Augmented Reality Using Wave Field Synthesis for Theatres and Opera Houses

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Introduction

Since the first introduction of Wave Field Synthesis by Berkhout [1] this audio technology has proven applicability to many fields of sound reproduction. Practical experiences in the last years have shown that combinations of WFS with stereophonic techniques are suitable for an effective integration of holophonic audio technology into a given application. In this paper, the authors summarize the technical and perceptive aspects of loudspeaker-based spatial sound reproduction and focus on a seamless system design from stereo via multi-speaker set-ups to WFS.

WFS for live sound reproduction

In the last years, immersive audio reproduction has been introduced in the domain of live sound and theatres. This development has been motivated by creative aspects of virtual reality systems and claims for a new definition of audio in live sound. From this point of view sound reinforcement systems in theatres can be considered a part of an augmented reality system introducing virtual sound sources into the real room. Therefore new requirements of audio reproduction and active room acoustics come into focus e.g.:

- Matching the position of the real visual and/or acoustical source with the localization of the virtual source
- Seamless integration of active room acoustics into the given environment.
- Immersion of the listener.
- Adaptive and interactive features for virtual sound sources.

It has been shown in the past that these requirements can be fulfilled in an elegant way using WFS. Using loudspeaker arrays with a small spacing allows for a reproduction of audio with high spatial resolution and complete phase control of the sound field up to the aliasing frequency given by the loudspeaker spacing. The immersion of the listener is improved by the distribution of the emitted sound energy over a loudspeaker array. The listener will perceive the emitted sound field, but ideally will be unable to localize one single loudspeaker.

Nevertheless WFS requires a large number of loudspeakers and considerable processing power. Therefore the authors propose new criteria under which conditions a stereophonic multi-speaker set-up or combinations with a WFS system might be appropriate from a perceptive and economic point of view.

- Localization of the source: distance and angle,
- Active room acoustics: control of first reflections and of the intelligibility
- Adaptive and interactive aspects of sound source control.

1. Localization of the source: distance and angle.

Listening tests have shown that the perception of distance relies on two independent cues in wave field synthesis: The perceived distance due to the first reflections of the room and the holophonic distance due to the curvature of the wave front [3]. On one hand the reflection pattern gives a direct indication of the absolute distance of the source [4]. On the other hand the curvature of the wave front is perceived only up to a distance of approx. 3m [2]. At a larger distance human hearing only perceives a parallax effect when the listener moves: The sound source seems to follow the listener more or less depending on its distance.

If angle only, neglecting distance cues for a moment, is a sufficient parameter for a given application, the audio system design may rely on a multi-speaker set-up with amplitude and / or delay panning. Simple cues for distance perception may be added using first reflections. If the azimuth angle, as well as an appropriate perceived distance of the sound source and the perspective of the sonic image is important, a wave field synthesis rendering system should be applied. Especially in those cases where surround effects need to be reproduced at both sides of the listener, a multi-speaker set-up may be sufficient since the spatial resolution of human perception for this range is only about 15° [2]. Combinations with a WFS system in front of the listener are suitable in many applications.

2. Active room acoustics: control of first reflections and of the intelligibility.

The control of the diffuse sound field and of first reflections in a real room using electronic audio reinforcement has already been implemented by various systems. For these applications the use of conventional reproduction methods with loudspeaker arrays are suitable. Array technology will provide a homogenous sound field in the listening area. But the control of source directivity opens further possibilities for the implementation of virtual acoustics. E.g. a cylindrical source reproduced by a WFS system with a well designed directivity will excite the room less than a source coming from a conventional audio system. In many cases it will be easier to control the desired directivity of a virtual sound source in WFS, than altering the directivity of a real loudspeaker. Therefore intelligibility can be enhanced by modifying the directivity of sound sources (especially in highly reverberant rooms. In this case a WFS system offers

clear advantages compared to a conventional reproduction system.

3. Adaptive and interactive aspects of sound source control.

In general interactive techniques are combined with 3D or holographic audio applications. Nevertheless combinations with stereophonic array technologies are imaginable: E.g. the adaptation of the reverberation time according to the attenuation due to public may be implemented using video tracking. The same tracking technology can be used to match the localization of virtual sound source on stage with the position of the real source, e.g. a singer. Such tracking techniques have been developed for interactive audio systems in the Swiss national project STILE.

Conclusions and system requirements

It has been shown that combinations of stereophonic techniques and WFS are justified from a perceptual and economical point of view in many applications. Therefore a scalable rendering approach is required to include both technologies in the same set-up. Since WFS requires an object-oriented approach this separated data representation of audio and parameters should be used for stereophonic rendering as well. In [5] a synchronized networked rendering technology for WFS has been introduced. This approach can be used for combinations with stereophonic rendering and is open to other applications via APIs.

References

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