The calculation of Binaural Parameters by means of HRTFs and Ando's method

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Abstract

The calculation of binaural parameters from numerical codes represents a very important goal during the design of Concert Halls and Opera Houses. Furthermore, they become strongly important whenever the calculated IRs are employed for auralization. In this paper two different new methods, developed in Italy and Japan, which start from Head Related Transfer Functions (HRTFs) and Ando's method respectively, were defined, analysed, and compared. Even though the theory and also the purposes were different in the two approaches, the calculation of binaural parameters was related. Then the two codes were utilized in a real case, in which the changes in the shape and in acoustical properties of the walls were applied. The comparison between the two approaches underlined some important advantages of both methods. The results from the calculation were finally discussed and presented.

1 Introduction

The measurements of Impulse Responses (IRs) in room acoustics are commonly performed by means of a dummy head or a pressure-velocity 3D microphonic probe. Spatial parameters, like LF and IACC, are calculated from these spatial IRs.

The pinnae in the dummy head act as a filter and modify the acoustical responses. In room acoustics design the simulation of Impulse Response is commonly developed in monaural technology. During the calculation of sound fields in auditoria the head of a listener contributes considerably in the proper calculation of binaural impulse responses. Therefore, recently many efforts are devoted to properly calculate binaural IRs, since the listener's head influences the sound that reaches his ears. In particular the absorption and the reflection of the skin, the diffraction of the nose and, above all, the "coding" inserted by the auricle, modify (both in magnitude and in phase) the perception of music, creating the presupposition for a better interpretation by the brain. The traditional computational techniques, achieved using conventional methodologies like ray tracing or image sources method, are not able to properly model those effects, missing precious information. Vice versa binaural techniques employed during measurements, achieved employing dummy-heads, are able to preserve them, and therefore considerable mismatch between measurements and simulations are common. Binaural parameters are here calculated by means of two different numerical models and compared.

2 Binaural Impulse Responses from HTRFs

The first method allows for the calculation of binaural Impulse Responses making use of the data set of Head-Related Transfer Functions (HRTF) measured at the M.I.T.

Each HRTF is an anechoic binaural impulse response, measured on a Kemar dummy head for a given azimuth and elevation of the sound source.

This calculation system was firstly presented in 2000 [1], and is going to be included in the RAMSETE pyramid-tracing software [2] as an additional plug-in.

During the tracing, early reflections (normally up to 5th-order) can be stored in a separate file, in which time delay and amplitude are saved separately for each sound source, as well as the coordinates of the last point of reflection in the geometry of the room. The computation of the proper HRTF for each early reflection starts from the calculation of the Elevation and Azimuth angles that each sound ray coming from the source forms with the listener's head.

Considering the Cartesian reference system and the relative position and orientation of the sound ray and of the receiver (which stands in a position and is looking toward a target point), two different angles are calculated, which are

- *Elevation* angle φ (fig. 1), which is the angle formed between the **X'Y'** plane and the **u** sound ray vector;
- *Azimuth* angle θ**,** which is the angle formed between the axis **X'** and the projection of the vector **u** on the **X'Y'** plane;

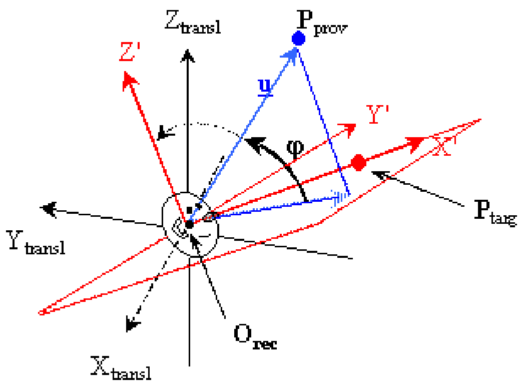

Figure (1): Elevation and Azimuth angles referred to receiver

2.1 Interpolation of the HRTFs

After the computation of Elevation and Azimuth angles with which the sound ray arrives at the listener ears, it is necessary to interpolate the appropriate HRTFs to be used in the signal filtering. This is not trivial, and required a special triangular interpolation algorithm, because the HRTFs measured at MIT Medialab are sampled at not-uniform azimuthal angular steps at different elevations.

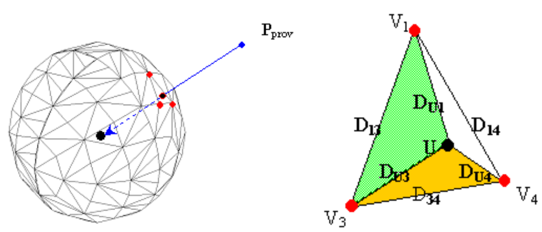

Figure (2): triangular interpolation of the proper HRTF

Therefore, the interpolated value of HRTF is calculated by the following formula:

$$HRTF(\varphi,\theta) = \sum_{i=1}^{3} P_i * HRTF(\varphi_i,\theta_i) \qquad (1)$$

Where the weighting factors P_i are simply the ratio of the partial areas to the whole area of the triangle.

A binaural pressure impulse response is finally created, summing in time domain, with their proper amplitudes and delays, the interpolated HRTFs of the direct sound and of any of the early reflections. The late tail is synthesized by two amplitude-weighted, uncorrelated white noise signals.

Acoustical parameters like IACC are therefore obtained by post processing of the binaural impulse responses.

2.2 Capabilities of the RAMSETE system

The interface of Ramsete allows the user to insert position and target point of sound sources (with directivity ballons) and receivers. Furthermore, the user can specify the calculation of early reflections up to a maximum order of reflections (3 in this case). Ramsete allows also for the modelling of surface diffusion and edge scattering, which strongly enhance the accuracy of simulation of IRs [3]. Even when no scattering coefficient is assigned, Ramsete defaults to a value of 0.1.

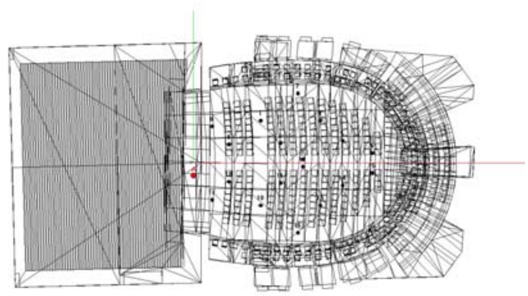

Figure (3): The numerical model of the theatre utilized with Ramsete.

3 Ando's method

3.1 Interface of Ando's method

Nakajima and Ando [4] proposed a new method to calculate acoustical parameters by using the "image-source method". The acoustical simulation of Ando's method allows users to input the location of vertexes and faces of a room, the positions of an omni-directional source and several receivers, and the maximum order of reflections. Furthermore, the absorption coefficient can be set for each surface. According to the number of reflections, the courses of sounds from the source to receiver are searched. F Figure (4) shows the geometric form of the theatre.

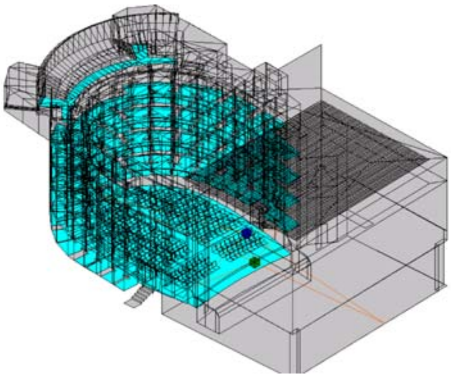

Figure (4): The geometry of the theatre with Ando's method.

3.2. Acoustical parameters

The acoustical parameters simulated by Ando's method are the following:

LL ; (Listening Level) [dB]

LL is the decay of SPL in respect with a sound source.

Δt_1; (Initial time delay gap) [ms]

The delay time of the first reflection after the direct sound. The first reflection is defined as the reflection with maximum amplitude coming after 5 ms (which means, excluding the reflection on the floor).

T_{sub}; (Subsequent reverberation time) [s]

T_{sub} is the result of the formula of Eyring-Knudsen as the average value for medium frequencies (500-1000 Hz). Therefore, T_{sub} depends on the volume of the room, on the areas of the surfaces and on the absorption of surfaces and air.

IACC; (Inter-aural cross correlation)

The correlation between the sounds that impinges on right and left ears. In the Ando's method, IACC is calculated using a data-base of experimental results of IACF (Inter-aural cross correlation function) produced by binaural responses of a dummy head, as the two samples shown in Figure (5).

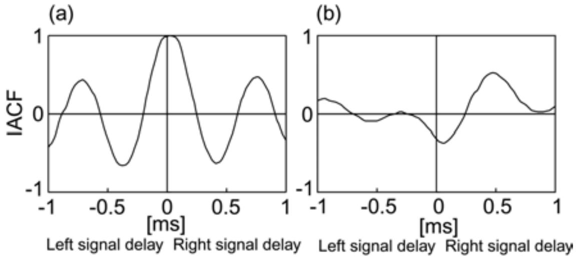

Figure (5): Two examples of IACF. The loudspeaker was located at (a) 0° and (b) 55° of right in regard to the dummy head. The sound source was musical motif A ("Royal Panuva" by Orlando Gibbons).

The Ando's method computes the amplitudes and angles of the direct sound and reflections. For the direct sound and all reflections, the IACFs identified by the incident angles are weighted by the amplitudes respectively, and the sum of results is regarded as the IACC. The equation is:

$$IACC \approx \frac{A_0 \cdot IACF_{(\alpha)} + A_1 \cdot IACF_{(\beta)} + A_2 \cdot IACF_{(\gamma)} + ...}{A_0 + A_1 + A_2 + ...} \quad (2)$$

where A_0 and $A_{1,2...}$ are the amplitudes of direct sound and reflections, and α, β and γ identify the incident angle of them.

3.3 Calculation of acoustical parameters

The Ando's method has been configured with limitation of calculation up to second order image sources, since no appreciable differences between second order and third order has been found.

4 The theatre analyzed

The two simulation systems were utilized in a typical Italian Opera house, the Teatro Comunale, situated in Treviso, Italy.

Earl Fiorino d'Onigo completed the first *Teatro d'Onigo* in 1692. In 1763, with the architectural plan of Galli Bibbiena, the theatre was restored and enlarged. During XIX century the theatre burned twice, and in 1869 it was definitely restored and opened. The appearance of the theatre comprises artistic painting and stuccos, both on the walls and on the ceilings, while the balconies are all made by wood and slightly covered with thin velvet tissue, especially on the columns. Despite its short reverberation time (approximately 1.1s), the theatre acquired a good reputation regarding acoustics. IACC, measured in 1998, resulted between 0.2 and 0.45, and

its very low value is probably the explanation of the good reputation [5].
In the simulation with the two different systems, the same geometry was utilized, with the same acoustical characteristics of the walls. One omnidirectional sound source was located in the stage, 1 meter on the left side, facing to the stage, in order to avoid symmetry-related artefacts during the calculation. The same 18 receivers were employed in both cases, positioned exactly in the same places and orientation.

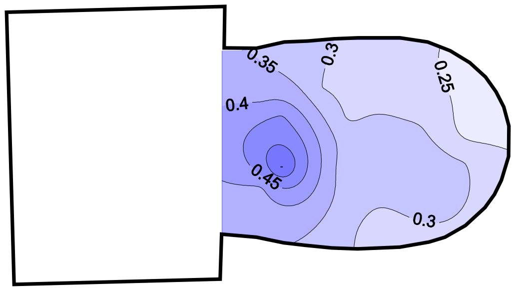

Figure (6) IACC calculated with Ramsete system

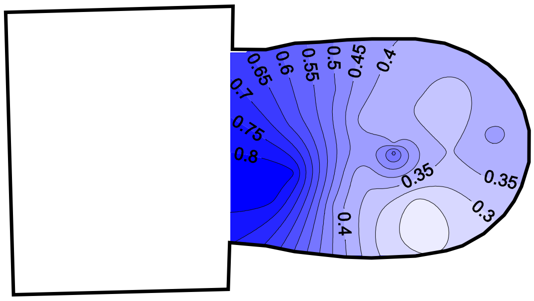

Figure (7) IACC calculated with Ando's method

5. Results and conclusions

The comparison of the simulation systems was limited to IACC, since it strongly characterizes spatialization in the audience area.
The maps of the results, shown in fig. 6 and 7, underlined the different behaviour of the two codes. It is noticed that the IACCs by Ramsete were calculated from IRs, while the IACCs by Ando's method were estimated by the measured IACFs of the musical motif A.Far from the stage the results matched, giving a value close to 0.3, which corresponds well with the experimental data measured in 1998.
On the contrary, close to the stage the differences are larger: the values predicted by Ramsete are still in the range of experimental values (<0.45), whilst the values predicted by Ando's method go up to 0.85. It is very important to ascertain the cause of the difference and develop the two systems in order to estimate sound fields more exactly.
However, the main reason for the different results depends on the fact that Ramsete did compute the whole reverberant tail, whilst Ando's method did compute just the direct sound and the first 2 orders of reflections. Furthermore, the Pyramid Tracing algorithm takes into account the surface's diffusion and the edge scattering, whilst the Image Source method always considers purely specular reflections.
In the next stage of this research, further parameters will be calculated and compared to experimental data, also in other rooms with different shapes. In this way the comparison between the two systems will be extended to several objective acoustical parameters.

6 References

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