How to discuss the uncertainties in room acoustic measurements

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Introduction

The discussion of measurement results has a long and cultivated tradition in room acoustical research and design. The measurement based documentation of the acoustics of renowned concert halls and also the discussion of acoustic shortcomings on the grounds of measurement surveys has proven to be a valuable method in developing new insights. Despite this practice one has to find that a fundamental aspect, i.e. the statement of uncertainty intervals, has long been disregarded. Without the statement of such intervals, however, it is generally not possible to assess the quality of the measurement results. Hence, the quality of the derived conclusions is undetermined.

On the other hand, for practical room acoustical design it is often required to achieve a previously defined design goal, i.e. the requirements as published in DIN 18041 [1]. In many cases the success of a design is evaluated by the means of comparing measurement results with the respective target values. Without including the intrinsic measurement uncertainty it is not possible to draw a clear conclusion whether such a design target is met or not.

In previous measurement round robin tests, i.e. the 3rd PTB Round Robin on measurements [2] it was one of the surprising results that even supposedly simple measurement objectives, such as determining the reverberation time (especially in smaller rooms), are afflicted with a remarkable uncertainty.

Using the GUM to discuss uncertainties

In recognition of a missing internationally accepted procedure to express measurement uncertainty ISO has released the *Guide to the Expression of Uncertainty in Measurement* (GUM) [3]. This document was developed on the suggestion of BIPM to comprehensively inform how uncertainty statements are arrived at and to provide a standardised methodology to treat uncertainties and develop uncertainty intervals. As a consequence the principles that are presented have been incorporated in many measurement standards – also in acoustics.

In its essence, GUM offers a seven-step methodology to acquire the uncertainty budget of a measurement:

1. Collecting information on the measurement and its input quantities x_i
2. Modelling of the measurement in terms of a model function f
3. Evaluation of the input quantities x_i
4. Combination of the results to obtain the value y and the uncertainty $u(y)$
5. Calculation of the expanded uncertainty $U(y)$
6. Statement of the complete measurement result $y + U$ and the coverage factor k
7. Preparation of the uncertainty budget

The challenge of this approach becomes obvious once the first step of the indicated procedure is completed. The measurement procedure in room acoustics is defined in standards such as ISO 3382 and ISO 18233. The measurement chain, as it is established in these documents may be graphically represented as in figure 1.

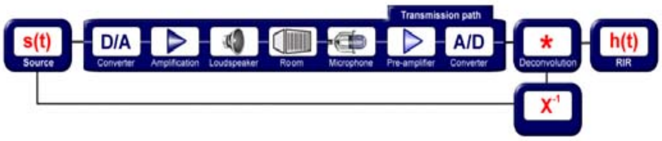

Figure 1: Scheme of the measurement chain as it is used in room acoustics to determine the room impulse response

Steps 2 and 3 have the potential to be non-trivial tasks since complex modelling might be necessary to transform the previously depicted measurement chain in a usable model function f with input quantities x that can be handled.

In previous approaches [4] it has therefore been attempted to avoid extensive modelling and conduct comprehensive measurement surveys. On the grounds of numerous measurements in different auditoria, with different sound sources, at different measurement positions with a multitude of different microphones different sources of uncertainty (for this specific measurement) have been compared and evaluated in respect of their contribution.

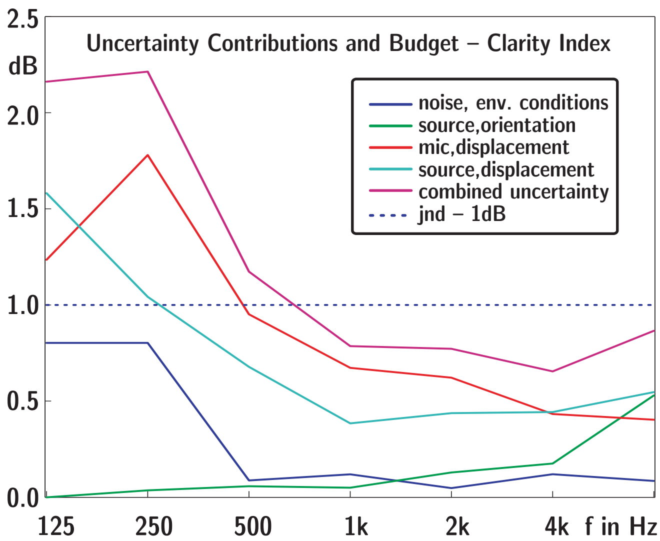

Figure 2: Graphic representation of the uncertainty budget for the measurement [4] of the clarity index (C_{80})

While this study first allowed the comparison of different sources of uncertainty to the overall measurement result, it has to be stated that the efforts to get such a result are quite laborious.

In order to capture the general idea it is helpful to go one step back and bring these results in context with the GUM procedure. Doing so one finds, that modelling has not been avoided after all. Instead the model function f, as shown in figure 3, has been established to

$$Y = f(X) = X \text{ , with} \quad (1)$$

$$\frac{\partial f}{\partial X} = c = 1. \quad (2)$$

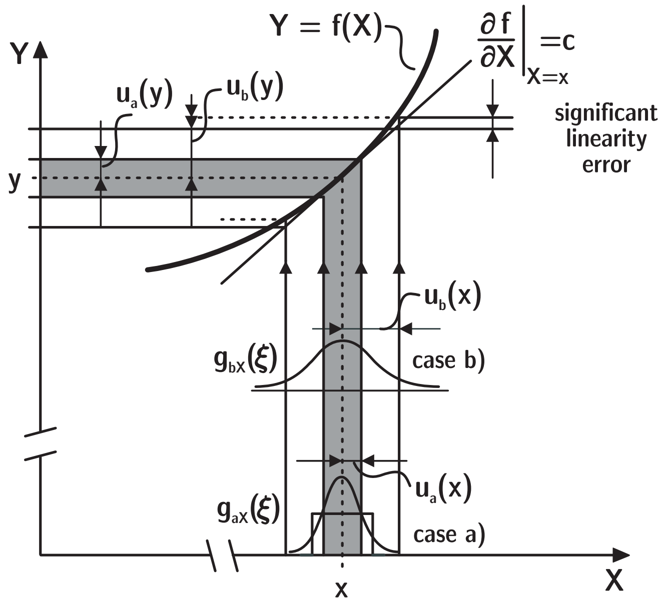

Figure 3: Graphic representation [5] of the relation between input quantity *x* and output quantity *y*

In this concept both input and output are the room acoustical single number parameters. The distribution, i.e. the spread of the input quantity is determined on the grounds of the above mentioned detailed measurement studies [4].

In order to reduce the efforts to develop the uncertainty budget for room acoustical measurements, more detailed modelling may be an advance. In consideration of the measurement chains' high complexity a singular influence of uncertainty is considered. Although the results of [4] suggest that the radiation directivity of measurement loudspeakers may not be the dominating source of uncertainty in measurements at lower frequencies, this aspect is still pursued. The experience from previous work [6] may simplify the task in understanding how modelling can be applied in making the uncertainty assessment easier.

Purpose of this specific Model is to predict how the input quantity of interest, i.e. the directivity of measurement sources, influences the output quantity, i.e. the room impulse response. The model [7], as it has first been presented, is based on Monte Carlo simulations. In it, the radiation directivity of the sound source is transformed into a probability density function (pdf) showing the probability that the radiated intensity level for an arbitrary direction varies around the mean over all possible directions. Following the concept of image source- and radiosity models this pdf is taken as the model input and in different Monte Carlo runs a number of room impulse responses are calculated (for details see [8]). In discussing the variation of the RIRs the variation of the output quantity is assessable. As the result of modelling it turns out that other factors such as reverberation, the room's volume as well as scattering from walls appear to have influence on the resulting RIR. These factors have to be considered as secondary input quantities.

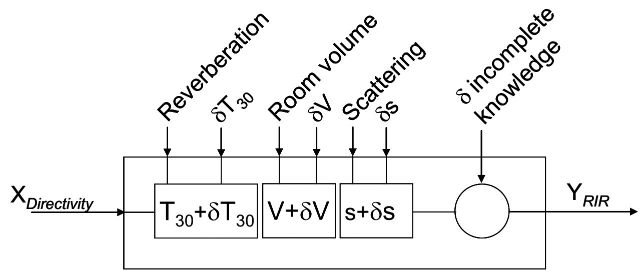

Figure 4: Generic transmission element of a linearisable measurement process

As part of the next step it is necessary to validate the model. This can be achieved by comparing a number of measurements with the model prediction while the different input quantities are varied to the fullest particle extent. At this point one of the conclusions might be that model is not always perfectly predicting the uncertainty that is experienced in real measurements. This discrepancy is accounted for by including another input quantity, namely "incomplete knowledge", in figure 4.

Conclusions and Future Perspective

Modelling is an extensive process that has the potential to substantially reduce the efforts that are necessary to develop the uncertainty of a routine measurement. Approaching this aspect from different viewpoints it is possible to determine the measurement accuracy standards, such as ISO 3382, presently allow. On the other hand it may provide the information necessary to assess the accuracy that can be achieved with specific measurement equipment. Furthermore it is possible do determine the requirements on measurement equipment or sample size in order to achieve measurements with a previously defined accuracy. As a future perspective it should be fruitful to develop models that are capable to predict the influence of the most significant input quantities.

References

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