Loudness-based reverberation analysis for room acoustics

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Introduction

Reverberation is defined as the late sound energy in a room. It can be quantified by the measures *reverberation time* and *reverberation level* (or diffuse sound level). The former can be used to describe how long the reverberation decays and is well established in practice [1]. The latter can be used to describe the strength of reverberation energy and is far less used in practice. Currently, there are shortcomings when trying to describe the main perceptual attribute related with reverberation, that is *reverberance*. An example from practice emphasizes this:

Two existing rooms were measured: A large church (7000 m^3) and a small chapel (700 m^3). The reverberation times T_{30} were 2.4 s and 1.9 s respectively. The clarity index C_{80} – another established measure to predict reverberance – was identical in both rooms ($C_{80} = 0$ dB). However, the second room sounded much more reverberant – despite the shorter reverberation time!

The main reason lies in the difference in reverberation level[1]. Therefore, an equal-reverberance listening experiment was conducted (previously discussed in [2]). In this paper, the results from the listening test are analyzed with three techniques to quantify reverberation.

Method

The two established methods to investigate auditory perception in rooms are laboratory and in situ testing. Both methods have advantages and disadvantages. Several of the advantages can be combined when testing in a room that is acoustically altered by adding reflections through loudspeakers. This semi-virtual environment offers a realistic surrounding while maintaining certain degrees of freedom.

Experiment

The experiment was conducted in a lecture hall equipped with many loudspeakers and such an electronic acoustics system (see Fig. 1). The lecture halls has a volume of circa 770 m^3 and a natural reverberation time of ca. 0.7 seconds at mid-frequencies.

Using the system VIVACE, four acoustic settings were presented, named "Reverb 1", "Reference Reverb (2)", "Reverb 3" and "Reverb 4". These reverbs differed in reverberation times as is shown later. The task was to set the four acoustic settings to an equal reverberance by changing the system gain, that is the reverberation level. 14 participants of which half were experienced listeners (acousticians with more than 10 years of experience in critical listening). The age averaged at 46 years with 12 male and 2 female participants. The test was completed in 9 minutes on average. For more details see [2].

After the stimuli were set at equal reverberance by the participants, impulse response measurements as well as audio recordings were conducted, serving as an input for the successive analysis methods (Table 1).

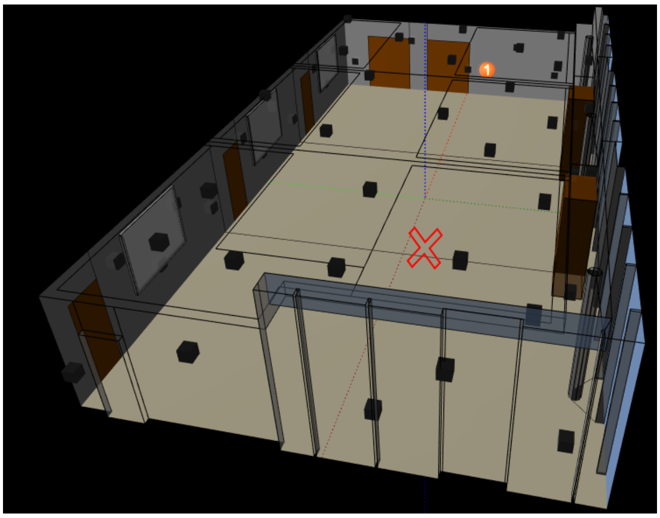

Figure 1: 3D-model view of the real lecture hall. Black rectangles show enhancement loudspeakers.

Table 1: Investigated methods for reverberation analysis

	Method		
	A - "Standardized"	B - "Hybrid" [3]	C - "Psychoacoustic" [4]
Input	Impulse response	Impulse response	Ear signal
Model	/	Loudness model DLM, TVL, ISO532-1:2016	Auditory model + processing
Output	Decay times T_{30}, EDT...	Loudness decay times	Reverberance predictor sRev

Results

"Standardized" - Method A

A conventional measurement of reverberation times T_{30} reveals differences of ca. 0.6 s (Fig. 2) between Reverb1 to Reverb4 – despite the perception of equal reverber-

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[1] In the above mentioned example the difference amounted to circa 9 dB as measured by the parameter late strength G_{late}.

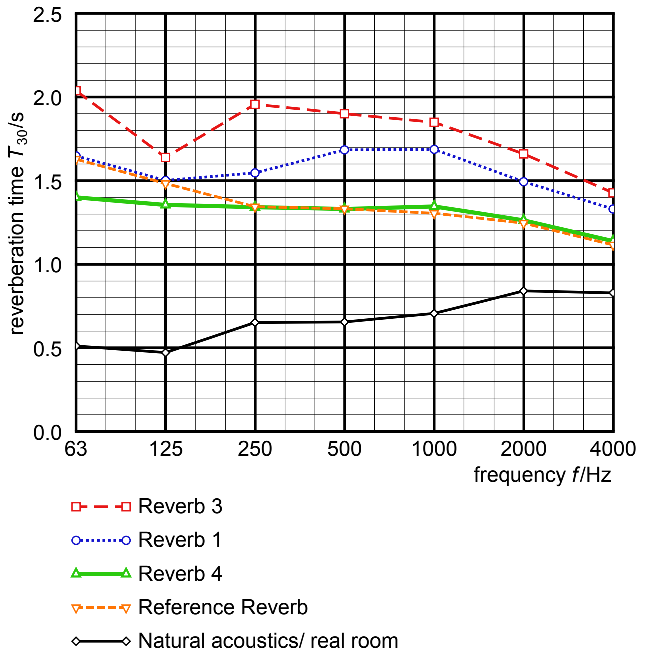

Figure 2: Reverberation times T_{30} for the four different acoustic situations with equal reverberance and the real room.

ance. Results for early decay time EDT are similar (not shown). The similarity in reverberance is not predicted.

"Psychoacoustic" - Method C

Method C uses an auditory model and subsequent separation procedure to analyze the audio signal at the ear in terms of dry and reverberant parts (foreground- and background stream). Thus, the method acts similar to a human listener.

The results from this fully psychoacoustic method are shown in Fig. 3. The real ream (RR) is predicted at a reverberance of ca. 0.8. Values of 1 are equivalent to maximum reverberance. This is the case for all tested stimuli R1-R4. Even though this suggests the prediction of equal reverberance to be correct, the presented stimuli surely are not the most reverberant listening impressions.

It thus appears that the method does detect the overall difference in reverberation between electronic reverberation on/off. However, due to scaling procedure involved in the tested version, method C appears incorrect here.

"Loudness decay times" - Method B

The remaining method B is a hybrid in the sense of using impulse responses but also auditory models. It delivers loudness-based decay times, such as loudness early decay time EDT_N. After an impulse response is fed into a loudness model (DLM, TVL or ISO532-1:2016) with a suitable calibration, decay times are calculated from the resulting loudness decays.

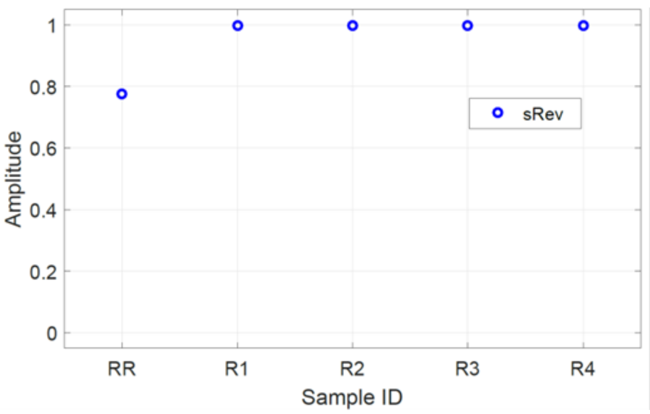

Figure 3: Results for the parameter sRev related to reverberance (output from the psychoacoustic analysis method C).

In Fig. 4 it can be observed that the loudness-based TVL model (solid green dots) correctly predicts the equal reverberance of the four stimuli (dashed orange area). The models DLM and ISO do not predict equal reverberance.

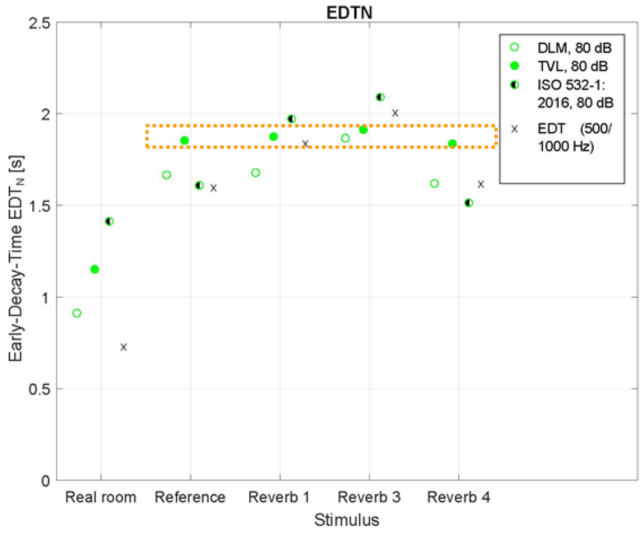

Figure 4: Results for loudness-based early decay time EDT_N. Orange area shows the equal reverberance "target".

The loudness-based analysis reacts to changes in reverberation level (Fig. 5). Increases in level of the impulse responses lead to increases in decay time. The louder the reverberation, the longer the reverberation time. Some inconclusive behaviour appears for the loudest setting of a maximum impulse response level of 100 dB.

It is found that the loudness-based early decay time EDT_N is found to be rather model-dependent, i. e. a different loudness model yields a different decay time. The only properly standardized model for instationary loudness ISO 532-1:2016 (revised Zwicker model) exhibited odd behaviour such as no increase in decay time despite higher level (not shown here). Loudness-based reverberation time T_{N30} (not shown here) did not fit well for equal reverberance. DLM and TVL were rather similar, the ISO model again was different and always shorter.

Discussion

The conventional method A does not predict the experiment well, just as it failed in the initial example with

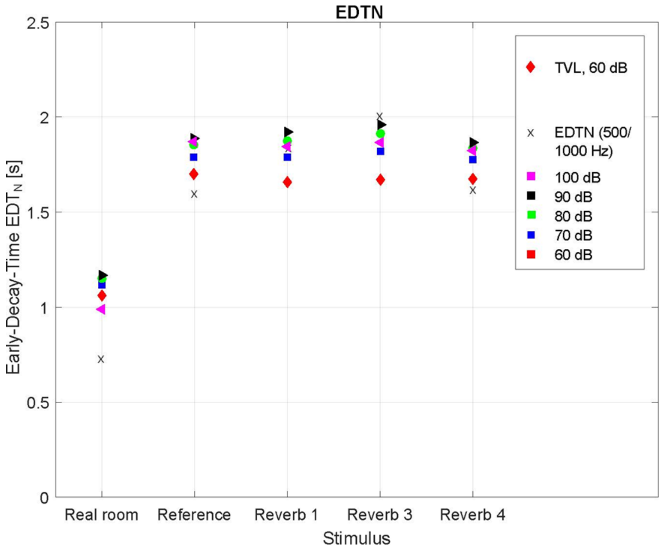

Figure 5: Results for the parameter EDT$_N$ from the TVL loudness model for different levels of the impulse response.

differently sized rooms. The relative calculation of reverberation time cannot react to and therefore account for the important differences in reverberation level.

The "psychoacoustic" method C appears promising in principle as it directly analyzes the audible signal. This is especially important when accounting for differences in reverberance from real-life sound sources [5]. However, it can been seen in this study and others that the predictor can react overly sensitive and thus strongly overexaggerate reverberance [6].

The loudness-based method B, emphasized in this article, appears promising in principle. Similar to the study by Lee et al [3] the loudness early decay time EDT$_N$ from the TVL model predicts well. The reverberation level, vital for predicting reverberance [7], is considered.

However, it is problematic that each loudness model will output more or less different loudness decay times. Possible reasons lie in the individual model processing steps with different time constants and middle ear filters [8]. The only standardized model ISO532-1 appears to be overall slow in its reaction to the impulse [9]. Also, the proper calibration of the impulse response needs to be discussed. Sound pressure level is not practical, instead we propose a sound strength calibration. Lastly, the predictors are inconclusive for high levels. For instance, background noise in the impulse response is amplified so much that the evaluation of the loudness decay times are affected.

Alternative: Combining conventional parameters

Cremer and Müller discussed a relationship between changes in reverberation time and room volume. Combined with the relationship between sound strength G and room volume V and reverberation time T, a change of reverberation time T from a given T_0 can be said to be equally perceived as a change in Strength G (Eq. 1).

$$\frac{T}{T_0} = 10^{\frac{-\Delta G}{10\theta}} \tag{1}$$

The experimental data above relate a change of 1.0 dB in reverberant energy to a change of decay time of 15%.

Summary

The present work shows that reverberation level plays a vital role for the perception of reverberance. The loudness-based impulse response analysis can outperform the conventional method. However, challenges such as the differences between loudness models remain.

References

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