Processing of Time Variant Multiple Input Multiple Output Room Impulse Responses

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Introduction

Multiple Input Multiple Output (MIMO) room impulse measurements of a high order [1] allow for the analysis of the acoustic properties of rooms in reference to specific source and receiver directivities [2] and their transfer into virtual reality environments.

High order MIMO measurements require a large number of transducers. Contrary to spherical microphone arrays (SMA), the construction of spherical loudspeaker arrays (SLA) of a high order is not reasonable. Sequential measurement procedures employing a lower order SLA with regular grids can be used to compensate this drawback [1].

Time-stretched measurements with off-site calibrated equipment are especially susceptible to time variances. Recent studies [3] have shown the impact of such time variances in room acoustic measurements.

Time Variances in MIMO Measurements

The room temperature is the dominant time variant component in long duration MIMO measurements [3, 4]. The influences can be divided in three parts: SMA and SLA equalization errors, as well as a changed wave field propagation. These errors add to the pre-existing MIMO system errors [5] and pose a problem if they significantly contribute to the total error.

A temperature profile (cf. Fig. 1) has been tracked during an overnight MIMO measurement [4]. It shows the shutdown and start effects of the air conditioning around the hours 1 and 15. The total temperature dynamic during the 16 tracked hours is about 3 K. A 2 hour period between the hours 8 and 10 with a temperature delta of 0.14 K has been identified as the optimum measurement time. For the following analysis these values are regarded as the usual temperature variances in concert halls and event spaces.

Simulation Method

The simulation uses a MIMO system error model developed by Morgenstern and extended by Berzborn [5, 6]. The far-field pressure generated by an SLA can be denoted as [5]:

$$p_S(k, r, \Omega_S) = \frac{r_{eq}}{r} e^{-ik\,\|r - r_{eq}\|} \mathbf{y}(\Omega_S)\mathbf{D} \tag{1}$$

The matrix $\mathbf{D}$ contains the SLA directivity at a distance of $r_{eq} = 2.00$ m. Analytically, it can be described as a spherical cap model consisting of the driver aperture functions and velocities, the complex conjugate basis of

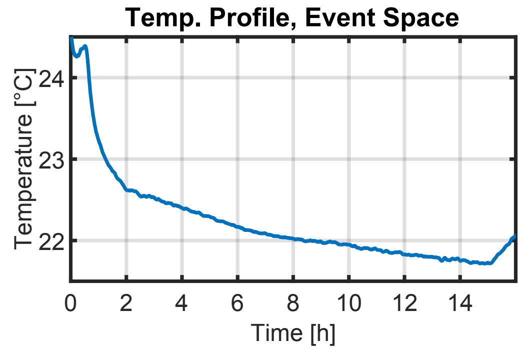

Figure 1: Temperature profile of an event space [4].

the SLA sampling and the modal strength [5]:

$$b_{n,S}(kr) = \frac{\rho_0 c(-\mathrm{i})^n}{k \mathrm{h}_n'^{(2)}(kr)} \tag{2}$$

The resulting pressure on a receiving SMA can be written as [5]:

$$\mathbf{p(k)} = \mathbf{B}\mathbf{y}^{\mathrm{H}}(\Omega_{\mathbf{R}}) p_S(k, r, \Omega_S) \tag{3}$$

The matrix $\mathbf{B}$ contains the spherical harmonic (SH) basis of the SMA sampling and the corresponding modal strength [5]:

$$b_{n,R}(kr) = 4\pi \mathrm{i}^n \left(\mathrm{j_n}(kr) - \frac{\mathrm{j}_n'(kr)}{\mathrm{h}_n'^{(2)}(kr)} \mathrm{h}_n^{(2)}(kr) \right) \tag{4}$$

Temperature changes affect Eq. 2 and 4 due to their dependence on the wavenumber k, causing a new MIMO system output $u_{Temp}(k)$ after equalization and beamforming. The influence on the propagation term in Eq. 1 is neglected. Given a reference MIMO system output $u(k)$, the resulting individual relative error for SLA and SMA is expressed by:

$$\varepsilon_{i,R/S} = 20 \log_{10} \left\| \frac{u(k) - u_{Temp}(k)}{u(k)} \right\| \tag{5}$$

Simulation Results

The reference system is simulated as in a previous study [5]. The MIMO system comprises an SLA ($r_S = 0.20$ m, SH order $n = 11$, cf. Fig. 2) and an SMA ($r_R = 0.11$ m, $n = 7$). The total system error is averaged over 50 random SLA and SMA orientations, with an SNR of 40 dB and aliasing errors. For the temperature variation simulation, k is varied according to the given change in temperature, whereas the MIMO equalization is kept as in the reference system.

Figure 2: SLA ($r_S = 0.20$ m, SH order $n = 11$).

Fig. 3 and 4 show the total MIMO system error (blue) of the reference system in comparison to the individual relative errors of SLA (yellow) and SMA (red) caused by the specified temperature change. It has to be noted that due to aliasing and noise error contributions, the operational frequency range of this MIMO system without temperature errors is limited to about 1.7 kHz to 3.5 kHz. A temperature error that affects this frequency range has to be considered as a problem.

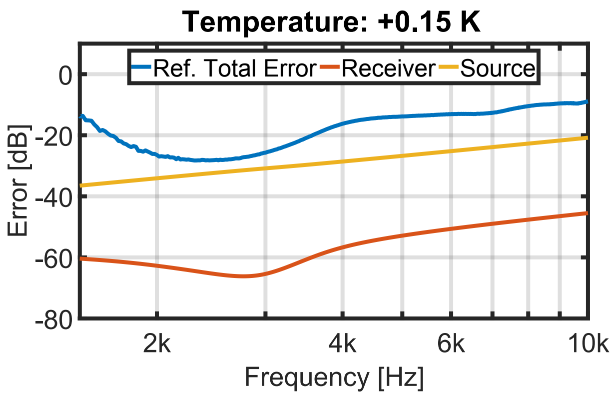

Figure 3: Total system error in comparison to individual temperature error for +0.1 K.

It can be seen, that at +0.15 K the SLA temperature error already starts to contribute to the total system error in the operational frequency range of the MIMO system. A temperature error at +3 K completely obliterates the operational frequency range of the MIMO system.

Conclusion

For the presented system the source temperature error is the dominant component. It starts to contribute significantly to the total system error at about 0.15 K temperature difference. This is about the magnitude of the previously identified minimum temperature fluctuation during a real measurement. At about a temperature difference of 3 K, which has been found to be a common temperature variation during a measurement night in an event space, the MIMO system is rendered unusable.

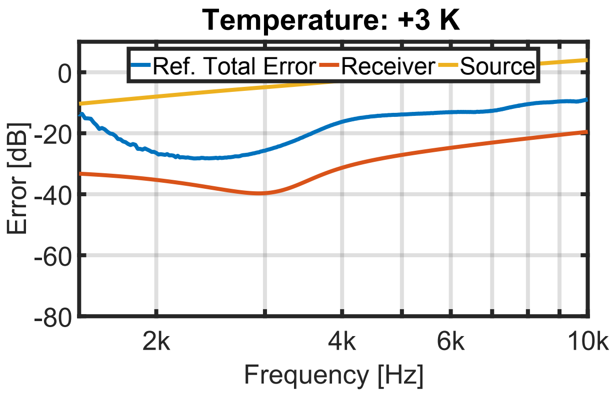

Figure 4: Total system error in comparison to individual temperature error for +3 K.

In practice two categories of MIMO temperature errors can be identified: differences between equalization and measurement, as well as intra-measurement fluctuation. Errors from both categories can be compensated by modification of the MIMO system equalization, if the temperature is tracked at all times during off-site calibration (directivity) measurements and the actual room acoustic measurements. The changes to the expansion term - well known in classic room acoustics [3] - are disregarded in this study. In non free field conditions these temperature changes cannot be compensated by the application of MIMO systems and remain an uncertainty in the room impulse measurements.

References

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