Realization of Surround Audio by a Quadraphonic Headset

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***Abstract*-- In this work, a four-channel headset achieving the 5.1-channel-like hearing experience is presented. It includes a 5.1- to 4-channel down-mixer, head related transfer function, and artificial reverberation in a closed space. From experiments, the proposed headset achieves similar hearing perception as a 5.1-channel loudspeaker system with much lower hardware cost.**

I. INTRODUCTION

With the rapid development of information technology and internet access in recent years, digital video and audio applications are widely employed in human life. For the increasing demands of human perception for multimedia, the traditional mono or stereo audio playback is not able to satisfy human ears. By placing multiple channels, such as 5.1 channels, at different positions, we are able to experience different three-dimensional (3D) spatial effects.

Currently, the market is able to provide high quality multi-channel audio systems though the cost of a loudspeaker system is relatively high. In views of limited available personal space, it is often not suitable by placing a multi-channel system in a crowded space that may also interfere with neighboring people. On the other hand, a conventional earphone set provides privacy but no surrounding perception. Therefore, it is desirable to produce a headset that provides privacy and the capability to experience the rich multi-channel audio in DVD or Blue-ray with much lower cost compared with a full loudspeaker system.

The multi-channel headsets in the market nowadays tend to be single-function approach, such as gaming headset with the bass enhancement. Unlike the above approach, we propose a four-channel headset that achieves the 5.1-channel-like hearing experience. In the proposed architecture, we utilize the Head Related Transfer Function (HRTF) to enhance the perception of spatial difference [1]. In addition, we utilize artificial reverberation to enhance the hearing experience of space. The hardware cost of the proposed four-channel headset is much lower than 5.1-channel loudspeaker systems because all the devices, such as audio adapters and earphone devices, in the proposed system are off-the-shelf components.

II. PROPOSED MULTI-CHANNEL DOWN-MIXING ALGORITHM

We modify the down-mixing structure of the standard ITU-R BS.775-1 [2]. The proposed method which practices Six-to-Four down-mixing is shown in Fig. 1.

The solution is of course not unique. We arrange the down-mixing based on the principle of energy conservation. The signal of Central (C) channel is reduced by 3dB and added to Front-Left (FL) and Front-Right (FR) channels respectively. The signal of Low Frequency-Effect (LFE) channel is also reduced by 3dB and added to Rear-Left (RL) and Rear-Right (RR) channels respectively. As a result, a four-channel output with Front-Left (FL'), Front-Right (FR'), Rear-Left (RL'), and Rear-Right (RR') channels is formed.

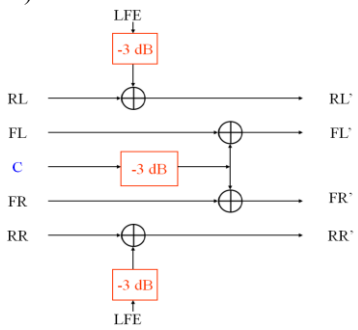


Fig. 1 Six-to-Four down-mixing structure

III. HEAD RELATED TRANSFER FUNCTION

Human auditory system (HAS) that is able to localize sound sources is based on the physical distance between two ears, which causes the sounds to arrive at two ears differently. The filtering effect of the head, torso, and pinna is thoroughly described by the Head Related Transfer Function (HRTF) [3].

One of the differences to HAS between a loudspeaker and an earphone is that the major part of HRTF is included in the loudspeaker path, but not in the earphone path. Adding HRTF into the proposed system can enhance the perception. An example that shows different HRTF coefficients with 4 directions is depicted in Fig. 2, in which the impulse responses of left and right channels are shown.

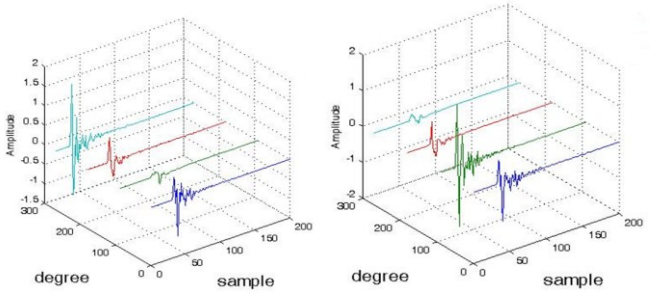


Fig. 2 Impulse responses for the four degrees of 0,90,135, and 180
(a) left channel (b) right channel

IV. ARTIFICIAL REVERBERATION

In the reflected sound field, in addition to sound waves from the source itself, there exist reflections of sound waves resulting from walls or obstacles. It is composed of three components: direct sound, early reflection, and late reverberation [4]. Generally the amplitude response of the early reflection can be formulated as exponential decay [5]:

$$h_{FIR}(n)=\begin{cases}10^{\frac{-60n}{20\cdot f_s\cdot R_T}}, & n=k\cdot\left\lfloor\frac{f_s}{R_D}\right\rfloor, \quad k=0,\ldots,k_{\max}.\\ 0, & else\end{cases} \tag{1}$$

where R_T is the reverberation time, R_D is the reverberation intensity, f_s is the sampling rate, $k_{\max}=T_e\cdot f_s$, T_e is the early reflection time, and $\lfloor\cdot\rfloor$ denotes floor operation.

Next the late reverberation can be realized by the framework with several parallel comb filters [6], which are shown in Fig. 3. This model is composed of six parallel comb filters and cascaded with an all-pass filter. These digital filters are used to simulate the reflection and reverberation states of a room effect.

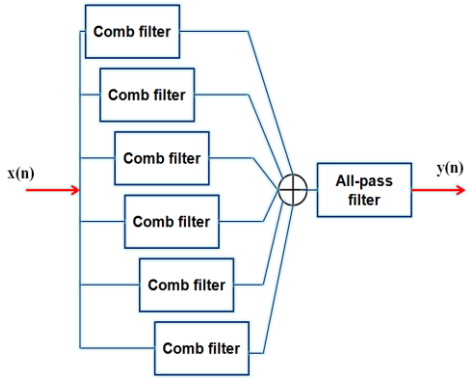


Fig. 3 Diagram of the Moorer reverberator [6]

V. Proposed Four-channel Headset and Subjective Hearing Test

The implementation of the Four-channel headset system is shown in Fig. 4. All devices are off-the-shelf components. In experiments, reference audio sequences are played back by stereo and multi-channel systems through loudspeakers and headphones. The score rating ranges between -3 and 3 for comparing two systems is shown in Fig. 5 [7].

Fig. 4 Designed Four-channel headset

Much better	better	Slightly better	About the same	Slightly worse	worse	Much worse
3	2	1	0	-1	-2	-3

Fig. 5 Score ratings

Eight listeners are invited to carry out these subjective hearing tests. The comparison is to compare whether four-channel headset can rival the multi-channel system or not in space hearing perception. The results and discussions for comparisons with stereo headphones and 5.1 channel systems are shown in Fig. 6 and Fig. 7, respectively.

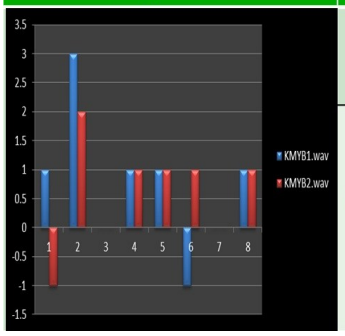
Comparison 1	Position difference
	Average score KMYB1.wav : 0.75 (Blue) KMYB2.wav : 0.625 (Red)
	Score ranges between 0 and 1, it represents that four-channel headset is **better** than stereo headphones in position difference.

Fig. 6 Subjective hearing test of position differences

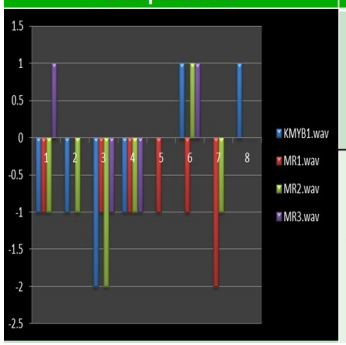
Comparison 2	Spatial sound field
	Average score KMYB1.wav : -0.375 (Blue) MR1.wav : -0,875 (Red) MR2.wav : -0.625 (Green) MR3.wav : 0 (Purple)
	Score ranges between 0 and -1, it represents that four-channel headset is **almost the same** of 5.1 channel device in spatial sound field hearing.

Fig. 7 Subjective hearing test of spatial sound field

VI. Conclusion

This work is to realize a four-channel headset that is able to produce multi-channel surround audio hearing perception. Subjective listening tests show that the proposed four-channel headset performs much better than stereo headphones and comparable with a multi-channel system.

VII. References

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