Application of GUM concepts on uncertainties caused by microphone placement

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Introduction

ISO 3382 [1] defines the framework for room acoustical measurements that are conducted in auditoria. Besides a definition how to calculate room acoustical single number parameters procedural aspects for measurement surveys, such as the number of source and receiver combinations to be evaluated, are established. Depending on the size of the auditorium a number of 3 source positions and at least 6 – 10 microphone positions are to be used to evaluate the acoustic conditions in performance spaces. This translates to an average of about 80 – 200 seats for every microphone position. In contrast to such requirements are the results of array measurements conducted in the Concertgebouw in Amsterdam [2]. While discussing lateral energy fraction LF it was shown, that already small changes in the microphone position yield a measurable difference in the single number parameter. A question that arises from these results is which degree of detail is required to sufficiently characterise the position the measurement was taken at (e.g. seat, row or audience area). The tools of the "Guide to the expression of uncertainties in measurements" (GUM) [3] are used to develop an understanding of this aspect and determine the measurement uncertainty that goes along with a statement of measurement position. To simplify matters a focus is placed on Clarity (C_{80}). The results are discussed in respect to the just noticeable difference (jnd).

GUM concept and general strategy

The strategy to discuss measurement uncertainties according to GUM relies on developing a model of the measurement process. The model function f quantifies how the measurement result, i.e. the output quantity Y, is affected by changes of the input quantity X. Ideally f is determined analytically. In cases where the measurement chain is complex, f may be determined experimentally. Assigning probability density functions (PDF) to the different input quantities X_i and propagating them through the model f, yields a PDF of the output quantity which is used to determine the measurement uncertainty of the output quantity Y. In situations where the requirements of the standard GUM framework are not met (i.e. nonlinear model function), Monte Carlo simulations (MCS) can be used to determine the PDF of the model output [3].

Measurements to determine the model function

In order to determine how much C_{80} changes when the microphone is moved by a defined distance the measurements conducted at Concertgebouw Amsterdam [2] were re-evaluated. For this analysis 509 room impulse responses, measured along an array of microphone positions with 0.05 m intervals over almost the full hall width (27.7 m), are available. Due to the regular spacing of the microphones a large number of microphone pairs are available that are at distances of multiples of 0.05 cm from another apart. The difference between the C_{80} results of each pair of microphones is an indicator how much C_{80} changes over distance. Statistical evaluation of these, up to 508 C_{80}-pairs (depending on the distance between microphones), showed that C_{80} differences are almost perfectly normally distributed around a mean of $\mu = 0$ and a standard deviation $\sigma_{C_{80}}$ that is shown in figure 1 as a function of distance between the two microphones. This implies that in average a displacement of the microphone has no effect on the C_{80} result. For individual displacements, however, a change in microphone position will alter the C_{80} result according to an additive white Gaussian noise (AWGN) process with a normal standard deviation as shown in figure 1.

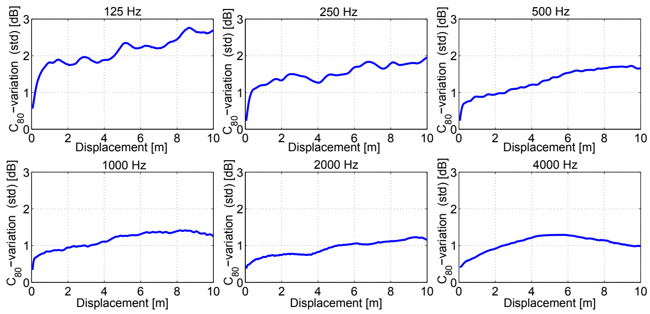

Figure 1: Change of C_{80} (normal standard deviation) due to a movement of the microphone by the distance x in meter.

Modelling this measurement in GUM-terms requires two steps. In the first step a flat model function $f(x) = 0$ is used to take the average effect of microphone displacement into account. In the second step an AWGN-process with $\sigma_{C_{80}}(x)$ as shown in figure 1 considers the individual C_{80}-change that has to be expected when moving the microphone. In GUM-terms this latter step considers "incomplete knowledge" about the underlying measurement process since it considers other factors (e.g. room shape, position of the microphone pair in the room, etc.) which cannot be considered otherwise in this empiric approach.

Monte Carlo Simulations

Figure 1 shows the model function depending on the displacement distance x. Due to its nonlinearity this function may not be approximated with a low order Taylor series without a significant approximation error. Hence, Monte Carlo Simulations (MCS) are used to determine the PDF of the output quantity (C_{80}). This is initiated by selecting a PDF to reflect the statistical properties of the input quantity. With imprecise information about the location a microphone was placed for measurements (e.g. only given by the seat or the row the microphone was placed in), it is expected that the probability the microphone was actually placed at the centre of the indicated object is higher than at its perimeter. Hence, it seems appropriate to assume a normal distribution with a mean of $\mu = 0$ cm and a standard deviation σ_x. σ_x is chosen

to be in the order of magnitude of half the dimension of the indicated object (e.g. ca. 0.25 m for a seat and up to a few meters for a row).
In a MCS set random selections for the input quantity (microphone position), with a fixed $\mu = 0$ and σ_x, are used to determine the statistical properties of the output quantity (C_{80}). For this study a MCS set is completed when the 68 %- and 95% probability interval has been determined with an accuracy of 3 significant digits. In 50 MCS sets the standard deviation σ_x of the input quantities PDF was stepwise incremented from 0 cm to 2.50 m.

Results – Measurement uncertainty

The results of the MCSs are shown in figure 2. For different frequencies the standard uncertainty (68%, solid) and the expanded uncertainty (95%, broken) of C_{80} are shown as a function of σ_x ranging from 0 m to 2.50 m.

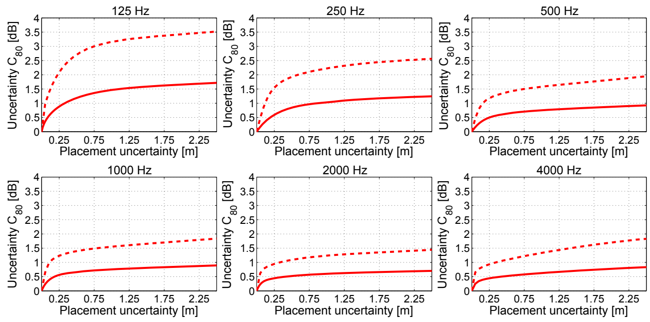

Figure 2: standard measurement uncertainty (solid) and expanded uncertainty (broken) of C_{80} due to imprecise information about the measurement position

If, for instance, it is unclear where a microphone was placed within a group of 9 chairs in the Concertgebouw (width of each chair 0.5 m) it can be read from figure 2 at 2.25 m (half the dimension of the object in question) that the standard uncertainty for C_{80}-measurements varies between ±1.69 dB for low and ±0.81 dB for high frequencies. The expanded uncertainty ranges between ±3.47 dB and ±1.77 dB for low and high frequencies respectively. In case information is available that a measurement was taken at a specific seat the uncertainty reduces to ±0.88 dB for low and ±0.44 dB for high frequencies (respectively to ±2.09 and ±0.93 dB for the expanded uncertainty).
The relevance of these results has to be discussed in view of the jnd for C_{80}. ISO 3382 quotes the C_{80} difference limen to be 1.0 dB. This would require reporting measurement positions with an accuracy of about 0.3 m considering the standard uncertainty for low frequencies. It should be noted, however, that in a survey by Höhne et al. [5] the difference limen for C_{80} was determined to have a value of about 2.5 dB. This value has been confirmed in own experiments in 2006 [6] and seems to be closer to practical experience. Such findings suggest that the required accuracy of reporting a measurement position is much lower (e.g. > 2. 50 m).

Limitations due to choice of sampling

In order to check the findings for plausibility the type of measurement sampling is reconsidered. Although the measurements in Amsterdam give a good idea how single number parameters are prone to changing over short distances it has to be stated that using a one dimensional array only allows to consider variability due to movements in one direction. Some parameters (i.e. C_{80}, D_{50}, G, EDT) have proven to be strongly dependent on the microphone distance to the sound source. This aspect my not be fully reflected in the presented data. In order to determine the effect of sampling the data collected in Amsterdam is compared to measurements conducted in a large auditorium in Aachen. 74 impulse responses have been measured on the ground floor of Eurogress Aachen. While these measurement positions cover the entire main parquet they are not spaced quite as close to each other compared to the Amsterdam measurements. In figure 3 the results for the measurements in both rooms are shown. The data has been prepared as described for figure 1. Since the distances in Aachen do not show quite a regular spacing as in Amsterdam a spatial raised cosine window with a length of 1 m has been used to calculated the gliding standard deviation. It can be seen, that while showing a similar tendency, the variance of C_{80} measurements in Aachen is slightly higher compared to results taken in Amsterdam.

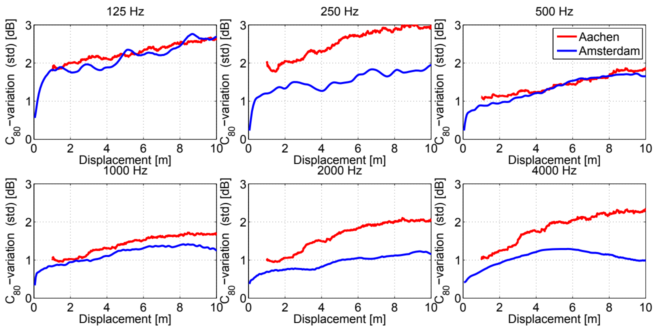

Figure 3: Change of C_{80} (normal standard deviation) due to a movement of the microphone by the distance x in meter.

Conclusions

In this contribution it was shown which accuracy is required when reporting the position where a receiver was placed for room acoustical measurements when C_{80} is discussed. These results have been compared to established references of just noticeable differences of clarity. As a result it was shown that the measurement position has to be reported with an accuracy of about 0.3 m when the jnd (1.0 dB) quoted in ISO 3382 is used. The jnds from other studies (2.5 dB) suggest that an accuracy of less then 2.50 m is required. It has to be noted, however, that the presented results are of preliminary nature since the data used for this study was collected in a single auditorium using a one dimensional array.

References

[1] ISO 3382-1:2009, Meas. of room acoustic parameters
[2] De Vries et al.,"Spatial fluctuations in measures for spaciousness", JASA 110 (2), p. 947 – 954, 2001
[3] ISO Guide 98-3:2008, Guide to the expression of uncertainty in measurements
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[6] Witew, "Is the perception of listener envelopment in concert halls affected by clarity?", Proc. DAGA 2006, Munich