Design and integration of a 3D WFS System in a cinema environment including ceiling speakers - a case study

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Introduction

With 3D picture being the driving force of today's motion pictures there is a growing need for adequate audio solutions with flexible 3D loudspeaker setups. While these audio reproduction systems have to fulfill highest quality demands, the amount of loudspeakers and effort of integration should be kept as low as possible to optimize commercial aspects.
This paper describes the design and integration of a newly developed 3D spatial audio solution based on wave field synthesis in a cinema environment. To meet the expectations toward a true 3D cinema experience, this system has been extended with the capability to drive ceiling speakers.

Reproduction System

The reproduction system's concept and the utilized algorithm is based on Wave Field Synthesis (WFS). There are special loudspeakers available on the market whose performance is optimized for the requirements of physical WFS [1]. However, this loudspeaker concept is neither matching the acoustical requirements of cinema sound systems nor allowing to reduce system and integration complexity.
Since recent research has lead to solutions using less speakers while maintaining the perceptual advantages of WFS, it is possible to work with a small number of individual speaker channels [2]. The choice and arrangement of the speakers is discussed in the next section.

System Design

On one hand the system itself has to be integrated in common cinema multimedia systems in regards to interfaces and compatibility that are predominantly defined by standards and best practices.
On the other hand, the acoustical design of the system has to deliver superior spatial performance and a sound performance that outperforms common audio systems.
The cinema, chosen for this case study has the dimension of 16m width, 8m height and 20m length and is therefor representing a typical mid size cinema with approximately 400 seats. The seating area covers the full width of the room, beginning 5m in front of the screen and extending for 13m.

Loudspeaker Criteria and Choice

The combination of cinema sound and the WFS concept requires each loudspeaker to cover the whole audience area with a consistent spectrum while inducing a maximum Sound Pressure Level (SPL) of 105dBC when fed with full range pink noise. According to the 1/r-law this particular cinema's loudspeakers have to invoke a maximum SPL of at least 128dBC in 1m distance. Additionally, the high criteria for the loudspeakers bandwidth and sound quality of the movie industry have to be fulfilled. Measurements have shown that state of the art cinema screen loudspeakers are reproducing a bandwidth from 50Hz to 16kHz.
The system utilizes multiple distributed subwoofers that are driven individually to allow direction dependent low frequency reproduction. To minimize the impact of dozens of cabinets on the cinema's aesthetics and budget this concept is used to diminish the bandwidth criterion for wall and ceiling speakers by applying bass management techniques. This enables smaller, cheaper and more unobtrusive speakers to be installed in the system. Nevertheless it's crucial that all utilized speakers independent of their concept and and components have a common tonality to avoid tonality changes to a signal that might be reproduced by different loudspeakers e.g. in a panning movement from the screen to the ceiling. In tis particular cinema we used 15"' 3-way speakers behind the screen and 12"' 2-way speakers for the other walls. Both speaker types are using the same tweeters and high frequency horn and have a 75° radial directivity. The ceiling array consists of 8"' 2-way speakers with 100° radial opening angle. The front and back is equipped each with double 18"' subwoofers at two positions.

Speaker Arrangement

The system consists of a horizontal ring, an equally distributed ceiling array of loudspeakers and subwoofers at several positions. Based on investigation on the spatial quality in relation to the speaker density the horizontal ring comprises 58 equidistant loudspeakers. The choice of feasible speakers as well as the positioning and aiming of the speakers has been supported by the acoustical simulation tool EASE. A binaural simulation of the system including the room acoustics has been done to support the design process and validate choice, number and arrangement of the speakers [3].
The most critical loudspeaker positions in terms of spectral coverage and SPL drop are the central region of the side walls and the ceiling speakers directly above the center of the audience area. Since the distance between loudspeakers at these positions and the listening area is very small a very wide coverage angle is necessary to address

the whole audience area with the high frequency portion of the signal. Furthermore, the level drop relative to increasing listening distance is very high with loudspeakers near to the audience. It is critical to increase the installation height of the ring loudspeaker over a certain amount to avoid strong vertical localization errors even though this would reduce the distance dependent level differences. Figures 1 and 3 are showing a top view of the direct sound coverage of the 8kHz third on the slightly tilted audience area of the cinema.

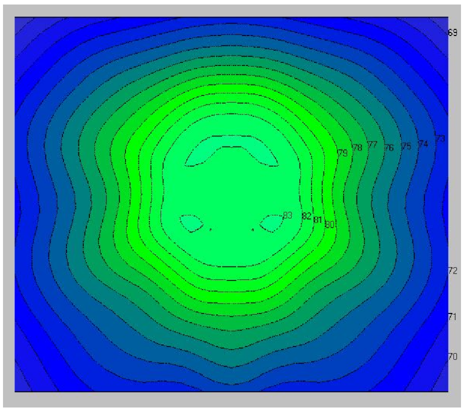

Figure 1: Direct sound simulation of central ceiling speaker, f = 8kHz, numbers in dB

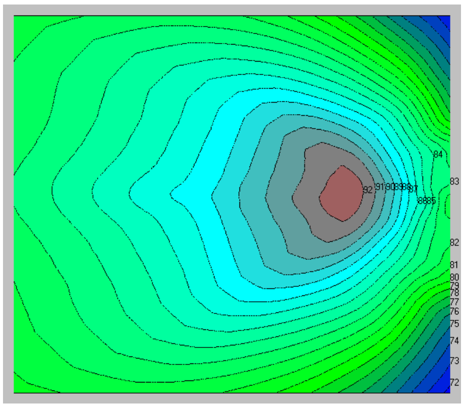

Figure 2: Direct sound simulation of middle side wall speaker, f = 8kHz, numbers in dB

The figures clearly show the level differences of up to 13dB over the listening area that are critical that could not be fixed with this particular design. The speakers of the horizontal ring follows the slope of the audience area to maintain the optimal coverage pattern for all side wall speakers. Due to this cinema's low ceiling height, the installation height of the rear and ceiling loudspeakers is almost identical. This arrangement evokes only little differences in elevation perception of sounds reproduced by the rear loudspeakers and the rear part of the ceiling array.

System Tuning

The tuning is based on multiple spatially distributed measurements of all speakers. The resulting impulse responses are adaptively windowed and averaged afterwards to obtain the direct sound response of every loudspeaker Based on the measurements FIR filters for every speaker are calculated. These filters serve multiple purposes: To be able to equalize coverage shortcomings due to the speakers, their physical integration and screen loss, the filters are compensating the systems response toward a user defined target response. In cinema environments all speakers except the subwoofers are tuned according to the X-curve to establish similar audio conditions throughout cinemas[4].
To compensate for different sensitivity and distance of the speakers, the level settings for every speaker are calculated and applied using these measurements as well.

Figure 3: Loudspeaker arrangement in cinema

Conclusion and Future Work

This paper describes acoustical design criteria for a 3D audio system for commercial use in cinemas by means of a real life installation. Shortcomings of this installation have been identified by assessment of the venue. Loudspeaker solutions which are allowing an improvement of the spectral coverage while lowering the speaker's installation height have to be evaluated. Even though, the system provides superior 3D listening experience and sound quality empowered by the perceptual advantages of WFS and can be designed flexibly for the particular venue and budget.

References

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