Investigation of Objective Parameters Correlating with Subjective Impression in Studio Spaces

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Abstract: Measured room acoustical parameter values are often investigated for correspondence with perceptual quality. However, these experiments usually deal with larger auditoriums rather then with smaller studio and listening spaces. The paper examines a set of selected objective measures on the changes of geometrical and acoustical properties of typical listening and recording spaces. The theoretical experiment is based on a conventional beam tracing room acoustical model. Results of this experiment show some clear trends in the relationship of architectural and room acoustical parameters.

1. Introduction

Sound fields in small rooms are generally characterised by impulse responses and transfer functions between pairs of their points. The objective (i.e. measurable) characterisation of the subjective impression by single number quantities is well known and widely accepted for large spaces (specially for concert halls and theatres) [1]. Such quantities are: reverberation time, clarity, centre-time, lateral energy fraction and so on. In small rooms however, other criteria are relevant, for example the temporal structure of early reflections, and the distribution of the room modes.

2. Small rooms

Studios and listening rooms are usually small in the acoustic sense. Physical laws of sound propagation do not depend on room size of course, and there is no principal difference between sound fields in small spaces and large spaces. However, there are several important differences in methods of investigations used for small and large rooms. Compared to large rooms, the propagation of sound in small enclosures is more influenced by wave effects because of the proximity of reflecting surfaces (walls, furniture) to the listening point and to each other. In addition, the sound energy does not travel as far before being reflected from the room surfaces, thus it is more unlikely to observe the build up of a diffuse field and the absorption by the medium is not as significant than in large rooms.

3. Investigation methods

The study of sound energy propagation within rooms has a long history. Because of the high complexity of pure analytic solutions, much of the applicable work has centred on the treatment of statistics of a hypothetical, randomly distributed sound energy. It has long been recognised that this simplified theory becomes invalid when the sizes of the enclosure are not substantially larger compared to the wavelength.

The problem may be simplified significantly by considering different ranges of object scales and frequency ranges. At low frequencies the wavelengths are so long that the sound wave is affected only by obstructions that are comparable in size with the principle dimensions of the room. At high frequencies, the sound field becomes more or less diffuse and the principles of statistical and geometrical acoustics may be applied.

In studios the source and the receiver are usually relatively close to each other and the influence of interference of acoustic waves reflected from closely spaced objects and walls is significant.

Theoretically, the wave equation might be solved for given boundary conditions by using spatial or temporal discretisation of the problem. Nowadays to solve the partial differential equations for a complex geometry, the Finite Element Method (FEM) and the Boundary Element Method (BEM) are successfully applied in acoustics. In practice these methods are frequently used for very small enclosures, such as for automotive spaces. In the case of studios however, the number of elements needed in the frequency range in question are typically too high to handle efficiently.

At higher frequencies the advanced computer models based on statistical and geometrical acoustics are well used.

4. Objective and subjective parameters

Searching for the relationships between the subjective aspects and sound field properties needs great experimental efforts. Much more subjective and corresponding objective parameters have been found for room acoustic evaluation of concert halls than of small rooms. Since the studio spaces are small in the acoustic sense, different objective parameters are needed to characterise these types of rooms.

There are different methods to find new parameters. The easiest one seems to be calculating parameters from impulse response. On the other hand, these parameters are calculated from computer model results, which are based on statistical and geometrical acoustics, therefore are suitable at the higher frequency range only.

5. Objective Measurements

In the first step the aforementioned method has been applied to calculate the objective measures. The set of measured room acoustical parameters consisted of the following ones:

- k_1 or “early-to-total” energy ratios represent the ratio in dB of received energy before a certain time limit and the total received energy (t_e):

$$k_1(t_e) = 10 \cdot \log_{10} \frac{\int_o^{t_e} p^2(t)dt}{\int_o^{\infty} p^2(t)dt};$$

- k_2 or "early-to-late" energy ratios represent the ratio in dB of received energy before and after a certain time limit (t_e):

$$k_2(t_e) = 10 \cdot \log_{10} \frac{\int_o^{t_e} p^2(t)dt}{\int_{t_e}^{\infty} p^2(t)dt};$$

- M or "M-factor" represents the difference of the early-to-late energy ratios for 5 ms and 20 ms time limits:

$$M = k_2(20\text{ms}) - k_2(5\text{ms});$$

- t_S or "centre-time" represents centre of gravity of the energy distribution in seconds:

$$t_S = \frac{\int_o^{\infty} t \cdot p^2(t)dt}{\int_0^{\infty} p^2(t)dt}.$$

In the above formulas $p(t)$ is the measured pressure impulse response between a source and a receiver in the room.

Note, that the parameters k_1, k_2 can be expressed from each other

$$k_1 = 10 \cdot \log_{10} \frac{10^{k_2/10}}{1 + 10^{k_2/10}},$$

and they represent the decay level at the time limit point on the energy decay curve (or EDC):

$$EDC(t) = 10 \cdot \log_{10} \frac{\int_t^{\infty} p^2(\tau)d\tau}{\int_0^{\infty} p^2(\tau)d\tau} = 10 \cdot \log_{10}\left(1 - 10^{k_1/10}\right) = -10 \cdot \log_{10}\left(1 + 10^{k_2/10}\right).$$

Parameters k_1 and k_2 are generalised versions of the well known D ("deutlichkeit" or "definition") and C ("clarity"). Parameter M on the other hand represents the level difference of the EDC between time points 5 ms and 20 ms indirectly. The indirect meaning of centre time is more complex, it relates to the total slope of the decay curve [2].

6. Subjective Experiments

The aim of the subjective experiments was to find correlations between the measured quantities and perceived quality. Objective values were derived from measurements in listening rooms, since they represent a well-controlled acoustical environment [3].

Preparatory to the subjective tests, a learning procedure was carried out in a reference listening room. The 40 minutes long test material consisted of different recordings. According to their perceived impressions while listening to the same material in different rooms, test persons filled out a questionnaire with the following issues:

- stereo accuracy,
- timbre,
- spatial impression
- transparency,
- frequency response,
- room modes,
- other resonances,
- noise from outside,
- main impression
- comfort impression.

7. Results of the Experiment

Correlations found between the measured room acoustical parameters and the perceived quality:

- centre time correlates good with transparency and spatial impression,
- M-factor relates to timbre
- k_1 and k_2 (t_e = 20 ms) shows correlation to stereo accuracy.

It should be noted that the results above are calculated by using wide band impulse responses (i.e. without any band limiting filtering). However, experiments are carried out to study possible correlations between frequency dependent parameters and subjective impression.

8. Modelling

Modern room acoustical modelling algorithms using theoretical assumptions of geometrical acoustics are proved to be accurate enough in general. However, these results are documented mainly for larger halls, such as auditoriums, concert halls, theatres, etc. Again, the assumptions of the geometrical and statistical acoustics fail at lower frequencies, especially in the case of small rooms. While in general accuracy greatly depends on the selection of the right material description (absorption coefficients and diffuse reflection coefficients), there is rarely reliable and generally available data below 125 Hz to find.

As mentioned earlier, prediction methods based on wave theory are computationally inefficient, since the linear sizes of elements in FEM or BEM meshes generally should not exceed the sixth of the wavelength, and even higher mesh density is required at sharp discontinuities. Geometrical methods are said to be reliable above the Schroeder frequency [4] or when the wavelength is smaller than about the sixth or fourth of the linear sizes of relevant reflecting surfaces.

On the other hand, most of the known room acoustical parameters can be derived from results of the geometrical model easily, thus their utilisation seems to be evident.

Geometrical methods can be validated by using an inverse method, where model parameters are fitted to a given room acoustical parameter, a set of room acoustical parameters or even the EDC itself [2]. Other useful application of the inverse approach is to experiment with different sizes and geometries of typical room shapes. A theoretical experiment compared the potential of the typical shoebox, trapezoid and reflection-free studio spaces with respect to the k_2(20 ms) parameter. The results showed systematic features for each geometries. Some of the more interesting conclusions:

- the floor or the equipment in front of the listener (e.g. mixing console) plays a significant role in every situation;
- the widest possible range of results can be provided with the shoebox room shape;
- the most narrow range and lowest values can be provided with the shoebox room shape;
- while results for the shoebox and the trapezoid room shapes depend on the quality of the surfaces near to the source, the quality of the reflection-free shape is determined by the rear corners.

One may conclude that a room model can always have enough degrees of freedom (number of surfaces, materials, acoustical properties, etc.) to fit ordinary responses. Validity fails if results from the inverse calculations are inconsequential (e.g. depend highly on the source-receiver position in the same room).

9. New Questions

Apart from the important conclusions, there are several questions revealed.

First of all, room acoustical parameters can be calculated for different frequency bands. Our former results were not band limited, although according to our experiences, the correlation improves at higher frequencies and fails at lower frequencies.

Other experiences also support the idea that conventional room acoustical parameters are inadequate to characterise low frequency phenomena. In addition, low frequency phenomena can have a significant effect on the overall quality, independently from the quality expressed by the conventional room acoustical parameters (like k_1 or k_2 for example).

Experimenting with the perception of low frequency phenomena calls for new methods both in measurement, prediction and subjective evaluation.

References:

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