Analyzing measurement uncertainty of room acoustic parameters

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Introduction

The uncertainties associated with measurements of room acoustic parameters as defined in ISO 3382 [1] are investigated. By comparing measurement results obtained by different teams for the same room, deviations larger than the just noticeable difference (jnd) have been found [2]. Since this is not acceptable, the single uncertainty contributions have to be analyzed separately. In order to provide unified results in all fields of measurements the ISO/BIPM developed the Guide to the Expression of Uncertainty in Measurement (GUM) [3]. Evaluating uncertainties according to the GUM often requires complex modeling or even Monte-Carlo Simulations, if an analytical expression cannot be given [4] or the input quantities, are not directly measurable. Therefore, applicable practical modeling techniques have been developed [5]. In this paper, a scalable linear uncertainty model similar to [6, 7] is proposed. Main input quantities are determined and investigated in detail. The combined uncertainty is calculated and the uncertainty budget will be discussed regarding measurement quality.

Application to Room Acoustics

According to the GUM procedures, the first step is to find a model function f connecting the output quantity y with the input quantities x_i in an appropriate way.

$$y = f(x_1, x_2, \dots, x_N). \tag{1}$$

In this case, the output quantity is the room acoustic parameter and the input quantities represent potential sources of error. Once a model function and all major influence factors are found, uncertainties $u(x_i)$ have to be associated with the input quantities. The combined uncertainty of the output quantity can be calculated as

$$u(y) = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}u(x_i)\right)^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}u(x_i, x_j)}. \tag{2}$$

In room acoustics, certain assumptions and simplifications have to be made to apply the GUM procedures. Correlations between the input quantities $u(x_i, x_j)$ in (2) are reasonably assumed to be negligible. As commonly known, the central measured quantity in room acoustics is the impulse response. Modeling the error propagation from the input quantities to the impulse response and forward to the derived parameters by means of a model function f is problematic, since the impulse response is not directly suitable as an input quantity in this context. In addition, the input quantities to the impulse response cannot always be measured directly.

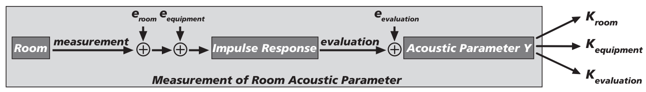


Figure 1: Capsuled sources of measurement errors.

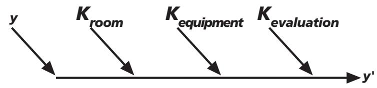


Figure 2: Linear uncertainty dependence graph.

As dominating uncertainty contributions can be found, it is applicable to analyze the variations of the output quantity itself by varying these input quantities under consideration of a linearized model function f [6]. Fig. 1 illustrates this approach showing abstract groups of capsuled errors. The linear dependence graph in Fig. 2 yields the equation for the corrected output

$$y = y' - K_{room} - K_{equipment} - K_{evaluation} \tag{3}$$

with the *correction factors* K_i capturing each uncertainty contribution by means of a standard deviation of the output quantity. Generally, dependence on frequency, position and shape of the room is assumed,

$$K_i = K_i(f, room, position). \tag{4}$$

Fig. 3 shows the grouping of input quantities, that mainly influencing the accuracy of a room acoustic measurement. The first two groups are discussed in this paper. The combined uncertainty can be calculated as

$$u(y) = \sqrt{\sum_{i=1}^{N} u^2(K_i)}. \tag{5}$$

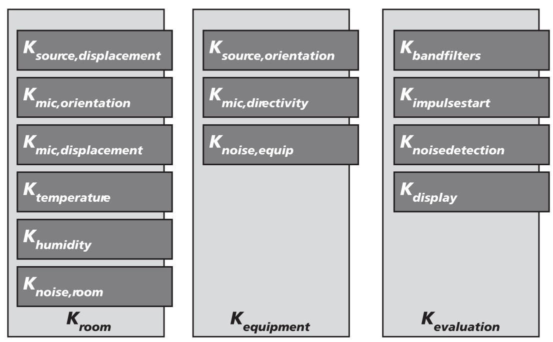
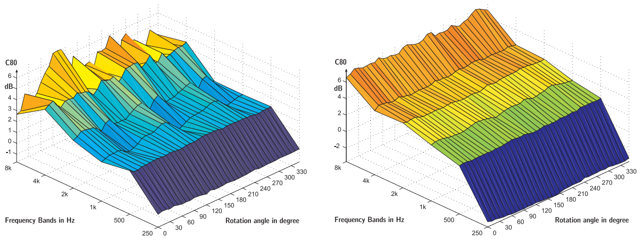


Figure 3: Abstract grouping of investigated sources of errors.

Measurement Results

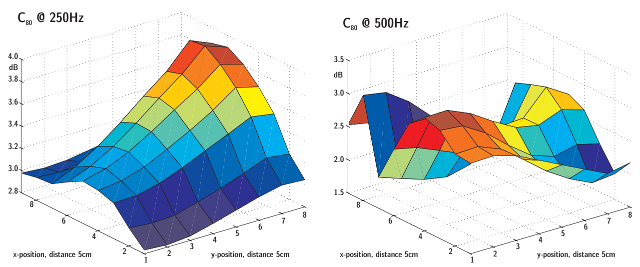
Experiments modeling the uncertainty of the input quantities in an appropriate manner have been developed, e.g. repeated measurements, rotation of the sound source, scanning the area within a seat with a microphone array.



(a) (b)

Figure 4: Variations of the clarity index C_{80} due to rotation of two different dodecahedron loudspeakers.

Fig. 4 shows increasing variations of the parameter with frequency for both sources used. In Fig. 4(a), a commercially available dodecahedron measurement loudspeaker and in Fig. 4(b) a special three-way dodecahedron loudspeaker [2] is used.



(a) (b)

Figure 5: Spatial variations within a seat position for two different frequency bands of C_{80}.

The spatial distribution of the parameters within a single seat position, is drawn in Fig. 5 for two low-frequency octave bands. As can be seen, the parameters are dependent on position. By only stating the number of the measured seat the uncertainty in position has to be considered. The argumentation for the source position is analog. Towards higher frequencies these variations decrease with increasing mode density. Further experiments and results have been obtained, which are not discussed in detail. A simplified uncertainty budget is shown in Fig. 6 for the investigated uncertainty contributions. The given uncertainty budget is to be understood for a parameter obtained by a single measurement in a room. In this case, the uncertainty exceeds the difference limen. By averaging over, e.g. more positions in a seat or different orientation of the source, the uncertainty contributions decrease accordingly.

Conclusion

An approach of modeling and determining uncertainty contributions of room acoustic parameters, according to the GUM procedures has been proposed. Main influence factors and their relevance regarding measurement uncertainty have been analyzed. Experiments have been designed and conducted to quantify each contribution separately. The combined uncertainty for the output quantity has been calculated and presented for the clarity index, representatively. The uncertainty budged for a single measurement shows values of the order of the jnd. Hence, a single measurement for one source-receiver pair is not sufficient. Instead, more measurement results have to be used to give an average result to reduce the range of uncertainty.

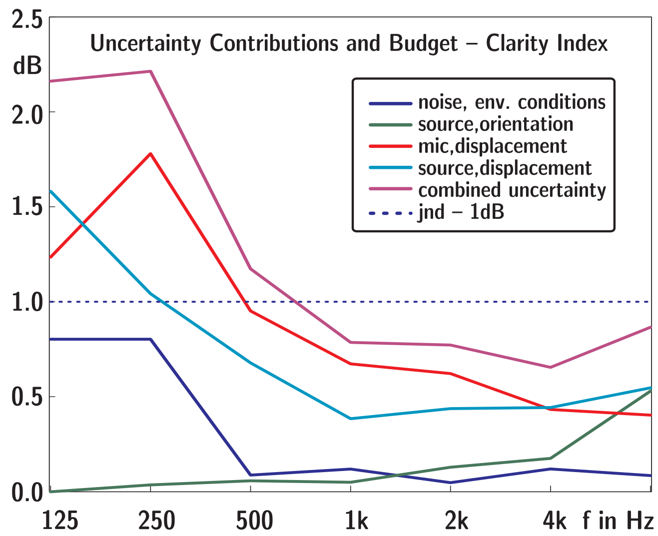


Figure 6: Uncertainty budget for the clarity index.

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