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Comparison among measured and simulated binaural impulse responses in different rooms

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ABSTRACT

The impulse response in a room is an important feature to determine the main acoustic parameters in a measurement point of a room or environment. This characteristic is dependent on the location where the receiver is located. The precise determination of this attribute can be integrated into a complete auralization process in order to obtain a real-time system. Nowadays, many audio applications takes into account the IR for developing audio application in several fields as virtual reality environments, teleconferencing, spatialization of sound, etc. In this work, we have determined (by measuring and simulating rooms) the BRIR in several locations of two rooms with different sizes, geometries and uses. The rooms measured and simulated are: a church and a multi-use room.

INTRODUCTION

The impulse response (IR) in a room describes the energetic arrival of the sound power emitted by a source. It determines most of the main characteristic parameters which describe the acoustic features in the room. For example, the reverberation time can be determined from the integrated impulse response following the method proposed by Schroeder [1].

This response is dependent on the location of the measurement or simulation point inside the room, so it is different depending on the pair source-receiver relative position. According to this, the dependence is reflected not only in the distance to the source and reflections which arrive to the receiver, but also in the orientation of the receiver with respect to the source.

The measurement or simulation of binaural room IR (BRIR) allows us to get approximated information about the perception related to the cues of a receiver in any point of the room. This binaural condition is obtained by using HRTF functions in the measurement or simulation process.

Maximum Length Sequence (MLS) measurement technique for the IR was first introduced by Schröeder in 1979. This technique has several advantages and inconveniences, and they have been widely discussed in the literature. This technique is based on the excitation of the acoustical space by pseudo-random signal having almost the same stochastic properties as white noise. The number of samples of one period of an *m* order MLS signal is: $L=2^m-1$. The IR is determined cross-correlating the measured output and the determined input (MLS sequence) [2]. Other interesting techniques are Inverse Repeated Sequence, Time- Streched Pulses and Sine sweep techniques.

MLS and IRS use pseudo-random white noise, while Time-Streched Pulses and Sine sweep techniques use time varying frequency signals.

Sine sweep technique improves the others, because it is not based on the assumption of a LTI system and it does not cause distortion artifacts in the deconvolved impulse response. It was first introduced by A. Farina.[5] This technique uses an exponential time-growing frequency sweep to excite the system. Applying this input, it is possible to deconvolve simultaneously the linear impulse response of the system and to separate selectively each impulse response corresponding to the harmonic distortion orders considered [2]. In this way, the determination of the IR of the room is practically obtained by convolving the measured output with an inversed filter which is the result of the inverse of the input signal in frequency domain.

The resulting IR is the combination of h(t) due to the first reflections in the room and the cue which is due to late reflections (see figure 1).

In other terms, the most precise methods to obtain the IR are those based in full wave solution (i.e. FEM, FDTD, etc). They can give good results in wideband, but they have much higher computational cost.

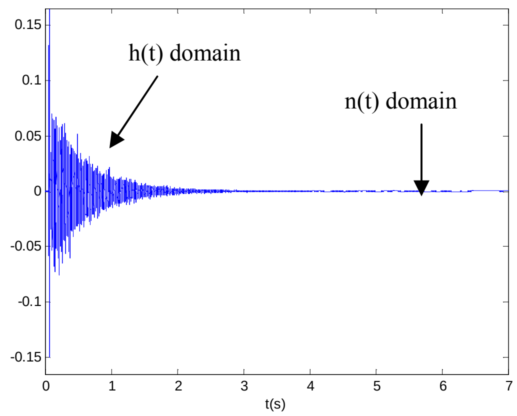


Figure 1. Domains in the IR

In this paper, the process to enable comparison between measured and simulated binaural signals is described by using cone-tracing and image sources hybrids algorithms for simulation and sine sweep technique for measurement. Impulse responses are obtained by using them in two rooms and the comparison is made.

METHODOLOGY

Our purpose is to get a methodology to be able to compare BRIRs from measurements and from simulations. To do it, first the BRIR is measured in each receiving point in the room by means of a dummy head (HeadAcoustics Measurement System – HMS IV™). This system records the sine sweep signal emited by an isotropic source (dodecahedron emitter). The software used to control and process this emission is WinMLS™ [5].

The cone-tracing and image source hybrid methods, used in CATT software [6], allow the determination of the IR from the echograms. A post-processing stage allows obtaining the BRIR by means of applying the Head Related Transfer Functions (HRTFs) as filters in the IR. As the simulated signal does not include direct sound, this is eliminated from the measured sound. As it is shown in the literature [7], this simulated BRIR is poor at low frequencies with this method. To allow comparison with measurements, a filtering of the BRIR measured and simulated signals have been done.

The filter used is a 3rd order elliptical filter is a high-pass filter with a soft ripple in the upper and in the lower zone. The cut-off frequency is centered in 500 Hz. The MATLAB code is:

```
>> [b,a]=ellip(3,0.2,20,0.05,'high');
>> [h,z]=freqz(b,a);
>> y=filter(b,a,signal);
```

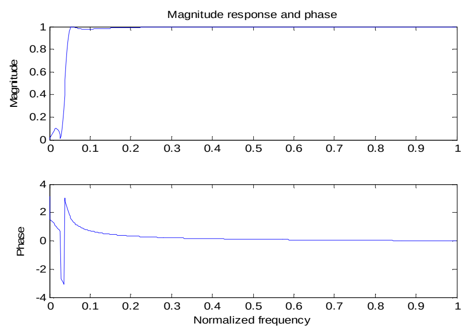


Figure 2. Elliptic filter designed.

After this filtering process, an estimation of the power spectrum density is applied. This estimation is made in order to make an auto-correlation of each signal, and a prediction of the power distribution of each signal (measured left and right, simulated left and right). To do it, a 12th order Yule-Walker Power Spectrum Distribution predictor was used.

RESULTS

In order to test this methodology, two rooms have been considered: a medium-size room for academic performances and a large room used for worship. The medium-size room is the Paraninf of the Polythecnic University of Valencia, with 2700m^3 (figure 3) and the large room is the Sant James Basilica in Algemesí with 12150 m^3 (figure 7).

The signals obtained from the simulations and the measurements have been preprocessed in order to get the same size in the frequency domain.

A medium-size room: Paraninf at Polythecnic University of Valencia.

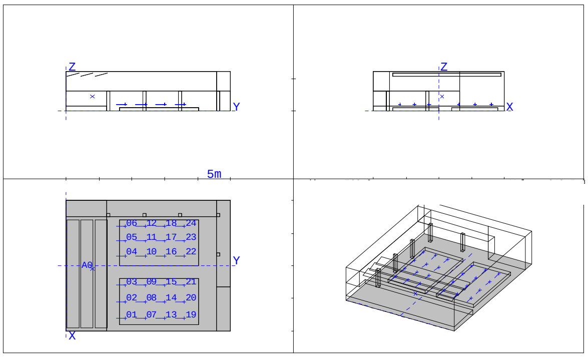


Figure 3. Geometric model for the Paranimf.

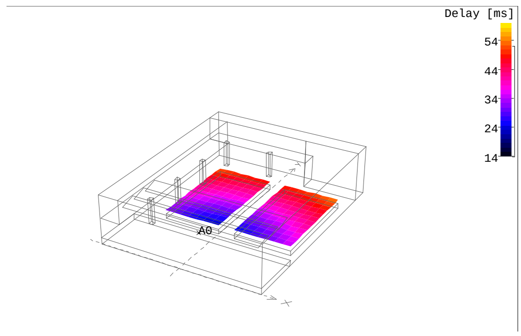


Figure 4. Delay colour map for the Paranimf.

Figure 4 shows a colour map of the delay simulated in the room. This plot shows a variation between 25 and 50 ms for different positions.

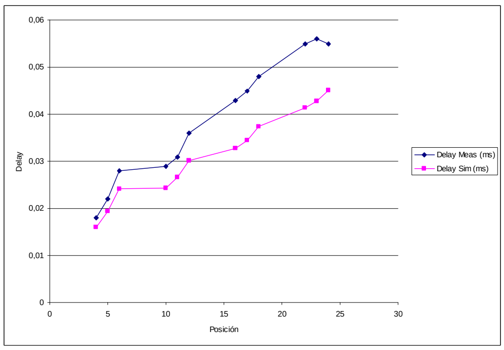
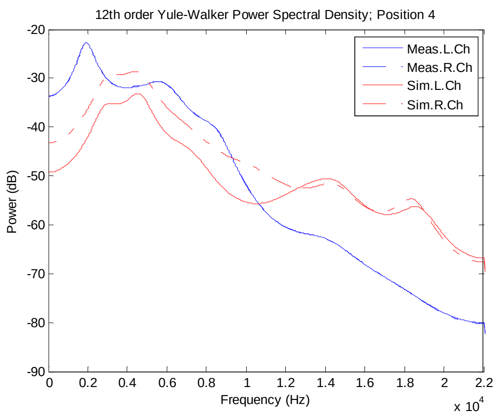


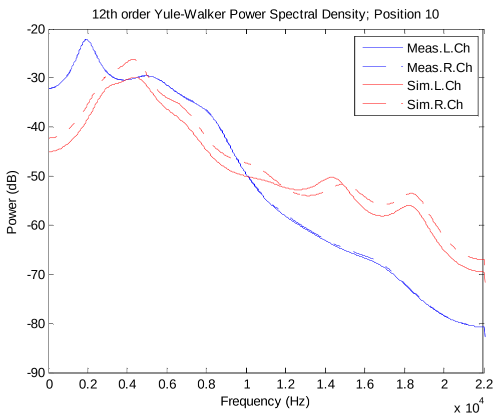
Figure 5. Delay plots of binaural measurements and simulations for the Paranimf.

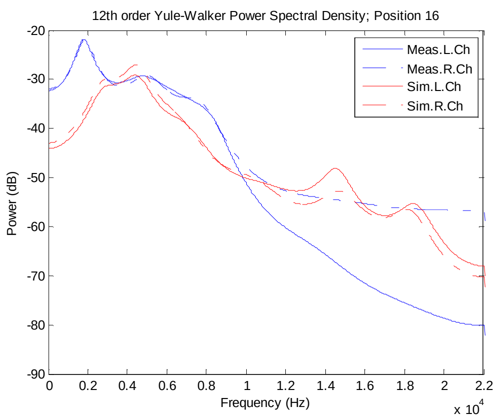
In order to compare measured and simulated impulse response, we have estimated the power spectral density by using Yule-Walker method.

Before this estimation of the spectral response, we have normalised all the signals in order to have a good amplitude comparison.

In the next figures we can see some results at six different positions. We can observe that in general simulated signals show less power levels than measured signals at low frequencies.







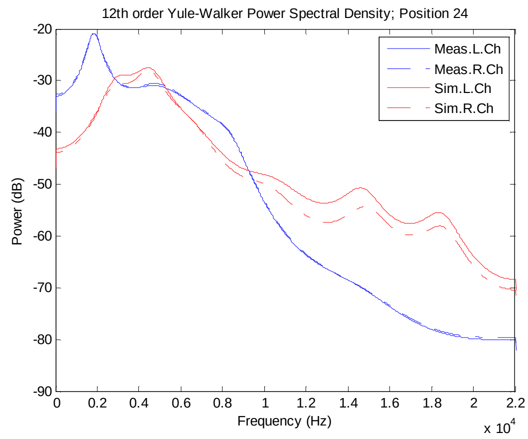


Figure 6. Plots of the PSD in different positions for the Paranimf (a), (b), (c), (d).

These plots show a quite good fit relation only at positions far from the source, where the effect of the late reflections are more relevant.

A big room: Saint James Basilica in Algemesi (Valencia)

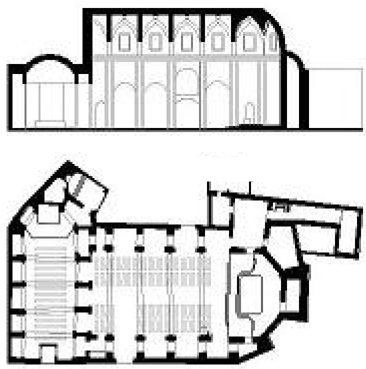


Figure 7. Plan for the Basilica.

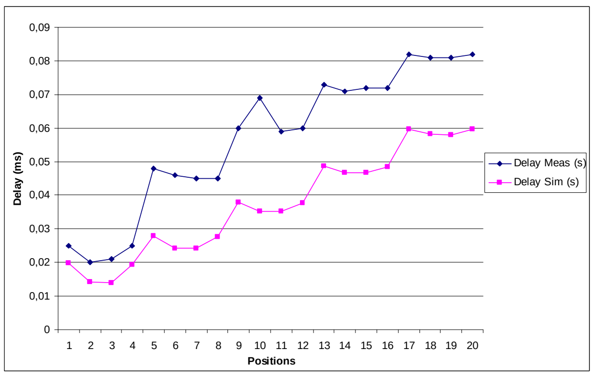
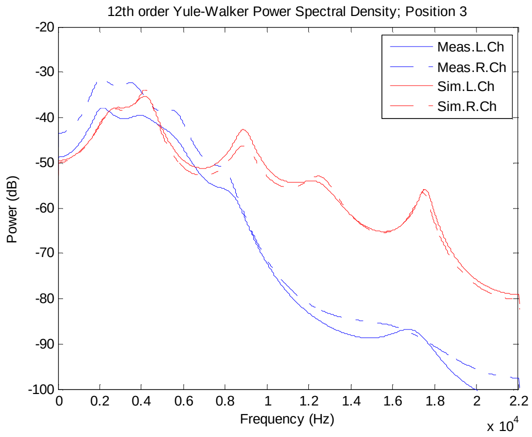
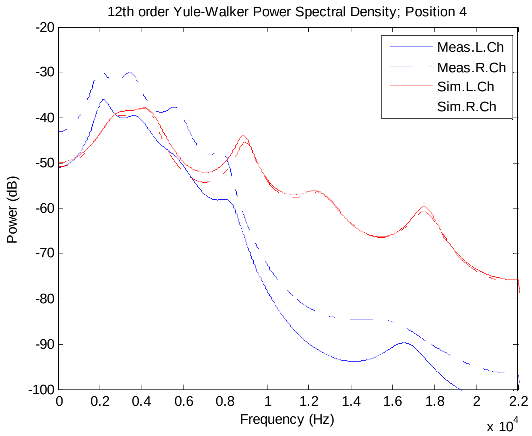
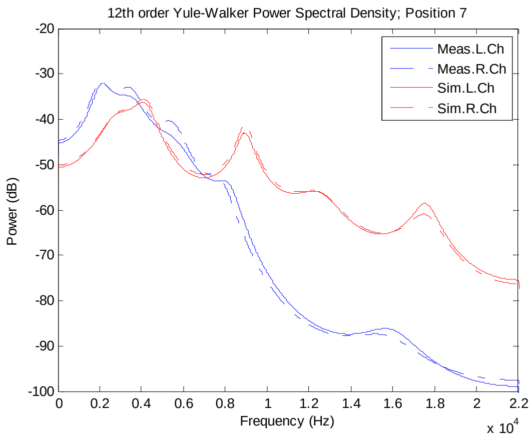


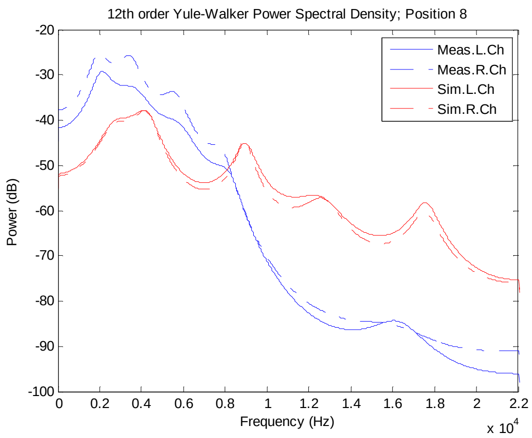
Figure 8. Delay plots of binaural measurements and simulations for the Basilica.

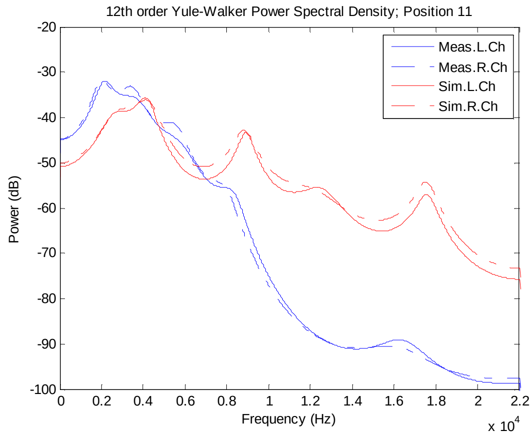
In order to compare measured and simulated impulse response, we have calculated the power spectral density. In the next figures we can see some results at six different positions.











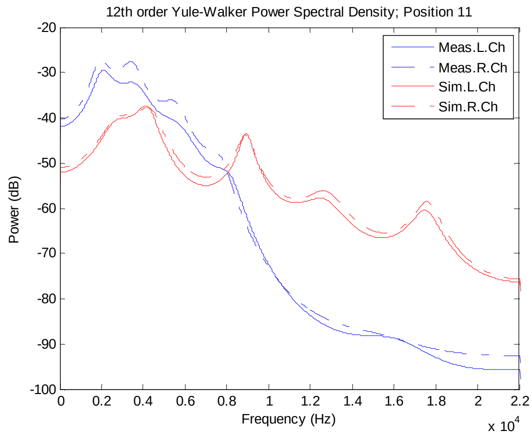


Figure 9. Plots of the PSD in different positions for the Paranimf (a), (b), (c), (d), (e), (f).

In this case, we can observe that in general simulated signals show very less power levels that measured signals at low frequencies. Now, there is a good fit relation up to 7kHz, only at positions near to the source. This means that simulated impulse response shows a bad behaviour at low frequencies and at near positions. Thus, the model must be adjusted with more precission to obtain better results.

CONCLUSIONS

This work shows a methodology to establish comparison between simulated and measured BRIR signals in a room.

In the process of assessment, two rooms have been tested and the results show that the source design in the simulation is very important. It also shows that the simulations are poor at low/medium frequencies. To solve this, some authors propose to work with combined methods with full-wave methods (i.e. FDTD or FEM) [7].

Some stages are critical in this comparison process: design of the source, adequate geometrical modelling and callibration.

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REFERENCES

1. M. R. Schroeder, "New Method of Measuring Reverberation Time" J. Acoust. Soc. Am., 37, 409-412, (1965).
2. Stan Guy-Bart, Embrechts Jean-Jacques, Archambeau Dominique. "Comparison of different impulse response measurement techniques". JAES, Vol. 50, Issue 4, pp 249-262, April 2002.
3. J. S. Suh and P. A. Nelson. “Measurement of transient response of rooms and comparison with geometrical acoustic models”. J. Acoust. Soc. Am., 105, 2304-2317, (1999).
4. Angelo Farina. “Simultaneous measurement of impulse response and distortion with a swept-sine technique”. 108th AES Convention, 2000.
5. Morset Sound Development, WinMLS 2004 measuring software, Users manual
6. CATT-Acoustics v8. User’s Manual: Room Acoustic Prediction and Desktop Auralization. CATT, Göthenburg (Sweden), 2002.
7. M. Vorländer, “Simulation and auralization of broadband room impulse responses”. TecniAcustica 2009, Cadiz (Spain).