Measuring Binaural Decoloration in rooms

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Introduction

For many years, the spectral properties of audio signals and room responses, and their perceptual effects, namely coloration are an open research field. Several studies have examined the perceptual effect of coloration in single channel room impulse responses (RIRs) [1,2]. However, in daily life, human listeners do not perceive single channel signals and their coloration effects, but rather binaural signals. In natural environments, as in a room, the signals arriving at the two ears are not equal, but rather decorrelated (dichotic listening condition). Several studies examined this situation [3,4] and compared the dichotic to a diotic condition in a threshold experiment over headphones. The findings show that the perception of coloration is stronger for the diotic case.

The aim of this study is to match the amount of coloration for the diotic listening condition that represents the perceived coloration of the dichotic condition. Based on the results a metric is proposed to quantify the perceptual effects of Binaural Decoloration. A method to change the coloration of a RIR has been developed through manipulation of the spectral content.

Theory

When a signal is played inside a room, the reflections introduce reverberation to the signal. The reverberant structure from the source to the microphone is described with the room impulse response (RIR) in the time domain, corresponding to the spectrum in the frequency domain. In order to represent the frequency content of a RIR, the logarithmic magnitude spectrum is used. The reverberation inside a room introduces spectral modulations around the mean value μ in the spectrum (see figure 1). This "spectral modulation depth" is measured with the standard deviation (σ_{spec}).

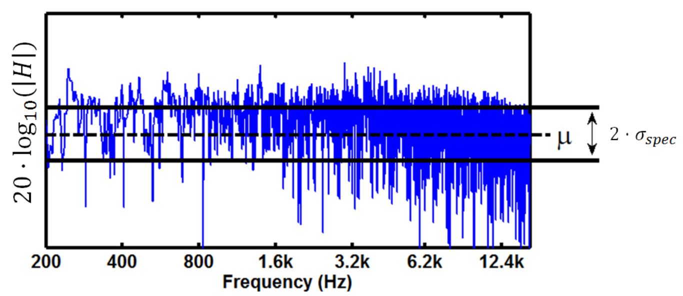

Figure 1: Logarithmic magnitude spectrum of a RIR

With the paper of Schroeder 1954 [5] a statistical approach for the description of the spectrum of a room has been introduced. The underlying assumption is that the sum of plane waves with random phases and amplitudes, with reflections arriving from random directions, at frequencies with a high modal overlap is a random process. This is valid above the Schroeder frequency and beyond the critical distance of the room. The result of the theoretical analysis by Schroeder is that this σ_{spec} of a single room is equivalent to 5.57 dB.
In this study a rather generic description of coloration is given, with a certain amount of abstractism:

Coloration in rooms is the spectral change attributed to the transfer function of the room

In this work, σ_{spec} is used in order to quantify the amount of modulations in the spectrum (also below the Schroeder Frequency), that are attributed to coloration.

Listening Experiment: Binaural Decoloration

Procedure

For the listening test on Binaural Decoloration, binaural RIRs (BRIR) have been used, recorded over an artificial head. To obtain a diotic condition, the left BRIR has been used. An experiment was designed where the strength of the coloration for the diotic condition was manipulated and matched over a slider to the dichotic condition.

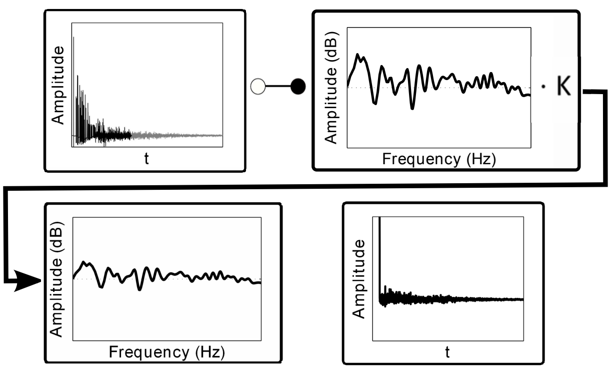

Figure 2: Blockdiagramm for adjusting the spectral modulation depth σ_{spec}

Table 1: Details to the BRIRs

Rooms	T_{60}	distance
office	0.43 s	1 m, 2 m, 3 m
stairs	0.86 s	1 m, 2 m, 3 m
hall (carolina)	1.5 s	1 m, 2 m, 3 m

Diotic condition To create a diotic presentation, the left ear signal of the BRIR has been used. To change the coloration, the following simplification has been applied to the RIR (see figure 2). The first part, namely the first 50 ms of the left ear BRIR was transformed into the frequency domain, where the logarithmic magnitude spectrum could be multiplied with a factor K. This allows to either increase or decrease the spectral peaks and dips. The resulting spectrum has been further transformed back into the time domain, creating a minimum phase filter shape. By convolving this filter for example with a dry recording of an instrument, the spectral content of the RIR can be imprinted on the signal. Listening participants were able to vary this factor K using a slider and consequently manipulate the coloration of the signal. The original spectral modulation strength was unknown to the participants. It is important to note that the temporal structure is no longer preserved together with the decay beyond 50 ms. But due to the fact, that most energy lies within the early reflections, they give a good representation of the spectral shape, while the later reflections only provide spectral fine structure.

Dichotic condition For the dichotic presentation a similar procedure as with the diotic presentation has been followed. The first 50 ms of the left and right BRIR were transformed into the minimum phase filter shape, for each channel separately.

Room impulse responses

The BRIR were obtained from the RIR database aachen [6]. Details can be seen in table 1. Three rooms were used, corresponding to three different reverberation times along with three different distances for each room.

Stimuli

Previous studies measured the effect of Binaural Decoloration with white noise as a test signal [3,4]. This study aims to measure the effect also over natural instrument signals. Here a piano (Kurzweil PC88 with no spatial effects apparent) was used as a test signal, which was convolved with the minimum phase filters obtained from the BRIR. The test signal has no pause or a decay phase, a ongoing structure, but still contains transient parts due to changes in chords.

Listening Setup

The listening test was conducted at the University of Oldenburg in a single-walled listening cabin and stimuli were presented over Sennheiser HD650 headphones at an average listening level of 65 dB SPL.

Participants

Six experienced listing participants took part in this study, with an average age of 32 years. To introduce the term "‘coloration"’ to the participant, examples with several spectral manipulations were given before the listening test. Every participant gave one estimation of coloration for each condition, without any retest. The standard error is used to display the deviation between the listening participants.

Results

To interpret the results from the listening test, the spectrum is analysed. Since the adaptive parameter was the modulation depth in the spectra, the resulting spectra are analysed over σ_{spec}. In figure 3 the results are shown. The Y-Axis gives σ_{spec} in dB, on the X-Axis, the different rooms subdivided with the three distance conditions are given. The red line represents σ_{spec} at the left and the right ear for the dichotic condition. For the left and the right ear different σ_{spec} are apparent, while the values are roughly between 5 and 6 dB, as to be expected from the theoretical $\sigma_{\text{spec}} = 5.57$ dB from Schroeder. Only for the Stairs condition at one meter, σ_{spec} seems to decrease. The thicker green line denotes the unchanged σ_{spec}, relating to the spectral shape that participants had to adjust. In blue the resulting σ_{spec} is displayed, that gives the adjusted coloration strength for the diotic condition, representing effectively a measure of the perceived dichotic coloration.

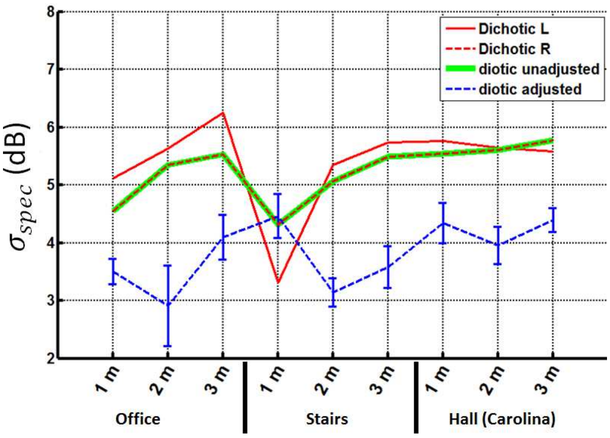

Figure 3: Blockdiagram for adjusting the spectral modulation depth σ_{spec}

Discussion

For nearly all conditions, Binaural Decoloration has been measured. The listening participants have adjusted the spectral moduluation depth σ_{spec}, roughly between 5 - 6 dB to a mean σ_{spec} between 3 - 4.5 dB. The difference represents the Binaural Decoloration in dB. Interesting to note are the stairs at 1 meter, which have an unconventionally low σ_{spec} for the left and the right RIR. In this case the mean was adjusted equal to the original σ_{spec}. A potential explanation for this is, that if the σ_{spec} for the dichotic condition is already low, the effect of Binaural Decoloration is not apparent.

Conclusion

In this study a method for measuring Binaural Decoloration is introduced. The aim is to match the perceived diotic coloration to the amount perceived under a dichotic condition. The method allows to measure a difference between the diotic and the dichotic condition, which can be attributed to the effect of Binaural Decoloration. Using this method it is possible to quantify the effect in dB and measure it for different signals/instrument.
Due to the fact that dichotic listening is the common mode of listening in natural environments, it can be assumed that Binaural Decoloration is a daily property of the daily auditory experience. Our hearing system (including the brain) seems to be able to reduce spectral changes, attributed to coloration. This Binaural Decoloration is a perceptual phenomenon that reduces the need for a very accurate spectral equalisation in virtual acoustics such as e.g. Wave-Field Synthesis.

References

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