SPATIALIZATION AND ACOUSTICAL SIMULATION IN THE BINAURAL TECHNOLOGY

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Abstract

The simulation of spatialization is a matter of great concern. In this paper the auralization technique has been improved, in order to ensure a comprehensive evaluation of spaciousness by headphones listening. Binaural impulse responses have been calculated after the definition of proper reciprocal positions between the listener and the sound ray. A numerical code has been developed, implemented and tested. An example of binaural auralization is here presented.

INTRODUCTION

The process of auralization involves the characterization of all the components intervening in the transformation of the acoustical signal along its path from the source towards the listener's ear. The source signal undergoes multiple reflections and absorptions on the room's walls and objects as well as on the listener's ear and skin. Each signal transformation can be interpreted by means of linear systems theory, providing time invariance of the physical intervening parameters.

The source signal is first transformed by the confining environment. An environment transfer function can hence be defined as the function which transforms the source signal into the signal which hits the outer ear. This TF can be either measured or simulated by means of computer codes.

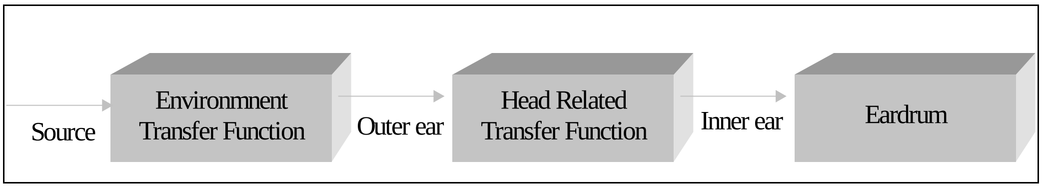


Fig. 1: schematisation of sound propagation from source to receiver

The head related transfer functions (HRTFs) are the functions which account for the transformation suffered by the signal from the outer ear to the inner ear. They capture the effects of sound diffraction by head and pinnae. The signal processed by the HRTFs can be readily heard and interpreted by the brain.

In case the TF is measured, the outcome of auralization is a signal representing the average acoustical field perceived by an "average" listener placed in the environment. If the TF is simulated, the issue of auralization is the signal that an average listener would hear if he was in the modelled environment. The two signals can be compared in order to validate the computer code, providing that the HRTFs are those calculated for the dummy head utilised during the measurements.

Spatialization could be evaluated in different ways: by reproducing sound signals by means of loudspeakers located in controlled environments, and by reproducing signal by headphones. In the first case, the b-format, the stereo dipole and the ambiophonics methodologies utilise different locations and acoustical treatments of the listening room. On the other hand, listening reproduced signal by headphones doesn't require any particular acoustical configuration of the listening room, but usually many information regarding spatialization and orientation of the listening head are lost.

The first approach is developed both from an experimental and a computational point of view by Farina and Tronchin at 17th ICA **[1]**. The second method is hereby derived.

GEOMETRICAL ANALYSIS AND HRTF INTERPOLATION

The sound ray provenience is traditionally supplied by two angles (ϕ: elevation; θ: azimuth) expressed in the fixed reference frame. Since the listener's head has not a prefixed orientation and is let free to point towards any direction, the above angles must be expressed in the local coordinate tern (ϕ: angle between the sound ray vector and the *X'Y'* plane; θ: angle between the projection of the sound ray vector on the *X'Y'* plane and the *X'* axis; Fig.2). The angles are derived as **[2]**:

$$\varphi = 90° - ar\cos\left(z'_{PROV} \middle/ \sqrt{(x'_{PROV})^2 + (y'_{PROV})^2 + (z'_{PROV})^2} \right)$$

$$\theta = ar\cos\left(x'_{PROV} \middle/ \sqrt{(x'_{PROV})^2 + (y'_{PROV})^2} \right) \qquad \text{if } y'_{PROV} > 0$$

$$\theta = 360° - ar\cos\left(x'_{PROV} \middle/ \sqrt{(x'_{PROV})^2 + (y'_{PROV})^2} \right) \qquad \text{if } y'_{PROV} < 0$$

Fig.3 exhibits the local frame axis and the fixed frame axis together with the azimuth and elevation angles with respect to the local tern.

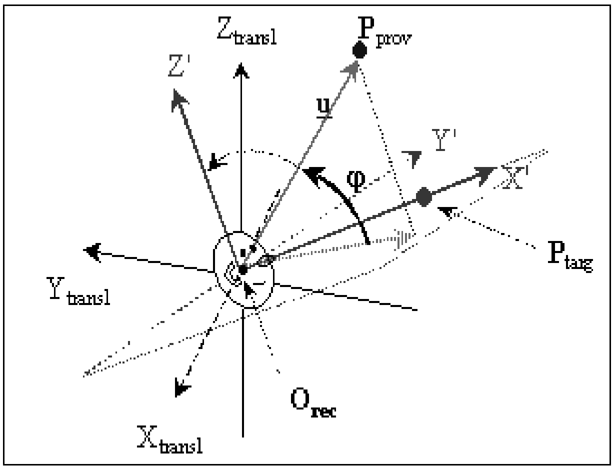


Fig.3: Sound ray provenience, orientation angles

Once the sound ray is located in the space surrounding the listener, its position is unlikely to coincide with one of the discrete directions where the HRTF has been measured. An interpolation hence is needed in order to give a HRTF for any given direction. The calculated HTRF for a direction passing through *U* (Fig.4) is a weighted function of the HRTF measured for V_1, V_2, V_3 over a tern of local coordinates so defined:

$$P_i = \frac{area(U, V_j, V_K)}{area(V_i, V_j, V_K)} \cdot$$

The weighted HRTF is hence:

$$HRTF(\phi,\theta) = P_1 \cdot HRTF(\phi_1,\theta_1) + P_2 \cdot HRTF(\phi_2,\theta_2) + P_3 \cdot HRTF(\phi_3,\theta_3)$$

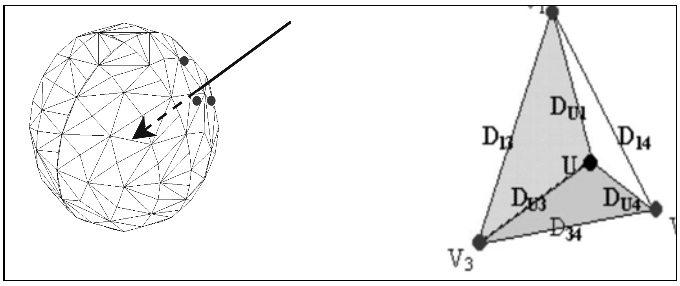


Fig.4: HTRF interpolation

THE CASE: S. DOMENICO CHURCH, UDINE, ITALY

The church of S. Domenico is a small modern church situated in Udine. Its acoustical response is very poor due to a strong component of the reverberant sound field. More over, the convex shape of the ceilings provides an undesired focalisation of sound rays. An acoustical treatment has hence been proposed in order to improve both musical listening and speech intelligibility. A similar cases have been treated by Cocchi et. Al. **[3]** on other churches.

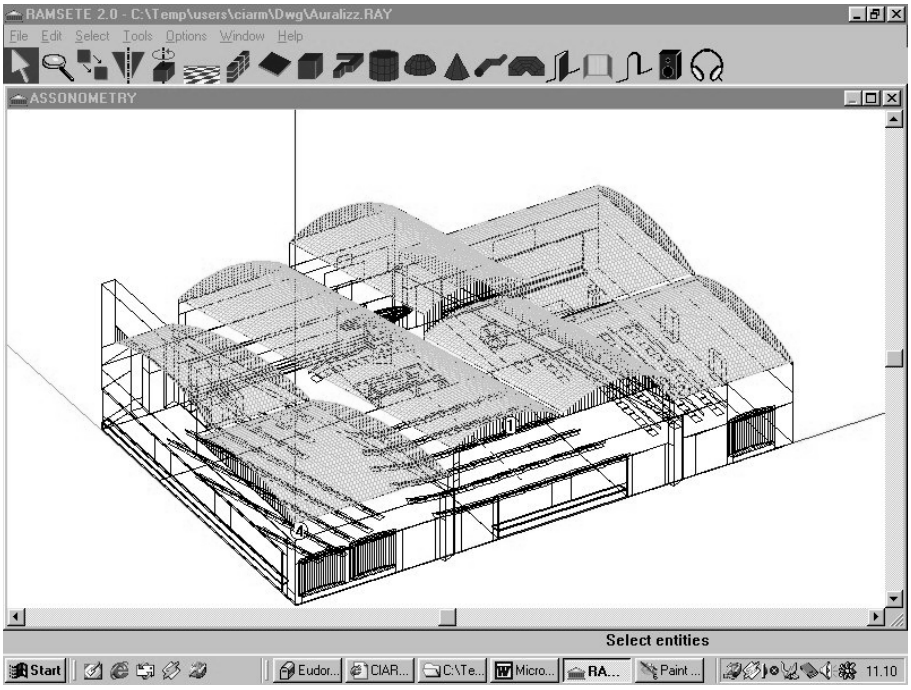


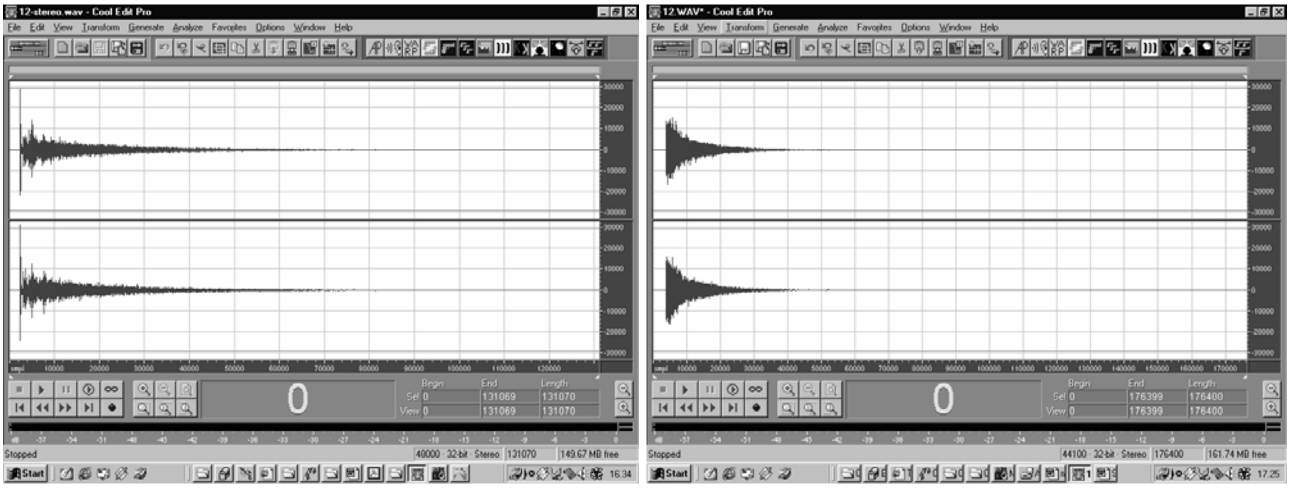
Fig.4: model of S. Domenico church, Udine, Italy

Both acoustical measurements and simulation have been performed using the binaural methodology. The measurements have been addressed to obtaining the binaural impulse response of several listening points. An omnidirectional loudspeaker has been located at the end of the main nave. At the same time the signal (sine swept) was received by a dummy head and a SoundField (MkV) microphone, and sampled in a multi-channel sound board (Layla, by Event).

The process of simulation started with the proper modelling of the church in the CAD environment of RAMSETE (Fig.4). The model contained both the absorption properties of the materials and the proper source and receivers positions. The material properties were carefully calibrated so to obtain computed values of reverberation time T20 and EDT as close as possible to the measured ones in the frequency spectrum 63-16000 Hz.

A new routine has been prepared and implemented in RAMSETE in order to account for the binaural IR of the dummy head, using the HRTFs measured at MIT **[4]**

The measures obtained on the unmodified acoustical environment showed a high EDT (3.3 seconds). The purpose of the acoustical treatment was then addressed to decrease it and to elide the focalisation effects. Both measured IRs of the unmodified environment and simulated IRs after the proposed acoustical treatment for one of the chosen receiving points are hereby reported.



	Begin	End	Length
Sel	0	131069	131070
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Fig.5: Measured IRs and after treatment simulated IRs.

The measured IRs exhibited a first strong contribute of the direct sound field. The elapsed decay time was hence very long. On the other hand the modelled IRs exhibited a much shorter EDT, as requested. The EDT decreased from 3.3 to 1.8 s.

Since the IR cannot be effectively compared through direct playback, a convolution with an anechoic piece is needed. The result to this is a very realistic reproduction of the simulated environment which supplies the listener with a feeling of sound spatialisation and high degree of sound directivity.

CONCLUSIONS

A proper numerical code has been developed in order to supply a simulated auralization of an acoustical environment. Simulated behaviour of the examined example shows good agreement with the measured one. Besides, this new methodology supplies the acoustician with a new tool for designing acoustical treatment considering both the traditional sound decay and the spatialization changes intervening after acoustical treatments.

This methodology can further be enhanced by considering also one position in the hall of the listener and modifying his head orientation with respect to the source. This matter has been analytically analysed but it has not been tested in the present paper where both the dummy head and the receiver modelled head point towards the sound source. A comparison between measured and simulated auralizations for several head positions could give useful additional information on the sound field embedding the listener.

REFERENCES

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