Monitoring of the Multichannel Audio Signal*

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Abstract. The paper describes operation algorithm as well as hardware and software realization of a detector, enabling a visual evaluation of acoustic perspective and dominating sound source direction in multi-channel registration and transmission of spatial sound. Proposed system may be successfully used in modern sound engineering studios, including "live" transmissions.

Keywords: Sound engineering, spatial sound, acoustic perspective, virtual sound source.

1 Introduction

The purpose of this paper is to present a monitoring method for multi-channel audio signal quality. The system for recording, transmission and archiving of stereo sound productions, known for many years, may be considered to be fully refined, also in the aspect of solutions developed to enable a full objective evaluation of final result quality features. The term "signal quality" used in this paper should be construed as a spatial effect quality; therefore, for a listener, it is a parameter pertaining to a sensation of being present in the location of acoustic event (i.e. concert hall, recording studio, etc.). Among other devices, an instrument to enable visual control of spatial effect in a real time, known as goniometer, is used for this purpose for stereophonic productions. However, in case of multi-channel production events (i.e. 5.1), which is five main channels and one LFE (Low Frequency Effects) channel, there are no efficient tools to evaluate signal quality within the context mentioned above. The problem is quite significant since multi-channel productions are utilized more and more often, frequently in "live" events (with the use of i.e. Dolby Digital coding).

Evaluation of the above described quality criterion is done by means of electric system analysis being associated with particular audio channels (for 5.0 or 5.1 systems), i.e. left front (L), central front (C) and right front (R), as well as left rear (LS) and right rear (RS)). Schematic diagram of this sound playing system is shown in Figure 1.
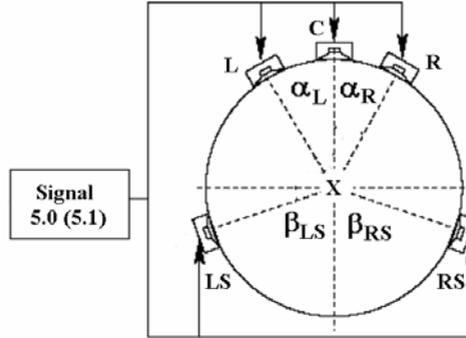

Fig. 1. Concept of sound reproduction 5.1 (5.0), according to ITU-R-BS.775-1 standard: $\alpha_L = \alpha_R = 30^o$, $\beta_{LS} = \beta_{RS} = 75^o$; (x - listener)

2 Multi-channel Sound Monitoring

A comprehensible method used in sound engineering for monitoring of multi-channel sound spatiality is the use of a immediate field sound monitors. One can conclude without difficulty that this method is totally subjective - since it does not always provide the assurance of getting a highest quality final product. It is therefore obvious that there is a need for a method that would bring explicit result of obtained effect observations. Sound "spatiality" may be construed as an ability to receive clearly defined planar acoustic perspective pertaining to virtual sound sources surrounding the listener. Similar interpretation, known as a lateral efficiency indicator:

$$LE(\theta) = \frac{\int\limits_{25ms}^{80ms} p_8^2(t)\cos^2(\theta)dt}{\int\limits_{0ms}^{80ms} p^2(t)dt} \quad 100\% \tag{1}$$

was proposed in 1980 [1] to describe a measure of spatiality illusion, i.e. a concert hall effect. LE is related to a ratio of reflections coming from a side to total direct and deflected reflections reaching the listener. q is an angle between direction of coming sound reflection and „ear-to-ear" axis of the listener, p - acoustic pressure measured with omnidirectional microphone, p_8 – acoustic pressure measured with a bidirectional figure-eight response microphone (microphone axis set at q angle).

In the period of dynamic stereo sound development, namely in sixties and seventies of the twentieth century a goniometer was used for visual evaluation of the acoustic space within so-called stereo base. These simple devices have been used by the sound engineering until today.

The goniometer is displaying Lissajous figures or patterns on its oscilloscope screen. Oscilloscope X and Y channels receive left and right signals from a stereophonic system. In case of a "strong" stereo effect, the displayed figure has considerably large area, while with "mono" signals, it is represented as a straight line. The related examples are shown in Figure 2.
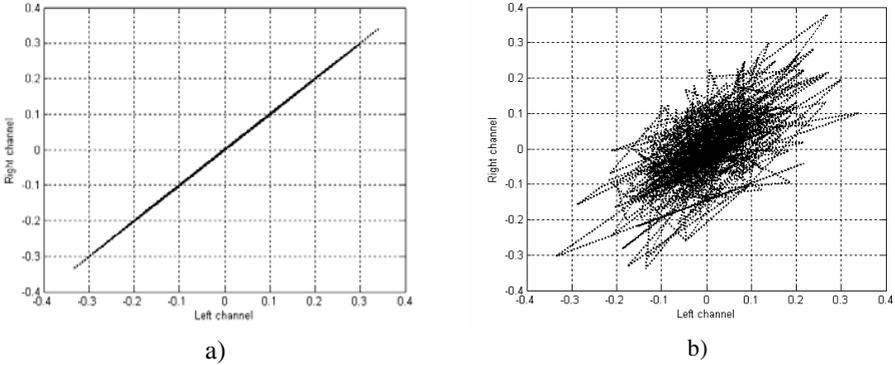

a)   b)

Fig. 2. "Lissajous" figures for: (a) mono signal, (b) stereo signal

It is obvious that this method can be also applied in case of multi-channel recordings. In that case, it would be prudent to use separate goniometers for various channel pairs, such as: L-C, R-C, L-LS, R-RS, LS-RS. However, a large number of charts makes it impossible to provide a quick analysis.

In [3], author this work propose to use a known technique to measure the amount of antiphase components, namely, the correlation coefficient, which is given in any text book (e.g. [5]) on statistics as:

$$\text{Corr} = \frac{\sum_i [(ch1_i - \overline{ch1}) \cdot (ch2_i - \overline{ch2})]}{\sqrt{\sum_i [(ch1_i - \overline{ch1})^2 \cdot (ch2_i - \overline{ch2})^2]}} \tag{2}$$

where ch1 or ch2 are one from set of multi-channel signal;   and   are the mean values of ch1 and ch2, respectively.

On Fig. 3 and 4 few exemplary diagrams made by the method described is presented.

Analysis of diagrams shown leads to following conclusion: algorithm RSS (**R**eal **S**urround **S**ound proposed in [3], Fig. 3f) makes possible to receive spatial effects similar to multi-channel recordings registration (Dolby Digital 5.0, Fig. 4) This conclusion can be also confirm by the listeners.
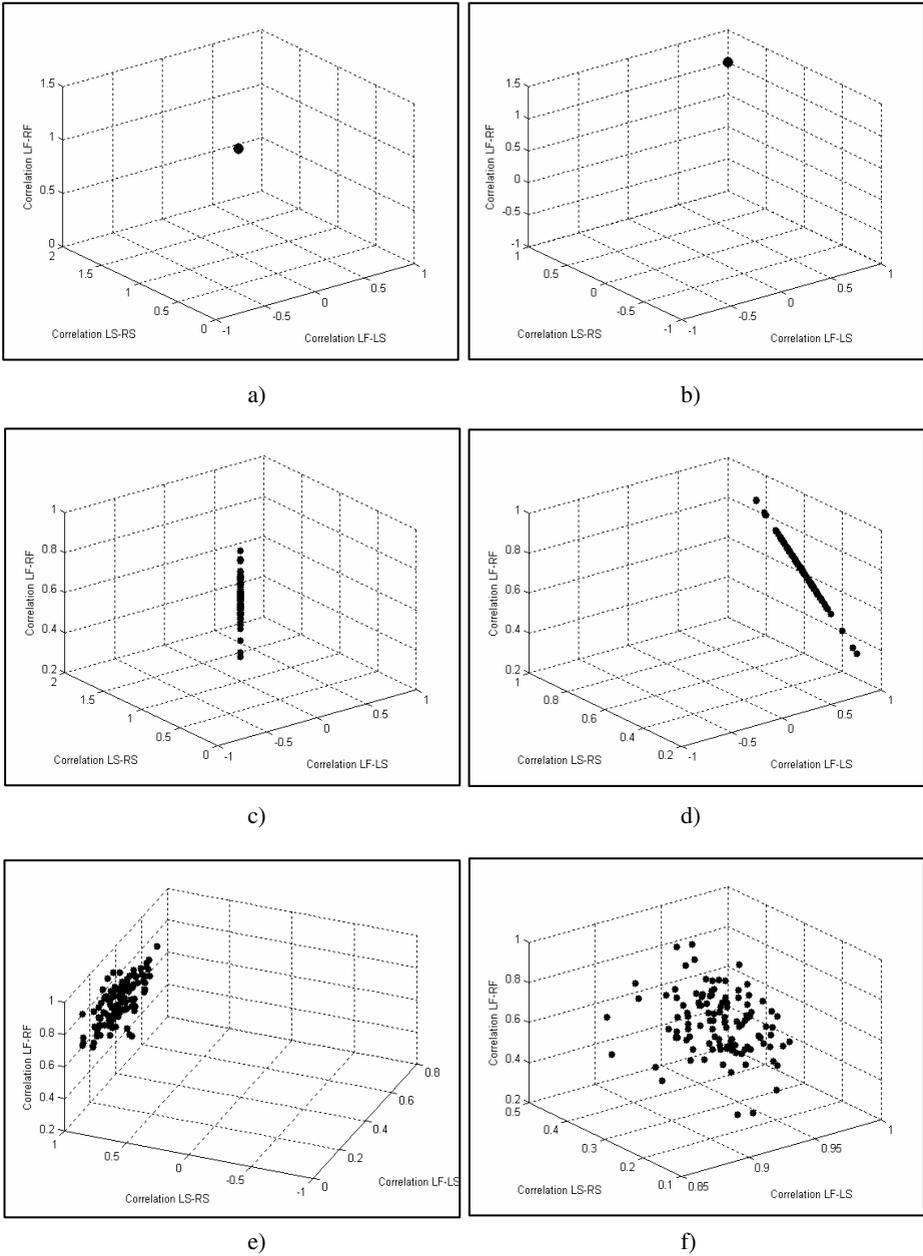
Fig. 3. Changes of correlation coefficient for following cases: a) mono signal: L=R, LS=RS=0, b) mono: L=R=LS=RS, c) stereo L and R: LS=RS=0, d) stereo: L=LS, R=RS, e) effect of matrix Dolby Surround decoder, f) effect of algorithm in [3] described (RSS)
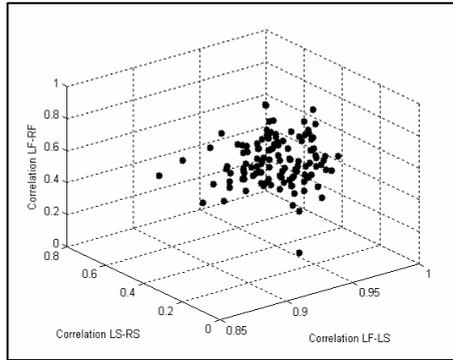
Fig. 4. Changes of correlation coefficient for multi-channel signal: Dolby Digital 5.0

There are other solutions known to resolve multi-channel sound spatiality, e.g. [2]. A special software and PC computers are used for visualization in all known solutions. Apart from that, a displayed image requires that the observer has an advanced knowledge within the area of sound theory [3, 6, 7], can interpret meaning of the displayed and is able to relate the image to acoustic impressions. The optimum solution would be if the principle of the visualizing device operation was similar to the one used at present in sound engineering, i.e. the goniometer.

3   Visual Sound Spatiality Detector

A concept of the proposed solution is based on the following assumptions:

> 1. Visualization pertains to 5.0 system (Fig. 1),
> 2. Acoustic wave (wave front) is propagated along straight line,
> 3. Sound sources (loudspeaker sets) are considered as points and the generated sound wave is ball-shaped,
> 4. There are no reflections, interference and diffractions within audio room.

Those assumptions provide for creation of a detection system, which enables observation of sound spatiality in "sterile" conditions, i.e. in a room without its own acoustics. Detector input signals are: L, C, R, LS and RS (Fig. 1). Sound monitors and listener are located within a coordinate system XY. Assuming that the acoustic pressure is inversely proportional to distance from a sound source and taking into consideration simple trigonometric relationships, one could calculate the components of value proportional to the acoustic pressure of the virtual sound source in XY coordinate system:

$$P_x = -\frac{\sin\alpha_L}{r_L}|L| + \frac{\sin\alpha_R}{r_R}|R| - \frac{\sin\beta_{LS}}{r_{SL}}|LS| + \frac{\sin\beta_{RS}}{r_{RS}}|RS| \tag{3}$$

$$P_y = \frac{1}{r_C}|C| + \frac{\cos\alpha_L}{r_L}|L| + \frac{\cos\alpha_R}{r_R}|R| - \frac{\cos\beta_{LS}}{r_{LS}}|LS| - \frac{\cos\beta_{RS}}{r_{RS}}|RS| \qquad (4)$$

where: |.| is a rectified full-wave signal from channels L, R, C, LS, or RS; α_x and β_x – are related angles shown in Figure 1, and

$$r_n = \frac{r'_n}{r'_C} \qquad (5)$$

is a standardized distance from related loudspeaker monitors to the listener[1] (n denotes: L, C, R, LS or RS), while r'_n and r'_C – are „physical" distances in meters.

For the formulated equations one can design an electronic system with operation similar to that of a goniometer.
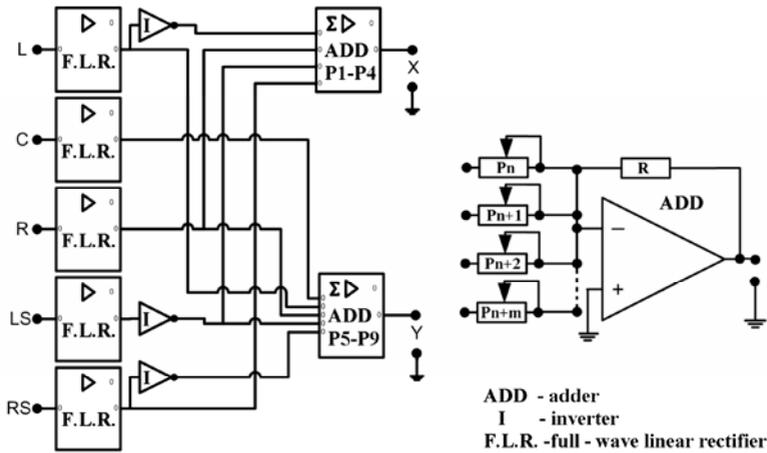

Fig. 5. Electronic „goniometer" system for 5.0 signals

The main components of this diagram are full-wave linear rectifiers. Potentiometers located at summing inputs are used to set the coefficients of factors |.| in equations 3 and 4. Settings of potentiometers depend on speaker set distribution geometry (α, β angles and r distances). For ITU-R-BS.775-1 standard: $\alpha_L = \alpha_R = 30°$, $\beta_{LS} = \beta_{RS} = 75°$. Therefore, resistances P1 to P9 should be: P1= P2 = P3= P4 = 2.00R, P5 = R, P6 = P7 = P8 = P9 = 3.86R for loudspeaker sets located on a circle.

For those formulated conditions and equations 3, 4 and 5, an image displayed on the oscilloscope screen will be similar to that shown in Figure 6:

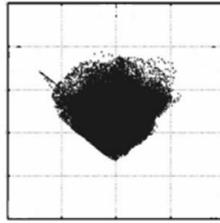[1] The listener is located in the middle of coordinate system from Figure 1.

Fig. 6. Example of oscilloscope screen shot for 5.0 signals

Therefore, an image quality, or in fact, legibility of the obtained results, may be significantly improved using PC visualization with appropriate software. Naturally, the algorithm base is still constituted by the equations $3 - 5$, but in this case signals from all channels are given in a digital form. Displaying the data points on a chart is done with so called overlapping. The overlapping process is carried out according to the following pattern:

1. Signals from all channels are divided to segments (windows) having equal numbers of M samples,
2. Currently displayed image consists of M window components for each channel,
3. Subsequent windows are overlapped on each other along the length of N components. It means that subsequent images contain M-N of "new" samples and N samples from the previous image.
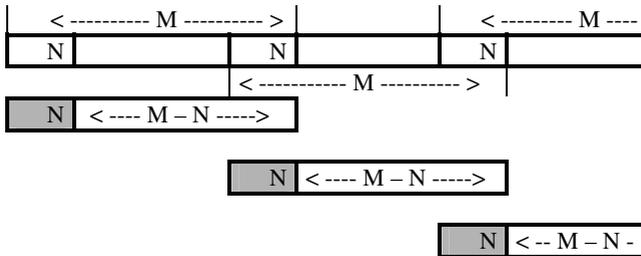
The process is shown in Figure 7.

Fig. 7. Overlapping process for one of the channels

In addition, what is quite significant, it is also possible to show other information, e.g. direction of a dominating sound source. The location point $D(\phi,r)$ on the circle placed on a straight line between the listener and the dominating sound source is clearly marked in the graph. Coordinates of that point are defined by the circle radius (equal to 1 for ITU-R-BS.775-1 standard) as well as:

$$\varphi = \arctan \frac{\max_{M}(P_y)}{\max_{M}(P_x)} \tag{6}$$

for a current window showing M number of samples.

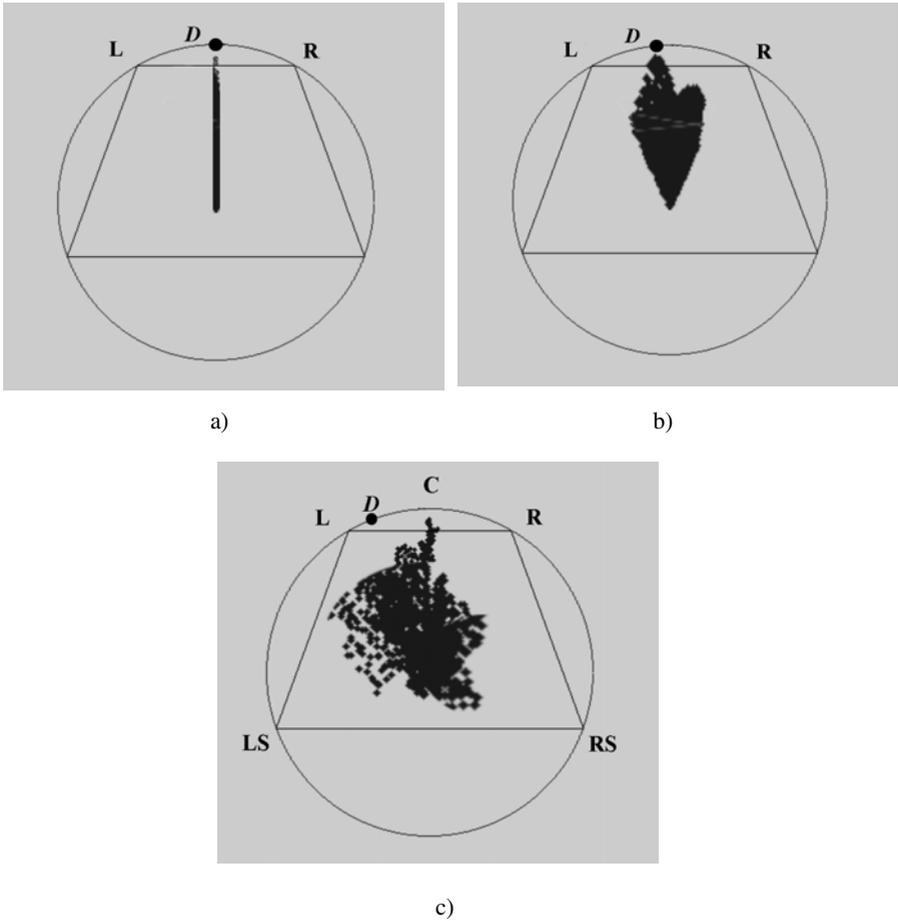The described algorithm provides a "visualization" of acoustic perspective, with examples shown in Figure 8.

a)   b)

c)

Fig. 8. Example of acoustic perspective and dominating sound direction for: a) mono: L = R, LS = RS = C =0, b) stereo: L≠R, LS = RS =C =0, c) 5.0 signals

4   Conclusions

Quality of the proposed solution was tested by the way of experiment. The test pertained to confrontation of displayed images with audio impressions of a group of "experts" (28 individuals). The listeners were presented test recordings, and their task was to indicate (by means of a laser indicator) where a dominating sound is coming from. Tests conducted in the professional Laboratory of Sound Engineering and Ambiophonics at the Faculty of Electrical Engineering (West Pomeranian University of Technology in Szczecin). Agreement of detector readings and listener observations

for the sound front stage was 4.8%, while 9.7% was registered for the rear stage. The resulting differences could be explained by the fact that a human can localize the front sound source position with accuracy of about 3^0, and the rear sound source position – with accuracy of 6^0 [4].

A concept of the described solution was presented at the Szczecin Studio of the Polish Television and was met with an appreciation by the producers and engineers.

References

1. Jordan, V.: Acoustical Design of Concert Halls and Theaters. ASP Ltd., London (1980)
2. Aarts, R.M., Irwan, R.: Two – to - Five Channel Sound Processing. Journal of the Audio Engineering Society (11), 914–926 (2002)
3. Kornatowski, E.: Spatial information filtration algorithm and surround sound effect indication. Electrical Engineering. Poznan University of Technology Academic Journals (58), 7–15 (2008)
4. Sztekmiler, K.: Podstawy nagłośnienia i realizacji nagrań, NCK Warszawa (2003)
5. Wojnar, A.: Teoria sygnałów, Wydawnictwo Naukowo – Techniczne, Warszawa (1980)
6. Yamamoto, K., Iwakiri, M.: Real-Time Audio Watermarking Based on Characteristics of PCM in Digital Instrument. Journal of Information Hiding and Multimedia Signal Processing 1(2), 59–71 (2010)
7. Wey, H., Ito, A., Okamoto, T., Suzuki, Y.: Multiple Description Coding Using Time Domain Division for MP3 coded Sound Signal. Journal of Information Hiding and Multimedia Signal Processing 1(4), 269–285 (2010)