Wave Field Synthesis: New Possibilities for Large-Scale Immersive Sound Reinforcement

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Abstract

Wave Field Synthesis (WFS), pioneered by Delft Technical University, has been around as a research topic for around 15 years. With the implementation of a large WFS array in the Ilmenau cinema, new applications for WFS technology are around the corner. The paper gives an introduction to basic WFS theory, explains major application areas including cinemas, concert halls and music performances (indoor and outdoor) of all kinds. For larger WFS arrays, some new problems had to be solved. Current designs allow better audio for large audiences including virtual sound sources at perceived locations inside and outside the array perimeter.

1. Introduction

Sound reinforcement has always suffered from compromises between good sound quality for only some listening positions (e.g. in the “sweet spot” of a traditional multi-channel arrangement) or only marginal sound quality for all listeners. The larger the listening room, the more difficult it became to provide high fidelity audio throughout the listening room. All this has changed with the availability of Wave Field Synthesis systems.

Wave Field Synthesis is a method to recreate an accurate (in two dimensions) replication of a sound field using the Kirchhoff-Helmholtz integrals. Over more than 15 years, researchers at Delft technical university have developed the basic methods and prototype implementations of WFS (see e.g. [1], [2]). Today it is the only applicable way to accurately give an impression of direction and distance of sound objects.

2. Basic Theory

The concept works with wave theory and the generation of wave fronts using loudspeaker arrays. Each loudspeaker in the array will be fed with corresponding signals calculated by means of algorithms based on Kirchhoff-Helmholtz integrals (See [2.1] for homogeneous media) and Rayleighs representation theorem. This theorem is formulated mathematically by two Rayleigh integrals [4].

\[
P_i = \frac{1}{4\pi} \int \left( \frac{1}{r} \left[ \frac{\exp(-jkr)}{r} \right] + \left( \frac{\exp(jkr)}{r} \right) \right) d\Omega \quad [2.1]
\]

For WFS these 3D-integrals are approximated for a finite number of identical loudspeakers placed in one plane. Without additional influence of the reproduction room the superposition of the sound fields generated by each loudspeaker composes the wave field in this plane perfectly up to the aliasing frequency. The aliasing frequency is given by the distance between loudspeakers. WFS enables an accurate representation of the original wave field with its natural temporal and spatial properties in the entire listening space only limited by the near-field properties of the loudspeakers used.

Virtual sound sources (point sources) can be placed anywhere in the room, both behind the loudspeaker arrays as well as inside the room (focus sources). The acoustical properties of the reproduced sound scene can either be the properties of the recording room, the properties of a prerecorded different venue or obtained from artificial room models. These properties can also be reproduced using plane waves (Figure 1).

![Fig. 1: Reproduction of sound sources and plane waves](image)

WFS can easily be combined with room equalization: To lower the effect of the actual listening space on the perceived sound, partial cancellation of early reflections can be used. In addition, a virtual listening room can be
added to the virtual sound sources by either synthetic acoustic spaces (as e.g. defined in the MPEG-4 standard) or by reproducing reverberation recorded in the room of the original performance.

3. Applications of WFS

Over the long run, WFS and mathematically related sound rendering methods like ambiphonic reproduction will find it’s way to all sound reproduction systems where it is possible to use more than just one or two loudspeakers.

3.1. Application areas

- **Concert halls:** The WFS algorithms exhibit intrinsic delay times short enough for life performances. If the acoustics of the concert hall are good enough that no room equalization filters are necessary, this is easy to achieve. WFS can make electronically amplified audio sound much more natural.

- **Open air events:** Key requirements for open air concerts are equal distribution of the sound pressure level across the whole listening area and spatial coherence of sound and visual scene on stage. While line arrays of loudspeakers can only satisfy the first requirement WFS can do both. Optionaly it is possible to create an artificial room around the listening space with acoustical properties like in-doors (esp. useful for classical concerts) and to place sound effects even inside the listening space.

- **Cinema:** In addition to an accurate representation of the original wave field in the listening room, WFS gives the possibility to render sound sources in their true spatial depth and therefore shows enormous potential to be used for creation of audio in combination with motion pictures. On February 19th, 2003 the first cinema equipped with WFS system started daily service in Ilmenau, Germany. A trailer, produced in a WFS and visual scene on stage. WFS automatically generates a realistic Doppler effect which might cause unwanted effects when used during music performances.

4. Conclusions

Wave Field Synthesis can be considered as the next revolution to audio reproduction after going to stereo and multichannel systems. It will find it’s way into concerts, cinemas, theme parks and, eventually, into the home. After long years of research, computational complexity is no longer an obstacle for wide spread adoption of WFS.

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6. References


