Uncertainties of IACC related to dummy head orientation

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Introduction

In ISO 3382 [1], the interaural cross correlation coefficient (IACC) is identified as a parameter to predict the spatial impression in auditoria based on binaural impulse response measurements. Despite standardisation the way how IACC results have to be interpreted is not agreed on. Aspects such as the relevant frequency bands or the reliability of IACC are currently discussed. In this contribution a first approach is initiated towards assessing the significance of IACC measurements. This is done using the ISO „Guide to the expression of Uncertainties in Measurements“ (GUM) [2]. Due to the complexity a focus is placed on the measurement error and the uncertainty introduced by inaccurately aligning the receiver (artificial head) with the sound source. The results are discussed with respect to just noticeable differences (jnd) and recently proposed signal based predictors for perception of spaciousness.

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 the influence of dummy head misalignment, binaural impulse responses were measured using the FABIAN [4] head and torso simulator (HATS). FABIAN allows for automated measurements with different horizontal and vertical head orientations above its torso. Measurements were conducted in three medium sized, shoebox shaped rooms (V: 3300-5180 m³, T_{30}: 1.14-1.83 s) using a dodecahedron loudspeaker. In each room FABIAN was seated at twice the critical distance from the source while facing it directly. BRIRs where measured for horizontal head orientation angles of ±70° in 1° steps.

IACC calculus and deriving the model function

The calculus to derive IACC from a BRIR is defined in ISO 3382 [1]. The measurements described above are used to assess how IACC is altered due to a misalignment α of the receiver to the source. This is reflected by the inner model function f_{IACC} presented in figure 1 for different frequencies. The graph shows how a misalignment indicated by the rotation angle α changes the relative IACC value in reference to a perfect alignment of the receiver (α = 0°). This graph is a direct result of the measurements conducted in one of the rooms.

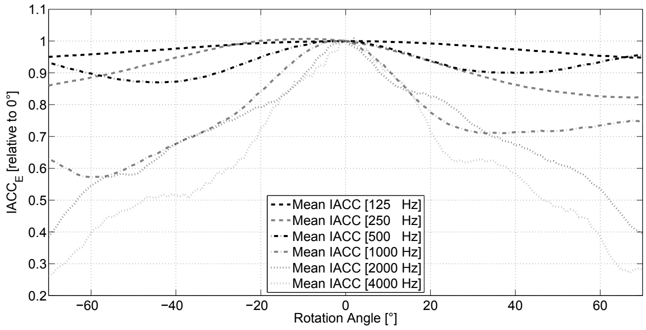

Figure 1: Relative change of IACC due to misalignment of the receiver to the source. Normalised to 0°.

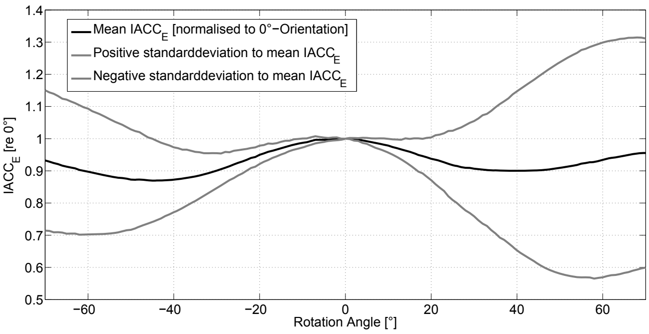

Figure 2: Relative mean IACC for the 500 Hz octave band as a function of the alignment (black). The grey lines reflect the standard deviation between the three measurements.

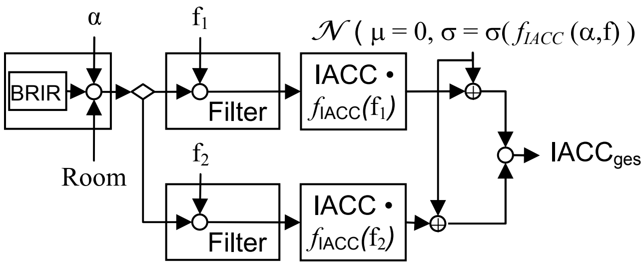

Figure 3: Calculating IACC from a GUM point of view

Since f_{IACC} is determined from sets of measurements in three rooms, each curve of diagram 1 has its respective standard deviation, which is a function of α as well. This is shown for the 500 Hz octave band in figure 2. This standard deviation accounts for other factors influencing the uncertainty (e.g. room, microphone position, etc.), which may not be included otherwise in this empiric approach. In GUM terms this is considered as "incomplete knowledge" about the underlying measurement process. Therefore, the ISO 3382 calculus is extended by a factor to include the error due to head misalignment (i.e. f_{IACC}) and an additive noise process with $\mu = 0$, and σ derived from the IACC distribution among the three rooms to model the incomplete knowledge.

Monte Carlo Simulations

Figure 1 shows the inner model function depending on the misalignment angle α. Due to its nonlinearity this function may not be approximated with a low order Taylor series without a significant approximation error. Hence, MCSs are used to determine the PDF of the output quantity (IACC). This is initiated by selecting a PDF to reflect the statistical properties of the input quantity. For reasons of good faith it is assumed that, when a dummy head is placed for binaural measurements, the alignment angle α reflects a normal distribution with a mean $\mu = 0°$ and a standard deviation σ_α. In a MCS set random selections for the input quantity, with a fixed μ and σ_α, are used to determine the statistical properties of the output quantity. For this study a MCS set is completed when the median and the coverage intervals have been determined with an accuracy of 3 significant digits. In 40 MCS sets the standard deviation σ_α of the input quantity PDF was stepwise incremented from 0° to 40°.

Results – Measurement error and uncertainty

The results of the MCSs are shown in figure 4. For different frequencies the relative measurement error and the uncertainty of IACC are shown as a function of σ_α ranging from 0° to 40°. If, for instance, it is assumed that the

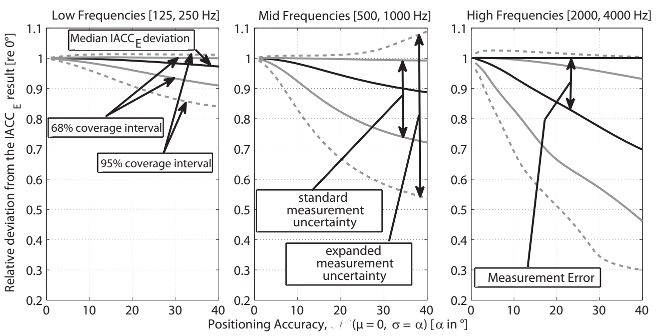

Figure 4: Relative measurement error (black) and uncertainties (grey) of IACC for different frequency bands as a function of the alignment error of the artificial head.

artificial head for an IACC-measurement was positioned with an azimuthal accuracy of $\sigma_\alpha = 10°$ it can be read from figure 4 that the measurement error varies between 0.002 for low and 0.07 for high frequencies. The uncertainty is between +0.005 and -0.013 for low and +0.059 and -0.175 for high frequencies. The measurement error can be compensated, provided a fair estimation of the alignment accuracy for the survey is available. The relevance of these results has to be discussed in view of the jnd for IACC. ISO 3382 quotes the IACC difference limen to be 0.05. This translates to a maximum tolerable placement error of about 10°. It should be noted, however, that in a survey by Kim et al. [5] the collected results of IACC jnds range from 0.04 to 0.7 depending on the absolute IACC value and excitation signal. These results are difficult to interpret from a measurement point of view since the used excitation cannot be considered. Signal based predictors may have the potential to overcome this disadvantage.

Signal based predictors

The measured binaural data sets were further analysed using a method recently proposed by Van Dorp Schuitman [6]. A room acoustical parameter which can be predicted by the model is Apparent Source Width (ASW), i.e. the perceptual quality that is claimed to be predictable by $IACC_E$ [1]. To derive the objective parameter, arbitrary binaural recordings are processed using a binaural, nonlinear auditory model which represents various stages of the human auditory system. In listening tests its predictions have been shown to correlate highly with perception. In order to analyse the measurements using this method, the binaural room impulse responses were convolved with two samples of an anechoic audio signal (male speech and cello music) before processing with the binaural model. From the resulting audio signal ASW was estimated. Figure 5 shows the mean results for both signals in the three rooms. From the results an angular dependence of ASW is predicted as well as a difference depending on the source signal. These results are in good agreement with the angular characteristics of the IACC measurements as well as with the signal dependent jnds for IACC. Nevertheless, further work is required to assess the latter aspect formally.

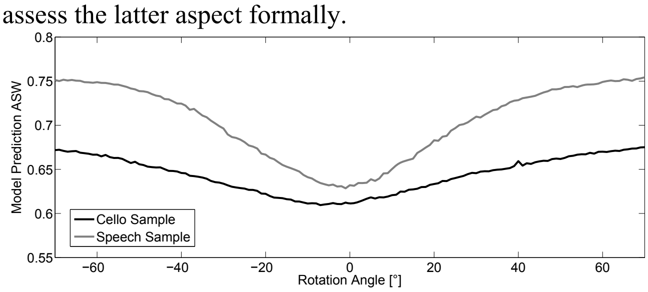

Figure 5: Mean model prediction for the Cello and Speech sample in the three rooms

Conclusions

Measurements of IACC distributions depending on different alignments of a head and torso simulator indicate that the measurement error of IACC measurements due to dummy head misalignment can be compensated. The maximum misalignment that may be tolerated depends on the applicable jnd for IACC. A tolerance of about ±10° seems acceptable in a practical assessment. Additionally, signal based predictors suggest a sensitivity of perceived spatial impression to head orientation. Further perceptual evaluation has to be conducted to clarify the significance of this aspect.

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