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NEW MEASUREMENT TECHNIQUE FOR 3D SOUND CHARACTERIZATION IN THEATRES

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Abstract

The definition and measurement of 3D properties of the sound field has been strongly improved in last years, as nowadays spatial properties of sound propagation are considered quite important during design of theatres and auditorium. Besides, a proper assessment of the degree of spatial accuracy is requested during sound reproduction inside 3D listening rooms, initially designed for acoustical virtual reality, but nowadays being employed also in the entertainment/cinema industry (Immsound, Auro-3D, NHK 22.2).

Normally, only monoaural or binaural measurements are performed, by means of omni-directional microphones and dummy heads, even though international standards like ISO 3382/1:2009 require measuring some spatial parameters (i.e. IACC, LE, LF): the last two parameters require to be measured with a pressure velocity (p/v) microphone, but still it is a 2-channels measurement only. 3D impulse responses are rarely measured and employed for sound reproduction. In this paper, an innovative procedure for measuring and analyzing the complete spatial sound information is presented. The description of this new technique is emphasized. Furthermore, the results of a wide campaign of measurements of spatial parameters among different rooms, including some ancient theatres, conducted with the novel methodology, are compared with the results of standard binaural and p/v measurements. The possibility to capture the complete spatial information in real spaces and the significance of 3D spatial parameters is then considered and presented in different cases.

Keywords

Measurements in theatres, 3D Auralization, Spatial sound properties

1. Introduction

The collection of sonic behaviour of ancient theatres and auditoria initially proposed by Gerzon [1] became extremely important after the burning of two theatres in Italy: Teatro Petruzzelli in Bari and La Fenice in Venice [2].

After that, many attempts were made to standardise the acoustic measurements in theatre and worships, [3,4] taking into account several position of sound sources, microphones, and conditions of the room. On the other hand, only few attempts were made to describe and standardise the test signal to use during the measurements, and the kind and variety of sound sources and especially microphones [5]. These specifications become quite important whenever the IRs are required to perform 3D auralisation of the room, rather than to obtain the numerical values of ISO 3382 parameters.

2. Previous measurement methods

A first attempt to capture the spatial information inside a theatre was done with the measurement method described in [5], which incorporates all the previously known measurement techniques in a single, coherent approach: three different microphone systems were mounted on a rotating beam (a binaural dummy head, a pair of cardioids in ORTF configuration, and a Soundfield microphone), and a set of impulse responses was measured at each angular position. The ORTF configuration is a standard method for recording stereo signals, in which the two cardioid microphones are spaced 170 mm and are diverging by 110 degrees each other. The Soundfield microphone, introduced by M. Gerzon [1], captures 4 signals, known as “B-format” signals: one omnidirectional (pressure) and three with a polar pattern called “figure of eight”, oriented along the three cartesian axes X,Y,Z (these three channels capture a signal proportional to the Cartesian components of the particle velocity vector).

The combination of the three aforementioned different measurement methods, properly combined, provided a general method from which all standard multi-channel formats (i.e., 5.1, 7.1, 10.2, etc.) can be derived.

3. New measurement method for multichannel impulse responses

The main problems with the previous method were that it was very slow, that the setup of the microphone system was delicate and tedious, and that it was difficult to combine the information coming from the three microphone systems employed.

Recently, a much more powerful, elegant and simple measurement system has been proposed, based on a spherical microphone array equipped with 32 capsules mounted on the surface of a small sphere (80mm diameter), which contains the preamplifiers, the A/D converters, and an audo-over-ethernet chipset, called the Eigenmike™ . This probe makes it possible to measure 3D multichannel impulse responses, providing a much finer spatial resolution than what was possible until one year ago [6].

4. Test signal and deconvolution

The excitation-deconvolution technique employed for the measurement of the impulse response is the ESS - exponential sine sweep method [7]. In this way it is possible to calculate the impulse response of the linear system avoiding contamination due to distortions, which usually occurs in the loudspeaker, and obtaining a large value of the S/N ratio.

5. Sound sources

The choice of the sound source could represent an important issue during the measurements and the following 3D auralisation. The standard ISO 3382/2009 requires using an omnidirectional sound source for measurements of room impulse responses. Even though the omnidirectional loudspeaker does not correspond to the effective directivity pattern of real-world sound sources, it is preferable to use it when the purpose of the measurements is to precisely determine the sound distribution in a room. It avoids exploiting room effects (abnormal concentration of energy and focalizations for selected orientations of the source), as can happen employing highly directive loudspeakers. The omnidirectional loudspeaker could be a dodecahedron (which contains 12 different loudspeakers) or an other type of omnidirectional source having an higher number of drivers (up to 18 or 24).

Some single-way transducers were developed, claiming to be ideal for these type of impulse response measurements (i.e., the B&K type 4295 OmniSource Loudspeaker): however this type of loudspeakers revealed to have insufficient power, and to create a strongly coloured spectrum, so in practice a good dodecahedron with proper design and equalization is still the most preferable choice. Indeed, most dodechaedrons are designed for building acoustics measurements, so they have a strongly coloured spectrum, too, and cannot radiate efficiently below 100 Hz and above 5 kHz. For wide-band impulse response measurements, to be used for auralization, it is necessary to get a specially-built dodecahedron, with wide frequency response (30 Hz to 16 kHz, minimum) and incorporating a perfectly-flat digital equalization system.

However, when the purpose of the measurements is to determine the acoustic response of a room when a particular kind of source is used (a particular musical instrument or the human voice), a directive sound source could be added to the omnidirectional one during the measurements (for example, an artificial mouth).

6. Microphones

So far, the ISO 3382/2009 standard [8] requires usually omnidirectional, monoaural microphones, to be utilised in the measurements of acoustic parameters, and only specifies the dimension of those microphones (preferably less than 13 mm). Moreover, the ISO 3382/2009 describes the characteristics of eventual binaural microphones (real heads or dummy heads), which could be used to measure binaural Impulse Responses and IACC. The aforementioned standard also considers using figure-of-eight microphones to measure some lateral-energy parameters, such as LE and LF.

6.1 Traditional microphone systems

Leaving apart the binaural measurements, a Soundfield microphone could be the optimal transducer for performing 3D impulse response measurements: the W channels is good for the monoaural parameters (omnidirectional), the Y channel provides the figure-of-8 signal required for computation of LF, and other two directive channels (X and Z) can be used for recreating the whole 3D soundscape inside a playback environment making use of the old 1st-order Ambisonics technology

However, a 1st order Ambisonics playback system is considered currently incapable of providing accurate spatial cues to the listeners, as this technology is incapable of synthesize sound fields exhibiting significant polarization, the sound is always coming almost from everywhere. A possible solution is to employ high-order Ambisonics (HOA) systems, which indeed require capturing a multichannel signal corresponding to the spherical harmonics expansion up to 3rd or 4th order. Albeit HOA revealed to work very well with synthetic signals (where the high-order spherical harmonics signals are computer-generated), the recording of HOA signals revealed to be problematic, even employing microphone arrays composed of dozens of elements: when the directivity of the harmonic patterns becomes high, the S/N ratio becomes poor at low frequency, and the spatial accuracy of the pattern is disrupted at high frequency, so that the useful bandwidth reduces to less than one octave band.

6.2 The new 3D Virtual Microphone System

For realtime recording/broadcasting applications, a new microphone system was recently developed by the RAI Research Center in Turin and by AIDA, a spinoff of the University of Parma. It is based on a 32-capsules spherical microphone array (Eigenmike™), and a realtime filtering software which is capable to synthesize up to 7 virtual microphones, which can be moved in real-time, and with variable directivity (zooming) capability. The "virtual" microphones, are controlled by mouse/joystick gestures in order to follow actors on the stage in realtime, and to zoom in or out, by changing the sharpness of the directivity pattern. The pattern is chosen among a family of cardioid microphones of various orders, according to this formula:

$$Q_n(\vartheta,\varphi) = [0.5 + 0.5\cdot\cos(\vartheta)\cdot\cos(\varphi)]^n \tag{1}$$

where n is the directivity order of the microphone.

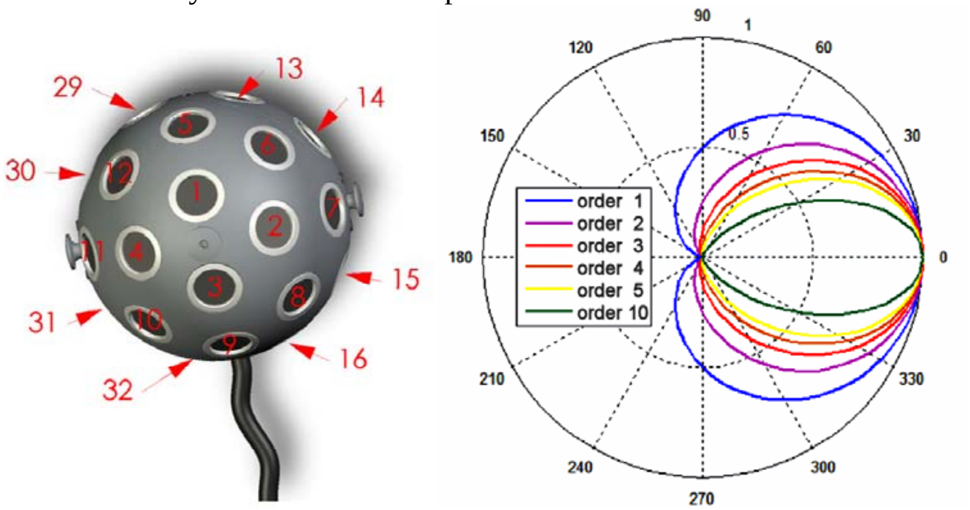

Figure 3 Capsule positions and directivity patterns of the 3D virtual microphone

When this system is employed for 3D impulse response measurements, indeed, instead of synthesizing just 7 virtual microphones with variable aiming and directivity, in realtime, a post-processing Matlab application is employed, which creates 32 virtual microphones, with fixed directivity patterns (6^{th}-order cardioids) and aiming (the same directions as the 32 capsules located on the spherical surface).

This way, the whole spherical surface is "spatially sampled" with an almost constant angular aperture: the resulting spatial sampling can hence be considered as a "PCM sampling", whilst the traditional spherical harmonics sampling employing in HOA can be though as a spatial "Fourier sampling".

If the aiming directions of the 32 virtual microphones are overplotted over a panoramic 360°x180° image taken from the microphone position, one can "see" where the 32 microphones are pointing, a shown in figure 4:

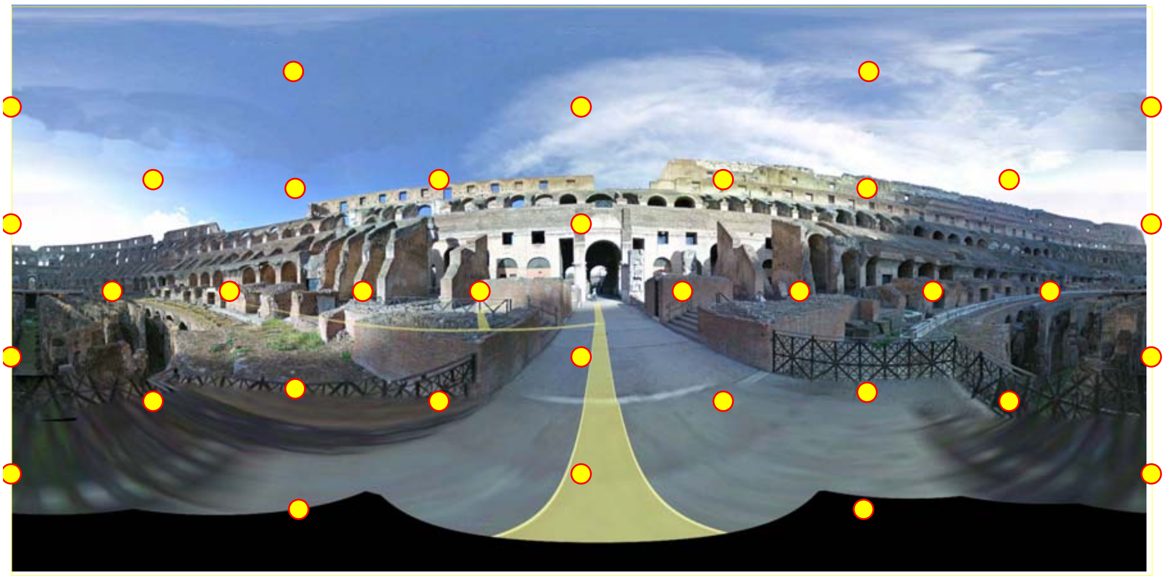

Figure 4 The 32 virtual microphones pointing all around inside the Colosseum in Rome

7. Post Processing

After at each measurement position a 32-channels impulse response has been measured, it is possible to post-process the results in two ways:

- A graphical analysis can be performed, showing the spatial distribution of the incoming energy along the running time – this allows to "see" from where the room's reflections are coming
- An audible rendering can be presented to a group of listeners, inside a special room equipped with a suitable array of loudspeaker, surrounding completely the listening area around a sphere

The graphical analysis is performed thanks to a Matlab program, which creates an animated color video rendering of the sound map, overplotted over the 360°x180° panoramic image. A frame of such video rendering is shown in figure 5.

The audible rendering is obtained by reprocessing the original impulse response recording: a new set of virtual microphones is extracted, one feeding each loudspeaker of the playback array. The directivity and aiming of each of these virtual microphones is obtained by solving a linear equation system, imposing that the signals re-recorded placing the Eigenmike™ probe at the center of the playback system are maximally similar to the original signals recorded in the theater. This approach, which is NOT Ambisonics-based, also corrects inherently for deviations from ideality of the loudspeakers employed, both in terms of magnitude/phase response, and in terms of placement/aiming/shielding.

8. Experiments

After testing the new measurement and post-processing system in the Auditorium of Casa della Musica, in Parma, a first "real-world" experiment was conducted inside La Scala theatre in Milan. A set of 32-channels impulse responses has been measured in 10 positions, along the stalls and the boxes. Figure 5 shows a "frame" of the video rendering performed at the Director's position, showing a strong reflection bouncing back from the side wall. The 3D impulse responses measured at La Scala have been employed also for high-quality spatial sound processing.

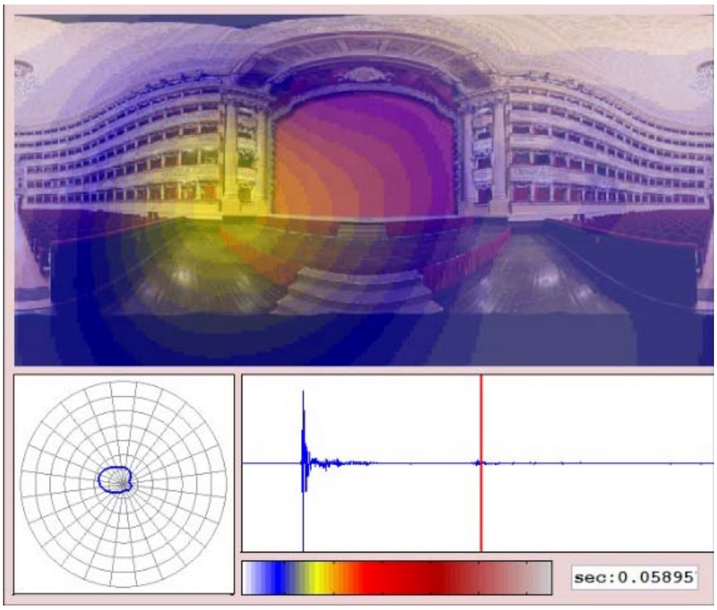

Figure 5 Snapshot of the video processing, a strong reflection from the side wall

9. Conclusions

This paper has described a new method for measuring 3D impulse responses in theatre, providing on one side a spatial resolution significantly better than what was obtainable with current technology, and, on the other side, allowing a very simple post-processing of the results, which allows both for an easy-to-understand graphical representation of the spatial-temporal information, and to re-employ the measured impulse responses as high-quality digital filters, capable of accurately recreating the theatre's envelopment inside a 3D surround system.

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