Room in Room Acoustics: the influence of the direct/diffuse sound field ratio in a listening room on played back recorded acoustics

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Summary

Room acoustical properties in music and voice recordings such as reverberation, definition, clarity and speech intelligibility are influenced by the acoustics (including electro-acoustics) of the listening room. Playing back recorded acoustics through loudspeakers in sound control rooms, lecture rooms, congress halls or cinemas affects the intended acoustics of the recording. In earlier investigations, the impact of listening room impulse responses on recording room impulse responses was shown by convolving many random combinations of practical (more or less) diffuse field room impulse responses. In this new study the influence of the direct sound contribution has been investigated. To this end, three typical loudspeaker sources were used for playing back recorded acoustics: an omnidirectional loudspeaker source (dodecahedron), a single loudspeaker (box) and a loudspeaker array (column). In order to have a sufficiently large measurement distance, this was done in a large (non-diffuse) sports hall (functioning as the 'listening room'). At various distances from the loudspeaker sources, from direct near field (0.1 m source-receiver distance) to more or less diffuse far field (10 m source-receiver distance), the influence of this hall and type of loudspeaker sound source on the played back recorded acoustics was determined using convolution techniques. The results are presented as a function of the source-receiver distance and as a function of the direct/diffuse sound energy ratio, directly derived from the measured impulse responses. The audibility of the difference between recorded and perceived acoustical properties is judged based on the JND (Just Noticeable Difference).

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1. Introduction

From earlier Studies [1][2] it is clear that recorded room acoustics (such as reverberation) can only be demonstrated in a room having a reverberation time shorter than the one in which the recording was made. Small acoustical details can only be judged and criticized when there is little acoustical influence from the playback acoustics on the recorded acoustics. For example demonstrating an anechoic recording only makes sense if it is played back in an anechoic room or using headphones. However, usually the listening or playback room in combination with the used sound system affects the recorded acoustics. This happens in class rooms, congress halls, cinemas and even in sound control rooms. In this new study the presumed positive influence of the direct sound contribution has been investigated. Three typical loudspeaker sources were used for playing back recorded acoustics: an omnidirectional loudspeaker source, a loudspeaker box and a loudspeaker array.

2. Background and earlier studies

When both the recording room and the playback (listening) room are reverberant, smoothing of the sound occurs. Therefore, in some cases it is impossible to judge the original recordings in detail. The room acoustics in the sound recording that we want to demonstrate or judge will be affected by the acoustics of the listening room. With a double convolution by which an impulse response from one room is convolved with a dry recording and afterwards the result is convolved with the impulse response of another room, it is possible to hear how a recording, made in a reverberant room, sounds when played in another reverberant room. The result is usually a smoothed sound signal. By using a pure impulse (Dirac delta function) instead of a normal sound signal to be convolved with both room impulse responses, we can examine what one room does with the other concerning the values for the room acoustic parameters. So it is possible to derive a ‘room in room’ acoustic parameter value from the smoothed room impulse response RIR or its derived energy time curve ETC (Figure 1).

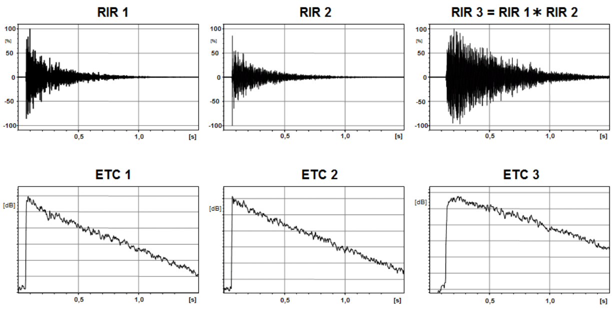

Figure 1. Example of the effect of ‘room-in-room’ acoustics on measured room impulse responses (RIR’s) and energy time curves (ETC’s) [2].

The theoretical background on ‘room-in-room’ acoustics using convolution is given in earlier research papers [1][2]. Perceptual studies on ‘room-in-room’ acoustics are carried out by Grosse and van de Par [3].

3. Measurement

3.1 Method

Three typical loudspeaker sources were used for this experiment: a dodecahedron (B&K 4292) as an omnidirectional sound source, a single 5” loudspeaker (diameter: 130 mm,) in a box (approx. 20 x 20 x 10 cm^3) as a slightly directive sound source and a loudspeaker array composed of 7 double cone 4” (diameter: 100 mm) loudspeakers as a strong directive sound source. The measurements were carried out on the longest central axis of a sports hall in steps of 0.1 m starting at 0.1 m in front of the sound source (near field) to 10 m source-receiver distance (more or less diffuse far field), resulting in 100 impulse response measurements for each sound source. To find the the influence of the hall acoustics (listening room) and the type of loudspeaker on the played back recorded acoustics, a diffuse field impulse response (recorded acoustics), measured in the diffuse field of the same sports hall using the dodecahedron, is convolved with all other impulse responses. All impulse responses have been obtained by deconvolution [4] using an exponential sweep as measurent signal, resulting in decay range (INR) values > 50 dB [5].

3.2 Condition

In order to have a sufficiently large measurement distance, the measurements were done in a large hall: in this case ‘hall 2’ of the Student Sports Centre Eindhoven (SSC). This hall has a volume of approximately 8,400 m^3. The floor dimension is approximately 29 m x 42 m and the height is 7 m. From a height of 2.9 m above the floor, walls have been aligned with acoustic absorption consisting of a so called ‘open lath’ construction. A detailed description of the hall is given in [6]. For all measurements the distance between sound source and cross wall was 10 m. Figure 2 shows an impression of the empty hall.

Figure 2. Impression of the sports hall used as the measurement room (view on cross wall).

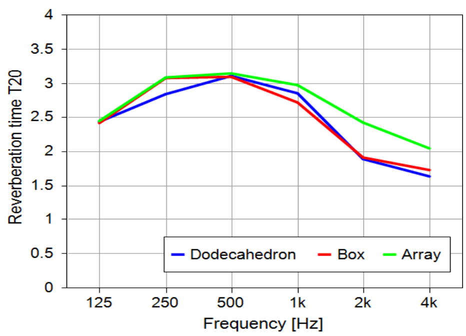

Figure 3. Reverberation time of the sports hall derived from all measurements, for each of the used sound sources.

The reverberation time T_{20} of the hall at the time of measurements is shown in figure 3, presented as an average over 20 measurements for each sound source at a source-receiver distance > 8 m. The hall temperature was 19 $^{\circ}$C. Note the deviant reverberation time values for the upper frequency bands using the loudspeaker array. This is caused by the combination of the strong directivity of the loudspeaker array and the direction dependent (non-diffuse) room acoustics.

3.3 Equipment

For the impulse response measurements the following components (and measurement signal) have been used:

- *software:* DIRAC 6.0 (B&K - Type 7841)
- *input/output:* USB audio device (Acoustics Engineering - Triton);
- *power amplifier:* (Acoustics Engineering - Amphion);
- *sound source 1:* omnidirectional (Bruël & Kjær - Type 4292);
- *sound source 2:* single 5” loudspeaker in a box;
- *sound source 3:* loudspeaker line array (7 double cone 4” loudspeakers)
- *microphone:* ½” omnidirectional (Bruël & Kjær - Type 4189);
- *signal:* exponential sweep 21,8 s

4. Results

4.1 Room acoustic parameters

Many room acoustic parameters can be derived from the room’s impulse responses according to ISO 3382-1 [7]. In this research three of them have been used, being the reverberation time T, the clarity C_{80}, and the centre time t_s.

4.1.1 Reverberation time T

The reverberation time T is calculated from the squared impulse response by backwards integration through the following relation:

$$L(t) = 10\lg \frac{\int_t^{\infty} p^2(t)dt}{\int_0^{\infty} p^2(t)dt} \quad [dB] \qquad (1)$$

Where L(t) is the equivalent of the logarithmic decay of the squared pressure [8][9]. For this investigation T_{20} with its evaluation decay range from -5 dB to -35 dB is used to determine T. The just noticeable difference for T is 5 to 10% [10] [11]. In this study a JND of 5% has been used.

4.1.2 Clarity C_{80}

The parameter C_{80} [12], is an early to late arriving sound energy ratio intended to relate to music intelligibility and is calculated from the impulse response using the following relation:

$$C_{80} = 10\lg \frac{\int_0^{0.08s} p^2(t)\,dt}{\int_{0.08s}^{\infty} p^2(t)\,dt} \, [dB] \qquad (2)$$

The just noticeable difference for C_{80} is 1 dB [7].

4.1.3 Centre time T_s

The parameter T_S [13], which is the time of the centre of gravity of the squared impulse response, can be expressed in ms using the following relation:

$$T_S = 10\lg \frac{\int_0^{\infty} t \cdot p^2(t)\,dt}{\int_0^{\infty} p^2(t)\,dt} \cdot 1000[ms] \qquad (3)$$

T_S is a room acoustic parameter related to the perceived definition or the balance between clarity and reverberance and avoids the discrete division of the impulse response into early and late reflections or energy such as with for instance the clarity C_{80}. The just noticeable difference for T_S is 10 ms [7].

4.2 Room in room acoustics

In order to find the influence of the playback or listening room acoustics (in this case a sports hall, which is not relevant for this study) on the perceived acoustics of a diffuse field recording, all measured impulse responses have been convolved with one diffuse field impulse response measured in the same hall at a distance of 10 m from the omnidirectional sound source. The impulse responses obtained from the convolutions are the so called ‘room in room’ impulse responses. The calculated parameter values of these ‘room in room’ impulse responses have been compared with the original (diffuse field) impulse response values and are presented by a deviation from the original parameter values as shown in figures 6 and 7. These figures show the results as a function of the source-receiver distance and as a function of the ‘direct/diffuse’ sound energy ratio, directly derived from the measured impulse responses. To this end the so called ‘Schroeder plot’ (obtained from the backward integrated p^2 of a room impulse response according to equation 1) [8][9] has been used. The initial drop in this curve is used as a measure for the amount of direct sound energy caused by the directivity of the sound source in relation to the diffuse sound energy (slope of decay line). Figure 4 shows an example of a Schroeder plot measured at a distance of 5 meter from a sound source. Figure 6 shows the initial drop value [dB] of the Schroeder plot as a function of the source-receiver distance for all used sound sources. The audibility of the difference between recorded and perceived acoustical properties is judged based on the JND (Just Noticeable Difference). The dashed lines shown in figure 6 and 7 indicate the JND. All measurements are presented for three octave bands: 500 Hz, 1 kHz and 2 kHz.

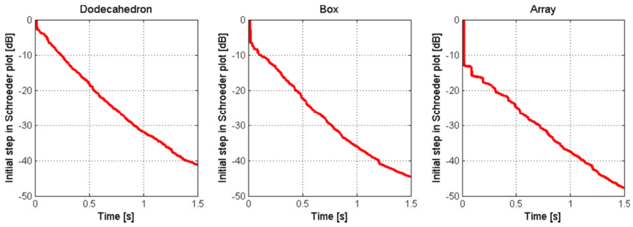

Figure 4. Example of three Schroeder plots measured in a sports hall at a distance of 5 meter from a dodecahedron (12 lsp's), a box (1 lsp) and a line array (7 lsp's).

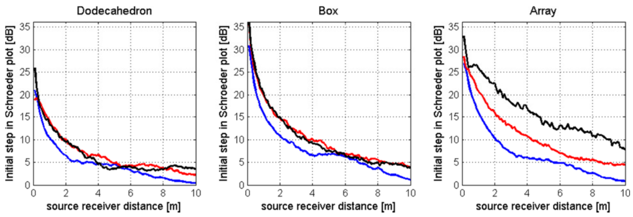

Figure 5. Initial drop value [dB] of the Schroeder plot as a function of the source-receiver distance and octave band: 500 Hz (blue), 1 kHz (red) and 2 kHz (black), for all three sound source types.

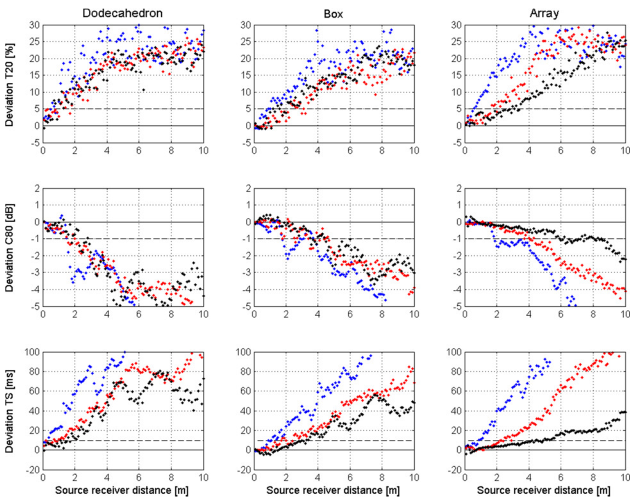

Figure 6. Difference between room acoustic parameter values of the recorded diffuse field room acoustics and the values for the same parameters when playing back the recorded acoustics in the same hall, presented as a function of <u>*source-receiver distance*</u>, source type and octave band: 500 Hz (blue), 1 kHz (red) and 2 kHz (black).

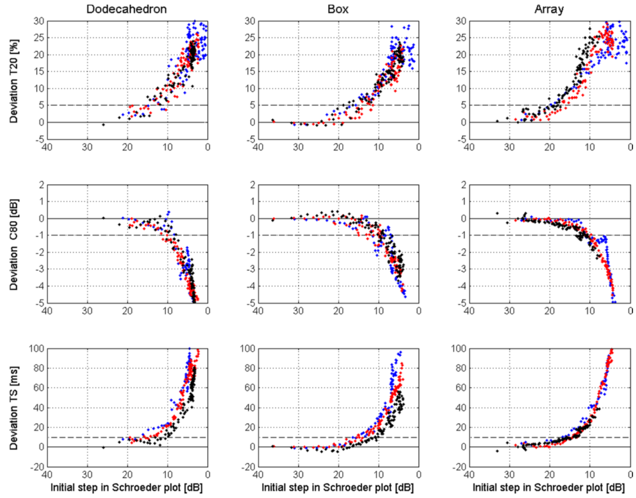

Figure 7. Difference between room acoustic parameter values of the recorded diffuse field room acoustics and the values for the same parameters when playing back the recorded acoustics in the same hall, presented as a function of the <u>*initial drop value of the Schroeder plot*</u>, sound source type and octave band: 500 Hz (blue), 1 kHz (red) and 2 kHz (black).

4.3 Discussion

Depicting the difference between a room acoustic parameter value obtained from an original room acoustic impulse response and a value obtained from the same impulse response affected by the playback room (in this case a sports hall) as a function of the source-receiver distance as a variable (figure 6), a fuzzy frequency dependent scatterplot is obtained. The measured initial drop levels of the Schroeder plots as a function of the source receiver distance (figure 5) show more or less irregular descending and frequency dependent curves. In particular the 'array-curve' shows a strong frequency dependency with maximum level differences of 10 dB between the given octave bands. Using instead the initial drop value of the Schroeder plot as the independent variable to describe the conduct of the parameter deviation values (figure 7), an almost frequency independent dense scatterplot following a clear curve, arises.
At a distance of 10 m (more than the critical distances) from the sound sources the parameter value deviation correspond (as aspected) with values from early (diffuse field) studies [1][2]: for T_{20} a deviation of approx. 30%; for C_{80} a deviation of approx. -5 dB. This is the situation where the

reverberation time of the recorded acoustics is the same as the reverberation time of the playback room ($T_{recording} = T_{playback\ room}$).

5. Conclusions

In general:
It seems that the initial drop in a Schroeder plot derived from a room impulse response can be used as a practical frequency and sound source independent measure for the direct/diffuse sound field ratio.

Specific:
Using the initial step in the Schroeder plot, the following can be concluded for T_{20}, C_{80} and T_s:

- To reproduce the reverberation time T_{20} (in a recording) in a playback room with the same reverberation time as in the the recording, at an accuracy better than the Just Noticeable Difference, an initial drop in the Schroeder curve exceeding 20 dB is required.
- Similarly, for the Clarity C_{80} a 15 dB drop is required.
- Similarly, for the Centre time T_s a 20 dB drop is required.

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