Continuous Directional Room Impulse Response Measurements

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Introduction

Directional room impulse response (DRIR) measurements of a high order [1] require a large number of sources and receivers, which can conveniently be grouped into arrays and are seen as multiple-input multiple-output (MIMO) systems. To achieve a high order on the source side sequential measurement procedures employing lower order spherical loudspeaker arrays (SLAs) with regular grids can be used [2]. This method requires a large number of measurements and is furthermore slowed down by the decay time of the inertia of the mechanical system at each measurement position.

Studies have shown the impact of time variances in long duration room acoustic measurements [3]. Combined with specialized array designs [4], continuous measurement methods can offer a faster approach for high order directional SLA measurements than sequential techniques [5, 6]. The method has already been applied to HRTF measurements [5] and various spatial room impulse response (RIR) measurements [7]. The goal of this study is to evaluate the benefit of a continuous method in realistic DRIR measurements.

Time Variances

The room temperature is the dominant time variant component in RIR measurements [2, 3]. Measurement errors resulting from temperature changes are added to the preexisting MIMO system errors [8] and pose a problem if they significantly contribute to the total error. Fig. 1 shows an overnight temperature profile with a minimum slope of $0.07\,^\circ\mathrm{K\,h^{-1}}$ [2].

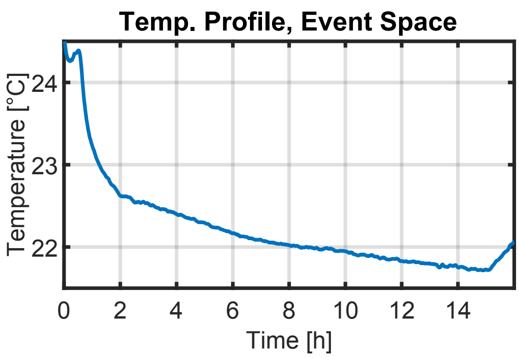


Figure 1: 16 hour overnight temperature profile of an event space [2].

Continuous Measurements

A modified normalized least mean-square (NLMS) type adaptive system identification method [6] for generic periodic sequences is used for the measurements. The signal

$$y(k) = \mathbf{g}^{\mathrm{T}}(k)\mathbf{x}(k) + n(k) \tag{1}$$

at a time instant k is the recorded result of exciting the time-varying acoustic system

$$\tilde{\mathbf{h}}(k) = (\tilde{h}_0(k), \tilde{h}_1(k), ..., \tilde{h}_{N-1}(k))^{\mathrm{T}} \tag{2}$$

with

$$\mathbf{x}(k) = (x(k), x(k-1), ..., x(k-N+1))^{\mathrm{T}} \tag{3}$$

of length N, including the additive noise $n(k)$. With the error $e(k)$, a modified NLMS algorithm [6] with a step size μ estimates the impulse response

$$\mathbf{h}(k+1) = \mathbf{h}(k) + \mu e(k)\mathbf{h}_{k \bmod N}. \tag{4}$$

The length of the estimated impulse response is restricted to the length of the reverberation time

$$t_{reverb} = t_{imp} = \frac{N}{f_s} \tag{5}$$

with the sampling rate f_s. $\mathbf{x}(k)$ must be selected accordingly. A source rotation introduces spatial aliasing artifacts [7]. For a constant quality of the results for each channel, which is related to a rotational base speed s_b, the actual measurement speed

$$s_m = \frac{s_b}{n_c} \tag{6}$$

is determined by the number n_c of channels used. The same is true for the effective excitation signal length

$$N_{eff} = N \cdot n_c. \tag{7}$$

Spherical Loudspeaker Arrays

For sequential measurements, SLAs often sample a regular grid of measurement directions. At each rotational position of the array all channels are measured individually. A current procedure for a spherical harmonic order 11 requires 288 measurements [2].

An SLA with an azimuth angle non-uniform HEALPix distribution with 4 subdivisions requires 192 measurements with 12 transducers for the same order [4]. The sheer measurement time is reduced by a factor of 1.5. However, at one rotational position not all transducers are at a measurement position. A continuous measurement renders the non-regularity of the grid irrelevant.

Figure 2: Measurement setup in lecture room.

Measurement

The measurement is done in a small lecture room, with a T30 broadband reverberation time of 0.7 s and a maximum narrow band T30 of 1.3 s at 200Hz. The Source receiver distance is 8 m.

Three individual channels of a dodecahedron [9] with a radius of 0.15 m have been used. The center points of the three transducers are located at spherical coordinate elevation angles ϑ_s specified in Table 1, which translate to the effective cylindrical rotation radii r_c.

Transducer	ϑ_s	r_c
1	37.4°	0.09 m
2	142.6°	0.09 m
3	100.8°	0.15 m

Table 1: Spherical elevation angle ϑ_s and corresponding cylindrical rotation radius r_c of the three used channels on a dodecahedron with a radius of 0.15 m.

The loudspeaker is placed on a computer controlled turn table to allow for a precise source rotation. The measurement signal is an exponential sweep [10] of a length $t_{imp} = 1.486$ s, the system response is recorded with a 1/2 inch condenser microphone.

The goal of this study is to compare the result of a static measurement with the same excitation signal properties to the result of a continuous measurement at the equivalent source orientation. The continuous measurement is started 30° before and ended 30° after the intended source position. The room and parts of the measurement setup can be seen in Fig. 2.

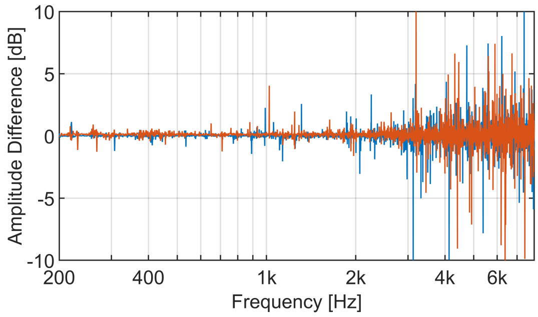
The continuous measurement yields a large number of RIRs, which represent measurement results in all source orientations covering the measured 60° range. To identify the one RIR corresponding to the static reference a maximum correlation search is conducted in a very confined range of angles around the reference angle. This procedure yields the best case example for the comparison.

Results

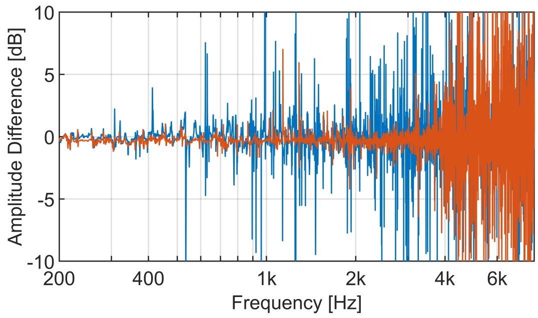
The continuous measurement is executed for several rotational base speeds s_b. As stated in Eq. 6, s_b can be considered the rotational speed of a single transducer. Table 1 lists the different r_c. With Eq. 7 these properties yield the distance

$$d_t = \frac{s_m \cdot \pi}{180°} \cdot \frac{N_{eff}}{f_s} \cdot r_c = \frac{s_b \cdot \pi}{180°} \cdot \frac{N}{f_s} \cdot r_c \tag{8}$$

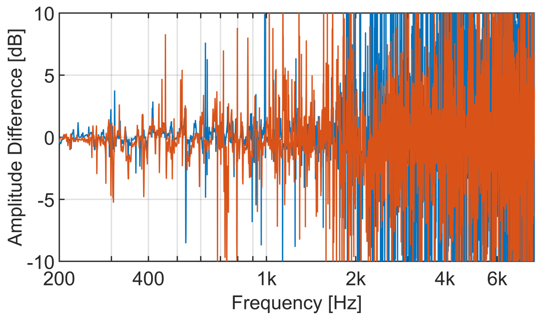
of the center of the transducer traveled during one effective excitation length. The measurement results can be discussed related to s_b for the whole array or related to d_t for an individual transducer.



(a) Repeated static measurement.



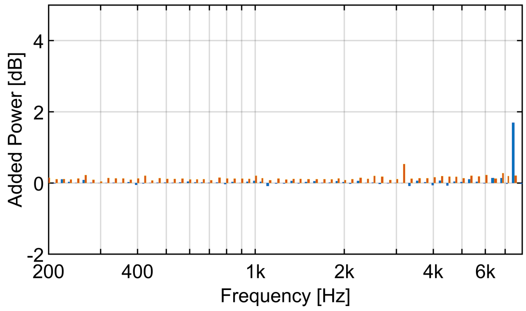
(b) $n_c = 3$, $s_b = 3\,°\,\mathrm{s}^{-1}$, $d_{t1} = 0.007$ m, $d_{t3} = 0.0117$ m.



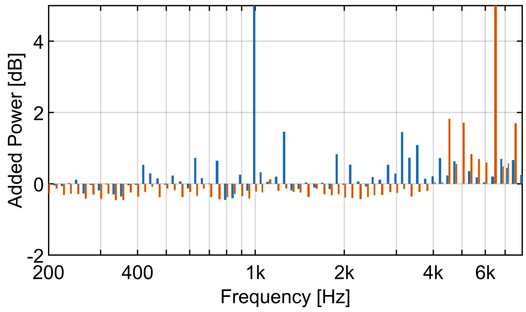
(c) $n_c = 3$, $s_b = 9\,°\,\mathrm{s}^{-1}$, $d_{t1} = 0.021$ m, $d_{t3} = 0.035$ m.

Figure 3: Spectral division of measurement results by one static measurement result for two of three channels. Red: channel 1. Blue: channel 3.

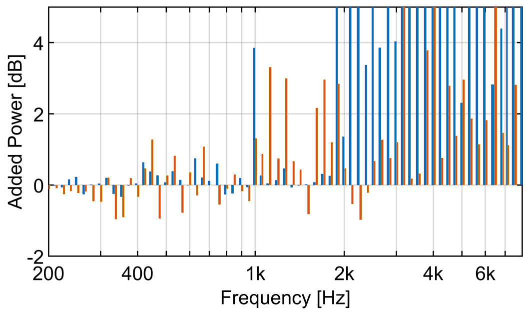
The time passed between the measurements in Fig. 3a is 60 s. The results show the maximum reproducibility that can be achieved in this setting and can be understood as reference. At about 1 kHz, occasional deviations can be seen for both channels. Figs. 3b and 3c and show the amplitude difference between continuous measurements



(a) Repeated static measurement (power).



(b) $n_c = 3$, $s_b = 3\,^\circ\,\mathrm{s}^{-1}$, $d_{t1} = 0.007\,\mathrm{m}$, $d_{t3} = 0.0117\,\mathrm{m}$.



(c) $n_c = 3$, $s_b = 9\,^\circ\,\mathrm{s}^{-1}$, $d_{t1} = 0.021\,\mathrm{m}$, $d_{t3} = 0.035\,\mathrm{m}$.

Figure 4: Added power in 1/12 octave bands of spectral division from Fig. 3.

and a static reference taken shortly before each measurement. Fig. 3b shows less artifacts for channel 1 with the smaller absolute displacement than for channel 3. Large amplitude differences appear above 4 kHz for the former, above 1.2 kHz for channel 3. Fig. 3c shows strong artifacts for both channels above 1 kHz, with much larger deviations in channel 3 above 2 kHz.

Fig. 4 confirms the observations in Fig. 3. The depiction of the power spectra offers a clearer view at the actual differences.

Conclusion

Continuous measurements can be applied for DRIR measurements if spatial aliasing is kept at a minimum. For the case of a completely non-uniform SLA, a full DRIR measurement of $n = 192$ directions with $n - 1$ rotations and a rotation time $t_r = 5\,\mathrm{s}$ yields a measurement time

$$t_m = n \cdot t_{imp} + (n-1) \cdot t_r = 1240\,\mathrm{s}. \qquad (9)$$

For a continuous measurement, this translates to a rotational speed $s_m = 0.29\,^\circ\,\mathrm{s}^{-1}$ for the same t_m. For a system with $n_c = 12$ this results in an $s_b = 3.48\,^\circ\,\mathrm{s}^{-1}$ and a borderline result quality up to 4 kHz for the investigated room, depending on the transducer position. The benefit of this continuous method lies mainly in the economization of the array positioning times when using few channels with non-uniform distributions.

Acknowledgement

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