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INTENSIMETRIC MONITORING OF ACOUSTIC QUADRAPHONIC RECORDINGS REPRODUCED THROUGH A 5.1 LOUDSPEAKER ARRAY

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ABSTRACT

Acoustic quadraphony is the application of sound intensimetry to audio recording and reproduction processes. Practical exploitation of this technology has been recently implemented by using the Microflown vector intensity probe which allows the direct measurement of sound pressure and particle velocity impulse responses. In order to evaluate the physical correspondence of reconstructed sound fields with the quadraphonic original one, an experimental test has been done by measuring the energetic quantities inside the “sweet spot” of a 5.1 playback system.

INTRODUCTION

In linear acoustics any sound event is represented by a set of four measurable quantities, sound pressure and air particle velocity, all of them being derived from a scalar field, the so-called kinetic potential, and obeying the wave equation. It can be shown that the wave equation itself can be written in a four-dimensional form and such quantities form a “four-vector” from which the conservation laws of energy and momentum are derived [1]. This approach leads to the introduction of the *quadraphonic momentum* of the sound wave, that in Cartesian coordinates is written as follows:

$$P(\mathbf{x},t)=\left\{\frac{p}{c}(\mathbf{x},t),\rho_0 v_x(\mathbf{x},t),\rho_0 v_y(\mathbf{x},t),\rho_0 v_z(\mathbf{x},t)\right\} \qquad \text{(Eq. 1)}$$

From the point of view of the energy transfer properties, two physical quantities like the intensity vector $\mathbf{j}$, expressing the instantaneous energy flux density at any fixed field position, and the sound energy density w have to be considered:

$$\mathbf{j}(t)=p(t)\mathbf{v}(t) \;\; ; \quad w(t)=\frac{1}{2}\frac{p^2}{\rho_0 c^2}+\frac{1}{2}\rho_0|\mathbf{v}|^2 \qquad \text{(Eq. 2)}$$

One way of analysing confined fields in terms of their energetic properties is through the calculation of a set of intensimetric indices varying between 0 and 1. The most significant one is the sound radiation index η, related to the fraction of energy travelling along the energy streamlines:

$$\eta=\frac{|\langle\mathbf{j}\rangle|}{c\langle w\rangle} \qquad \text{(Eq. 3)}$$

As it has been pointed out in previous papers, the knowledge of energy-based quantities provides a great deal of information related to sound fields spatial properties like directionality, degree of energetic confinement, diffuseness [2]. It is then reasonable to state that even in the context of sound perception a correct procedure for achieving a complete acoustical reconstruction of a sound stimulus at any point of space must be implemented in a quadraphonic control system, meaning that all the above mentioned four functions need to be determined during the recording process in order that they can be reproduced as faithfully as possible afterwards. Innovative reproduction techniques capable of recovering the complete energetic behaviour of sound fields are currently under investigation by the FSSG-CNR group in the framework of European project IP-RACINE [3]. A subtask of this research program aims to check the quadraphonic consistency of the reproduced field with the original one, and for this reason an intensimetric test has been defined and actually applied to a commercially available standard 5.1 diffusion system. The test exploits the polar pattern characteristics of the four quantities involved in the quad recording process (omnidirectional for pressure and figure-of-eight for velocity) and use the quad set of signals as input for an *Ambisonics*®-like first-order encoding/decoding system designed for B-Format decoding. This way, appropriate panning functions to be used as feeds for specific loudspeakers array can be easily programmed by linearly combining the quadraphonic signals. The case of interest here is of course the ITU standard 5.1 Surround, typical of cinema sound playback systems. In this paper intensimetric results characterizing the performance of a conventional 5.1 rendering based on linear transcoding of quadraphonic signals will be presented. The investigation has been carried out by comparing intensity measurements directly obtained from original acoustic quad recordings with those obtained in the sweet spot of a surround system. A first test has been done for verifying how correctly the system itself can reproduce the directionality of a source in free field conditions. The second one focuses more deeply on the reproduction quality of recordings performed in reverberant spaces. The transducer chosen for the acoustic quadraphonic recording is the *Microflown*®: a new generation intensimetric probe capable of detecting the particle velocity signal in a direct way by the double hot wire anemometry technique [4].

COMPARISON BETWEEN REAL AND REPRODUCED SOUND FIELDS

Materials and methods

The test has been carried out following the procedure below:

1. Acoustic quad recording of sound event (short anechoic speech) inside a test room using a loudspeaker as a source and a 3D Microflown intensity probe as a receiver;
2. Calculation of <u>real</u> intensimetric indices from recordings of step 1;
3. Transcoding of pressure and velocity signals into 5.1 format;
4. Reproduction of transcoded signals by means of a 5.1 loudspeaker setup;
5. Acoustic quad recording of the reproduced sound event and calculation of <u>virtual</u> intensimetric indices;

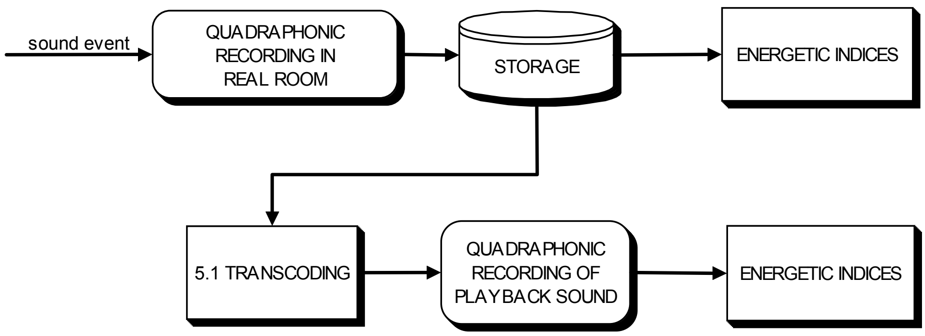

Figure 1.- Flowchart of the real/virtual intensimetric test

As regards the quadraphonic recording inside the room, instead of being captured directly form the sound source, signals have been obtained by convolutions between measured impulse responses and anechoic pressure signals [2]. The practical reason of this approach is the need of reducing the background noise characterizing the particle velocity signals of the Microflown probe. Since measurements of impulse responses obtained by modern techniques, such as those based on MLS or swept sines, greatly reduce the sensor self noise due to the large amount of energy carried by the excitation at every frequency interval, even the quality of pressure and velocity signals after the convolution process takes advantage of the low noise of the impulse responses. The transcoding of pressure and velocity signals into 5.1 is done by recreating the signals corresponding to five virtual microphones with directional pickup patterns aiming at the loudspeakers positions. A virtual microphone aiming at an angle φ_i in the horizontal plane can be expressed as [6]:

$$S_i = (1 - A_i)p - A_i[v_x \cos(\varphi_i) + v_y \sin(\varphi_i)] \qquad \text{(Eq. 4)}$$

The coefficient *A* determines the polar pattern, ranging from omnidirectional (*A*=0) to figure of eight (*A*=1). A value of *A*=0.5 was chosen for each microphone, corresponding to a cardioid polar pattern. The five virtual microphone angles are 0°, ±45° and ±135° for the Centre, Right, Left, Rear Right and Rear Left signals respectively. A *Matlab*® routine has been implemented for applying Eq. 4 to the quadraphonic data. The LFE signal is obtained applying a low-pass filter to the pressure signal, with a default cut-off frequency of 120Hz. The playback system has been assembled according to the ITU standard, i.e. positioning the loudspeakers (in our case five Genelec two-way monitors 1030A) at the angles 0° (Centre), ± 30° (Front Right and Front Left), ± 120° (Rear Right and Rear Left). The experimental setup has been placed in the small anechoic chamber of the FSSG-CNR acoustic laboratory which allowed us to set a loudspeaker array diameter of about 2.5 m, a value which revealed hardly sufficient for listening but appropriate for measurements in a single point. In fact, these have been done by placing in the middle of the circle the same 3D Microflown sound intensity probe which had been previously used for measuring the quadraphonic impulse responses. As regards the reference frame, the X axis was oriented towards the central loudspeaker and the Y from right to left. The whole system, including a subwoofer (Genelec 7060A) and five stands is shown in Fig. 2.

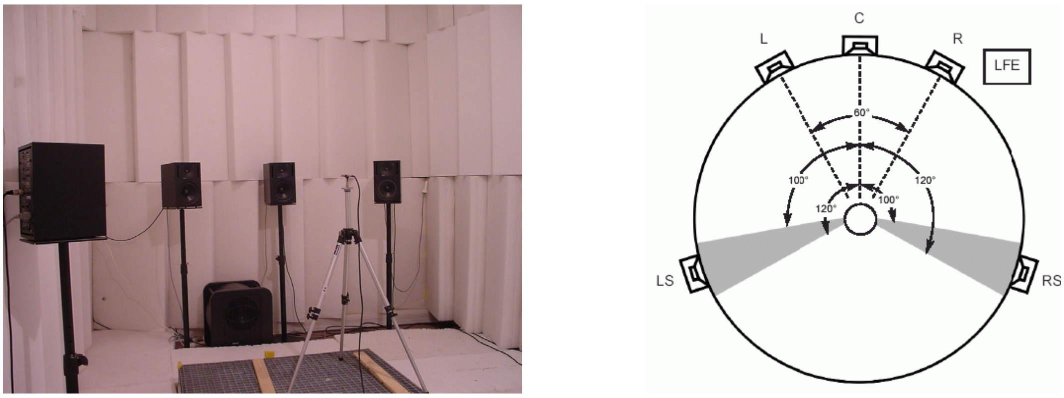

Figure 2.- Left: the 5.1 loudspeaker setup in the anechoic room.
Right: geometrical disposition of the loudspeakers

Obtained results

a) Evaluation of performance in case of plane waves

In order to verify how correctly the system itself can reproduce the intensimetric properties of a plane-wave sound field a preliminary test has been executed. A loudspeaker, fed with a 100Hz-20kHz sine sweep was placed along the circle of the 5.1 system and its sound was recorded in the sweet spot with the Microflown probe. The transcoding process has been applied to the recorded data and the corresponding surround signals were played back through the same 5.1 system, recording the reconstructed sound field to be compared with the original one. Ideally, the intensity vector and the η index should coincide. Fig. 3 and Fig. 4 show the comparison of sound intensity vector plot for the original and the reconstructed fields in the case of a 40° and 60° direction of arrival respectively. In both cases the average direction of the reconstructed field is rotated towards the centre of the system and a slight scattering of the vectors is evident. These effects translate into a slight narrowing and blurring of the sound field. The scattering effect is due to the fact that a larger number of sources is involved in the playback stage, as a consequence of the cardioid choice made for the virtual microphones pattern. The rotation towards the centre is caused by the asymmetry of the loudspeaker placement with respect to an off-axis direction of arrival and by the largest number of speakers near the centre and the lack of speakers at the sides. The worst case is the 180° source, shown in Fig. 5, where the lack of a rear speaker and the wide separation of the rear left and right channels causes an image instability and a widening effect comparable to the well known stereo “hole in the middle” effect. The comparison of the η index, shown in Table I, confirms that the radiation characteristics of the fields are well matched for the front and side sources, while in the case of a 180° source the result is closer to a diffuse field.

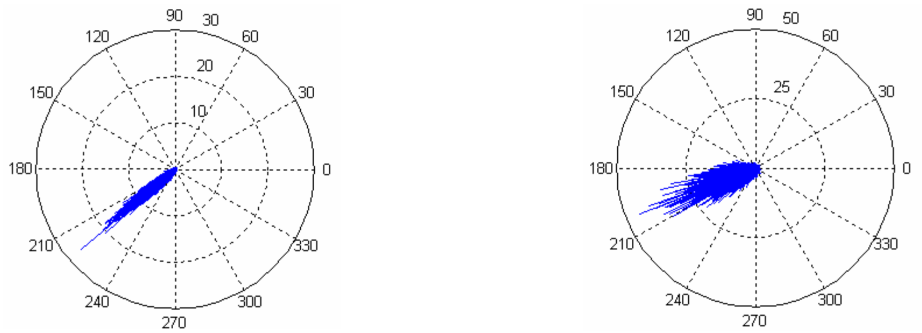

Figure 3.- Intensity polar plots of plane waves.
Left: direct measurement from loudspeaker at 40°; right: measured during the 5.1 playback

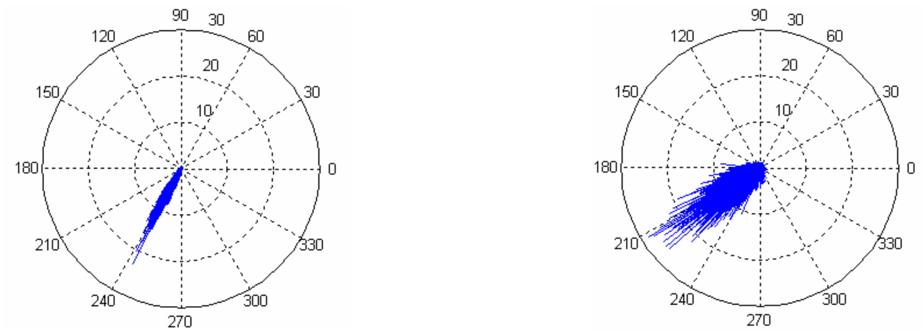

Figure 4.- Intensity polar plots of plane waves.
Left: direct measurement from loudspeaker at 60°; right: measured during the 5.1 playback.

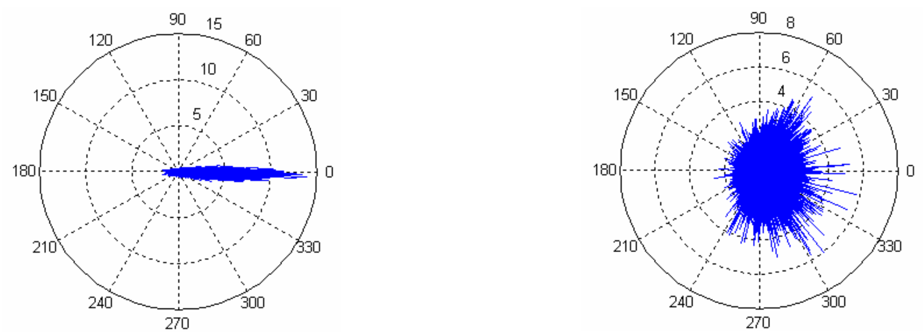

Figure 5.- Intensity polar plots of plane waves.
Left: direct measurement from loudspeaker at 180°; right: measured during the 5.1 playback.

Table I.- η index of the real sound event and the 5.1 playback corresponding to different directions of arrival of the test plane wave.

	front	**40° Left**	**60° Left**	**110° Left**	**180° Rear**
Direct	0.88	0.85	0.82	0.74	0.75
5.1 playback	0.83	0.81	0.80	0.73	0.17

b) Evaluation of performance for reverberant sound fields

Results obtained when reproducing reverberant sound fields recorded in two big spaces will be now reported. The first environment (room A) was a shoebox shaped concert hall (33.9 m × 10.5 m × 7.3 m) with a reverberation time of about 2.3 sec at mid frequencies. Two measurements have been taken as shown in Fig. 6: no.1 at a distance of 4 m, 30° on the right of X axis ad no. 2 at the same distance behind the probe. The second one (room B) was a long corridor with vaulted ceiling (128 m long, 6 m wide, 8.3 maximum height) having a reverberation time of about 4.5 seconds at mid frequencies. The probe has been positioned in the centre of the corridor with the X axis oriented along its length and the source, a dodecahedron loudspeaker, has been placed in two points: the first in front of the probe and the second behind it at a distance of 2 m and 4 m respectively (see Fig. 6). In all cases both the probe and the source were at a height of 1.5 m.

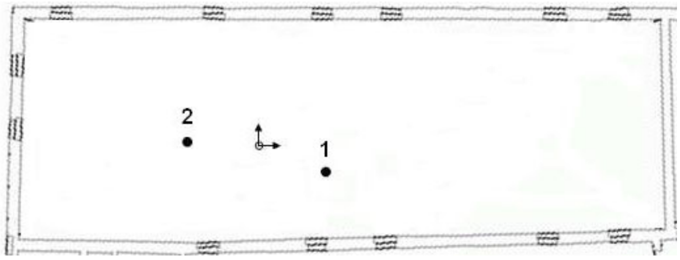

Figure 6.- Plan of room A (concert hall).

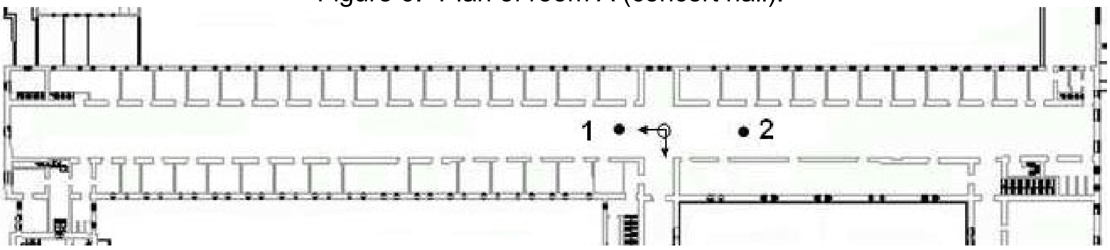

Figure 7.- Plan of room B (corridor).

The intensity vector plot comparisons (Fig. 8 and 9) show that the direction of the reproduced sound field is maintained in the case of front or side sources, although a slight rotation towards the centre is evident. The results for a back source reflect the aforementioned inherent limitations of the 5.1 system which give rise to a diffuse field preventing a faithful reconstruction. The increase of η index for front and side directions can be interpreted as an inability of a 5.1 system to recreate a field characterized by the predominance of oscillating energy and is due to the fact that the reconstructed field is basically a superposition of plane waves, as long as the wavelength is comparable to or shorter than the radius.

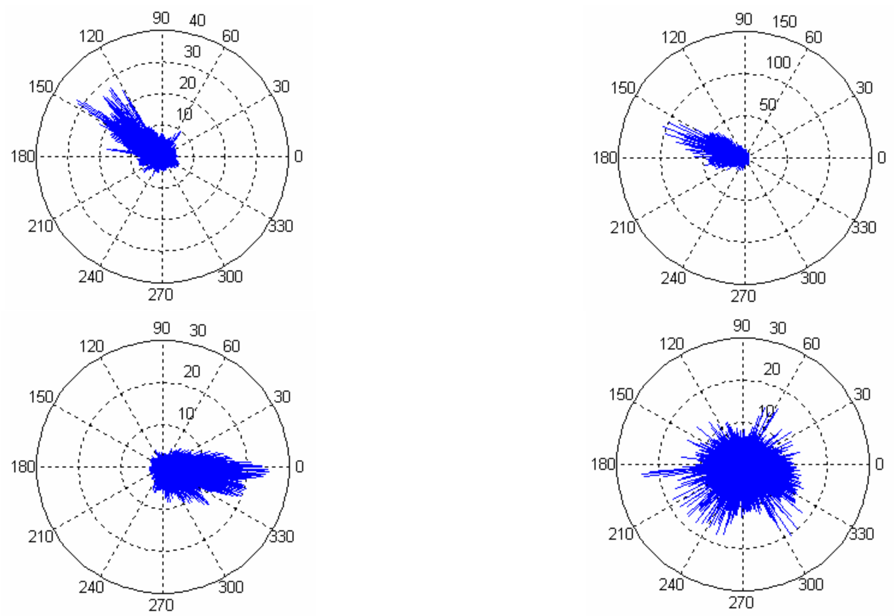

Figure 8.- Intensity polar plots of the sound field in room A.
Upper plots: meas. point 1. Lower plots: meas. point 2
Left: direct measurement from recording; right: 5.1 playback.

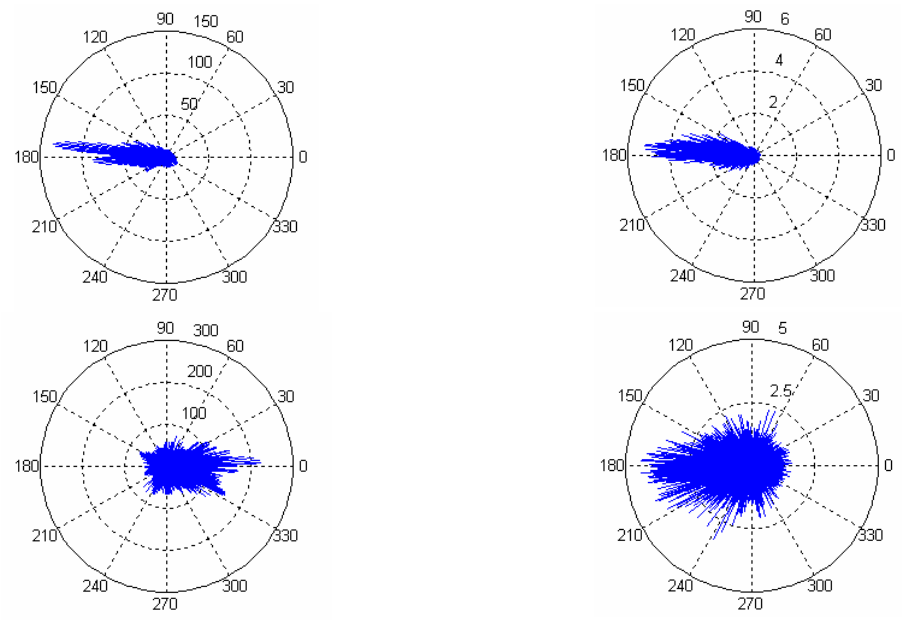

Figure 9.- Intensity polar plots of the sound field in room B. Upper plots: meas. point 1. Lower plots: meas. point 2 - Left: direct measurement from recording; right: 5.1 playback.

However, in the case of sources at 180° the value of η decreases, in agreement with the defect already pointed out in the previous section, showing the tendency to recreate a diffuse sound field.

Table II.- η index of the real and reproduced sound events in the two environments.

	B, 1	B,2	A,1	A,2
Direct	0.45	0.32	0.34	0.56
5.1 playback	0.69	0.28	0.65	0.12

CONCLUSIONS

An intensimetric method has been illustrated for characterizing the performance of 5.1 renderings of recordings executed according to the acoustic quadraphony approach. Even if in the executed test an *Ambisonics*®-like first order encoding/decoding system has been used, the monitoring methodology here presented is quite general and could be used in principle for testing also other reproduction systems even based on different principles (Acoustic Holophony, WFS, etc). As shown by the results the biggest fault in a 5.1 standard reproduction system is its scarce capability of reproducing rear directionality and sounds events recorded in reverberant spaces where oscillating energy is usually prevailing over the radiant one.

ACKNOWLEDGEMENTS

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