Figure 2. *Results from each of the four subjects showing the percentage of trials in which they responded that the test sound was more reverberant than the reference sound. The reference sound had a reverb decay time of 2.0s.*

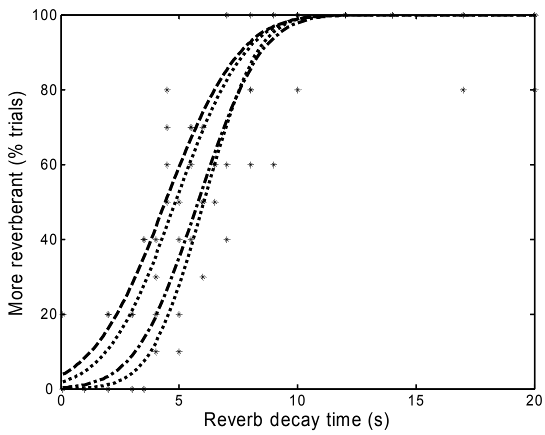


Figure 3. *As in Figure 2, but with a reference reverb decay time of 5.0s.*

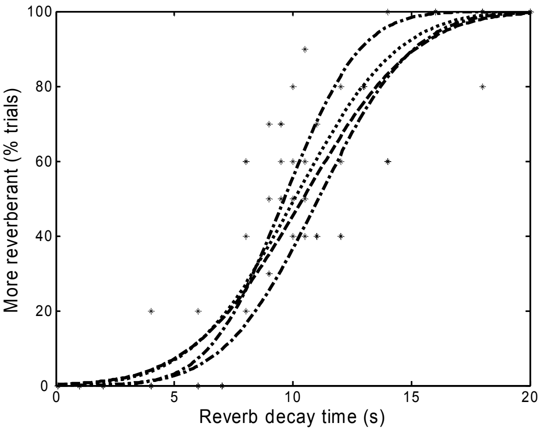


Figure 4. *As in Figure 2, but with a reference reverb decay time of 10.0s.*

4. DISCUSSION

The psychoacoustic data indicates that the reverberant decay time has to increase by approximately 60% or decrease by approximately 30% before the change in decay time is accurately perceived. The asymmetry of these changes also indicates that the larger the RDT, the less sensitive the human auditory system is to these changes. The results suggest hat human sensitivity to reverberation decay time is in accordance with Weber's law. The relatively large differences in RDT required for perfect detection limits the resolution at which information can be encoded using RDT in an ambient data communication system.

With regard to algorithms for encoding information using RDT, if the RDT is modified linearly with the data, then listeners will not know with absolute certainty when the signal has crossed a critical threshold, but will be able to follow increasing and decreasing trends in the signal. In addition, most listeners should be able to accurately follow moderate changes in reverberation. In terms of an ambient data communication system, this result may be acceptable because the system is not intended to give a precise representation of the data value. The user can always ascertain a more precise value for the data offline, if it is required.

5. REFERENCES

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