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Investigations on the Diffuseness of Wave Fields in Reverberation Rooms

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Motivation

Measurements performed according to the international standard ISO-354 [5] in a reverberation room require the wave field in the room to be diffuse. However, studies show high uncertainties in the method and a poor inter-laboratory reproducibility of the results [4]. The assumption arises that these problems are in part caused by a non-diffuse wave field. Metrics proposed in the literature will be discussed regarding their robustness and performance.

The Diffuse Wave Field

The diffuse wave field is defined by its spatial characteristics, namely

- an isotropic incidence of an infinite number of uncorrelated plane waves,
- a resulting isotropic energy incidence. [4]

Simulation

In the spherical harmonic (SH) domain, at the coordinate center, a plane wave field can be written as the superposition of plane waves [1]

$$a_{nm}(\omega) = \sum_{q=1}^{\infty} Y_n^m(\Omega_q)\, \mathrm{e}^{-i2\pi\varphi_q(\omega)}, \tag{1}$$

where n, m are the spherical harmonic order and degree, respectively and Ω_q and φ_q are the direction of arrival (DOA) and phase of the q^{th} plane wave. The plane waves were simulated carrying complex exponentials with

- a length 32768 samples,
- **equal phase for correlated waves**,
- uniformly distributed **random phase for uncorrelated waves**.

All simulations were carried out with plane waves arriving from directions **covering the full unit sphere** and **covering only one hemisphere**. The number of plane waves composing the plane wave field was varied from a single plane wave to a maximum of 150. The SH order of the plane waves was varied from one to 10. The DOAs are chosen as the center points of sphere partitions with equal area [2], cf. Fig. 1. To find a set of points on one hemisphere, all points with an azimuth angle $\phi \leq \pi$ were discarded and the number of total points increased until a new point on the desired hemisphere was found.

Estimators

Diffuseness and isotropy estimators have been proposed in the literature. Both, diffuseness and isotropy will be discussed alongside.

Directional Energy Variation (DEV)

The DEV diffuseness estimator is calculated as [1]

$$\psi_{DEV} = 1 - \frac{\mu}{\mu_0}, \tag{2}$$

with μ being the deviation of the directional energy at a receiving point from its mean. μ_0 is a reference calculated analogously for a single plane wave. The directional energy is calculated using a plane wave decomposition beamformer in the SH domain [1].

Monopole Ratio (MPR)

The isotropy estimator after Nolan [3] is calculated as the SH coefficient ratio,

$$\iota_{MPR} = \frac{|a_{00}|^2}{\sum_{n=0}^{N}\sum_{m=-n}^{n}|a_{nm}|^2}. \tag{3}$$

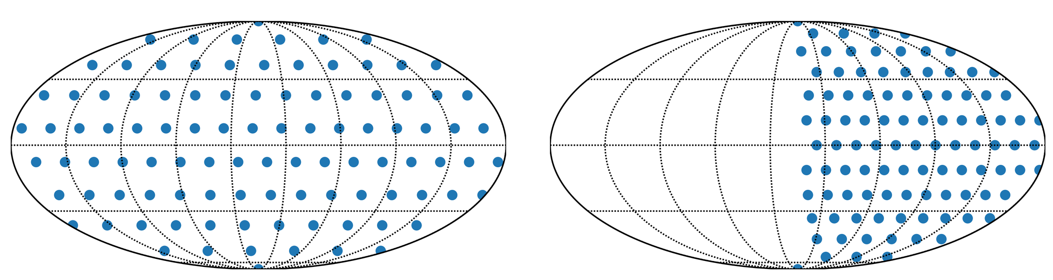
Hence, it describes the ratio between an omnidirectional receiver and receivers of higher orders. In [3], Nolan discusses that the estimator neglects the phase information of impinging waves.

COMEDIE (CMD)

The CMD diffuseness estimator [1] is calculated as

$$\psi_{CMD} = 1 - \frac{\sigma}{\sigma_0}, \tag{4}$$

where σ is the deviation of the singular values of the spatial correlation matrix in the SH domain from their mean. σ_0 is a normalization factor for a wave field comprised of a single plane wave. This estimator is very similar to the DEV estimator. However, as it is based on the spatial correlation, it takes the requirement of the waves being uncorrelated into account.



(a) Covering the full sphere. (b) Limited to one hemisphere.

Figure 1: Direction of arrivals for 100 plane waves, calculated according to Leopardi [2]. The coordinates are calculated using the Mollweide map projection.

Results

Figure 2 shows the results for all diffuseness/isotropy estimators for simulated plane wave fields.

The DEV isotropy estimator

- shows very similar behavior for correlated and uncorrelated plane waves,
- reaches its maximum for a number of plane waves equaling the number of SH coefficients.

The MPR isotropy estimator

- shows similar results as the DEV estimator for correlated waves,
- yields an isotropy of zero for uncorrelated waves, contradicting the isotropy definition.

The CMD diffuseness estimator

- increases linearly with the number of uncorrelated waves and is robust against correlated waves,
- reaches the maximum for a number of plane waves equaling the number of SH coefficients.

Conclusion

- The results for CMD agree with the definition of a diffuse field composed of **uncorrelated waves**.
- The DEV estimator yields similar isotropy results for **correlated and uncorrelated plane waves**.
- The MPR estimator only yields consistent results for **correlated plane waves**.

References

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[4] Mélanie Nolan et al. "The Use of a Reference Absorber for Absorption Measurements in a Reverberation Chamber". In: *Proceedings of Forum Acusticum*. Krakow, 2014.

[5] International Organization for Standardization. *ISO 354:2003 - Measurement of Sound Absorption in a Reverberation Room*. 2003.

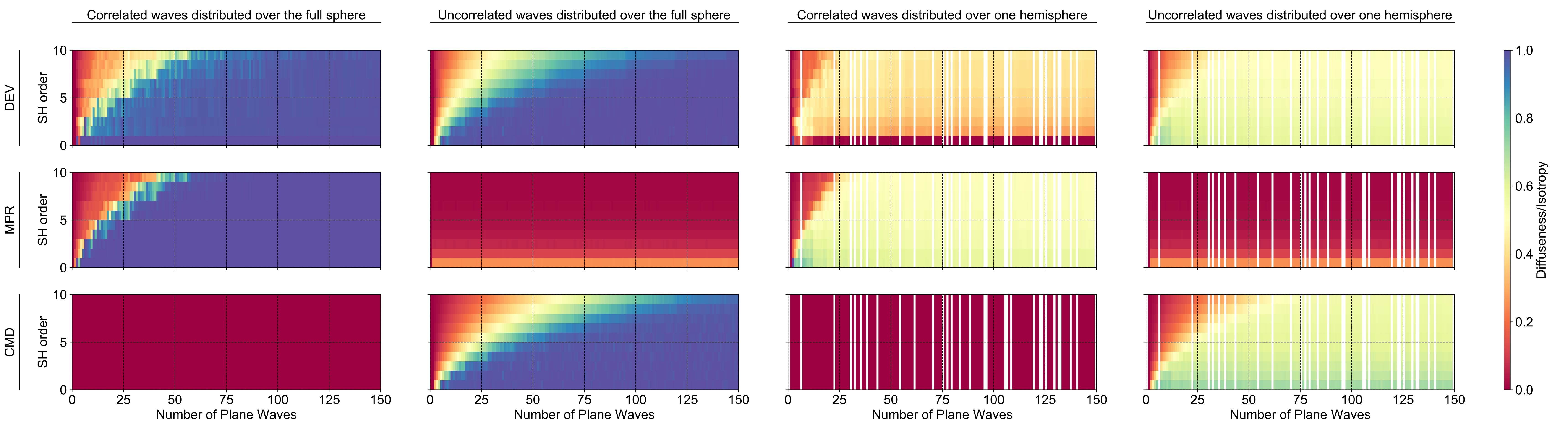

Figure 2: Diffuseness and isotropy estimates for correlated and uncorrelated plane wave fields with DOAs covering the full unit sphere or only one hemisphere. Blank lines represent the case where no distribution of DOAs fulfilling the equal area partitioning on one hemisphere were found.

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