UNCERTAINTIES OF ROOM ACOUSTICAL MEASUREMENTS – INFLUENCE OF THE EXACT SOURCE AND RECEIVER POSITION

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1 INTRODUCTION

Despite normative references (i.e. ISO 3382 and ISO 18233) which define how to conduct and analyse room acoustical measurements, not all influences of measurement uncertainties have been discussed comprehensively. As a consequence the statement of results, including the associated uncertainties, may not be regarded a matter of course. Instead array measurements conducted in Concertgebouw Amsterdam [1] or the comprehensive survey of all listening positions in different auditoria by Akama [2] show that room acoustical single number parameters vary measurable from one measurement position to the other, hence are severely affected by a measurement uncertainty. In previous work [3] the authors have discussed the spatial variation of the sound field with the goal to develop conclusions that can be used to determine the measurement uncertainty under realistic measurement conditions for the coverage of choice. In this previous investigation it has been discussed how accurate microphone positions have to be documented in order to derive results with a thereof dependent measurement uncertainty. For the practitioner it is of particular interest to get significant results with efficient means. This implies a sufficiently accurate measurement survey of an auditorium with a minimum in measured microphone positions. In this study additional measurements in 4 auditoria as well as array measurements in 1 auditorium using 4 loudspeakers have been used to broaden the existing data base and approach the question how singular measurements are appropriate to describe entire audience areas.

2 MEASUREMENTS TO DETERMINE THE MODEL FUNCTION

2.1 Measurements in audience areas

In previous studies measurements have been taken in different concert halls, namely in Aachen (Eurogress), Cologne (Philharmonic hall), Dortmund (Konzerthaus) and Leipzig (Neues Gewandhaus). In these measurements about 100 receiver positions were measured in sequence giving an overview how room acoustic parameters vary in a macroscopic scale over the entire audience area.

2.2 Array measurements

In order to determine how the sound field and the parameters vary in a microscopic scale array measurements sampling the sound field in a Cartesian 5 cm grid have been collected over a 2.1 m x 2.4 m surface. For this measurement four measurement sound sources have been used playing back interleaved sweeps.

3 EMPIRIC MODEL FUNCTION

The model function f is a pivotal point of the GUM [4, 5] conform discussion of measurement uncertainties, as it is the functional connection of the input quantity X and its effect on the output quantity Y. Here the model function should show how a single number parameter changes as the microphone is moved by a distance x. This information can be determined empirically from the measured data when every two microphone positions are compared to each other. In surveys in which receiver positions are arranged in irregular grids this leads to a relation that is not continuous, since the distance between any two microphones is unique. To derive a uniform model function the results are processed using the mean deviation of the parameter as it is calculated with a gliding average and a window length of 1 m. The same analysis is in principle applied to the data collected from the array measurements (with a regular sampling grid). Due to the different dimensions of the measurement setup, however, the window was chosen to have a length of 0.02 m. The comparison of the results measured by any two individual microphones with a common distance to each other yields a distribution of C_{80} that is normal with a mean $\mu = 0$ and a standard deviation σ that is dependent of the distance between the microphones. The standard deviation is shown in figure 1.

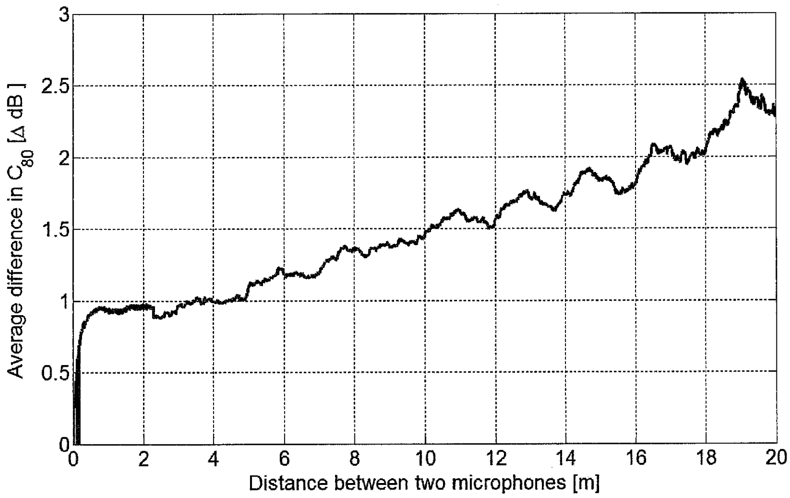

Figure 1: Model function showing how C_{80} at 500 Hz differs in average between two microphones that are a distance x apart from each other.

In order to keep the data and the parameters discussed at a manageable number for the remainder of this text the results are discussed for the C_{80} clarity parameter at the 500 Hz octave band.

4 MONTE CARLO SIMULATIONS

The goal to determine the distribution of room acoustical parameters over an audience area based on a singular measurement requires defining a probability distribution of the input quantity. For reasons of mathematical simplicity an audience area of circular shape as shown in figure 2 is considered. In this audience area the number of seats with a given distance to the center of the circle increases linearly. This can be illustrated using the probability density function (pdf) shown in figure 2.

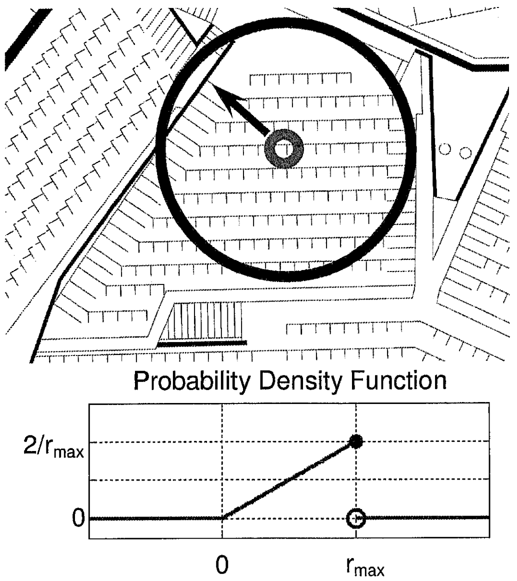

Figure 2: Probability density function showing the distribution of measurement positions within the blue circle and their distance to the center (red)

To calculate the range of C_{80} – values that have to be expected in an audience area of circular shape with a given radius r, Monte Carlo Simulations (MCS) are carried out. In these MCS possible distances d of receivers to the center position are randomly chosen according to the pdf shown in figure 2. For each of these chosen distances d a change in clarity is determined based on a random sample from a normal distribution with $\mu = 0$ and $\sigma(d)$ as it can be determined from the model function in figure 1. Repeated MCS yield a distribution of differences in clarity. Additional MCS are carried out until the 2.5%, 16%, 84% and 97.5% quantiles can be determined to an accuracy of three significant digits, i.e. additional MCS-trails will not change the result within the stated degree of accuracy. These Monte Carlo Simulations are repeated in steps for different radii r of the circular audience area.

5 RESULTS – MEASUREMENT UNCERTAINTY

The results of the MCSs are shown in figure 3. For the 500 Hz octave band the standard uncertainty (68%, solid) and the expanded uncertainty (95%, broken) of C_{80} are shown as a function of radius σ_r of the audience area. From figure 3 it can be read that 68% of C_{80}–values, in an audience area of 5 m radius, lie within ±1.0 dB. For an audience area of the same size 95% of the C_{80}–values lie within a range of almost ±2 dB.

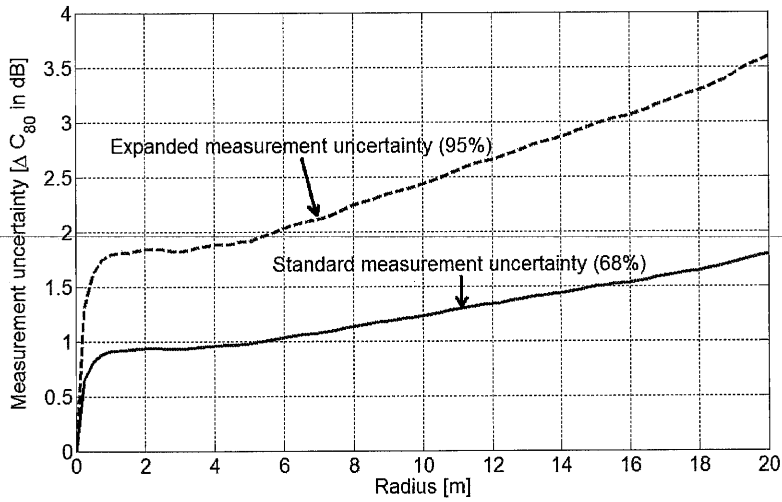

Figure 3: Standard measurement uncertainty (solid) and expanded uncertainty (broken) of C_{80} for a circular audience area with a radius r, based on a single measurement.

The relevance of these results has to be discussed in view of the jnd for clarity. Cox [6] determines the difference limen for clarity in synthetic sound fields to about 1.0 dB. This would allow the use of singular measurements based on a standard uncertainty for audience areas with a radius of about 5 m. A generalisation of measurement results with a 95% accuracy doesn't seem reasonable at all. It should be noted, however, that in a survey by Höhne et al. [6] and own work [7] the difference limen of C_{80} was determined to have a value of about 2.5 dB. Such values seem to be much closer to practical experience. Such findings would allow the use of singular measurements to characterise audience areas with 10 m radius with an uncertainty of 95%.

In the discussion of the shown results there are some aspects that should deserve further consideration. First, it has to be noted that array measurements have only be conducted in Eurogress Aachen. It is unknown whether the measured conditions are applicable to other auditoria. Second it needs to be realised that the transition between data from array measurement to data sets taken within the entire auditorium is not continuous for all frequencies. This could suggest that the sampled data is not representative. In a third aspect it needs to be investigated how characteristic the model function (e.g. figure 1) is for an individual auditorium, i.e. how representative a single common model function is for a larger number of auditoria.

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