Analysis of Three Approaches to Wavefield Synthesis

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Abstract

Wavefield Synthesis (WFS) is a spatial audio technique whereby pressure wave fronts are reconstructed using an array of loudspeakers. This allows for the reproduction of a directional image of an auditory event located behind the transducer array. This poster will explore the design and analysis of two wavefield synthesis systems, and the proposal of a third. The first of these methods is a simple reproduction technique mapping a microphone array to a driver array with the same dimensions. In the second method, spatialization will be achieved from a mono source using signal processing techniques.

Methods

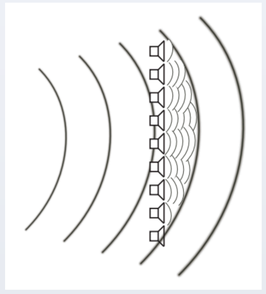


Figure 1 From Spors et. al. [1]

The first technique for WFS mentioned above is a naïve approach, whereby impulse responses are recorded at discrete locations in front of the microphone array at various room locations (bottom left, bottom right, center, top left, and top right).

The second approach is to use a singular channel of audio and apply spatial processing to achieve localization. Firstly, a virtual source is placed in the 'background' of the room. The Euclidian distance from this source and each of the drivers is calculated, and using the speed of sound, the relative time delays and intensity differences across the channels are obtained. Delay and scaling is then done accordingly on each channel.

The results from both of these methods will help prove that source localization is feasible using our designed array of drivers, seen at right.

References

[1] Spors, S., Teutsch, H., Rabenstein, R.: High-quality acoustic rendering with wave field synthesis. Vision, Modeling, and Visualization, 101–108 (2002)

[2] A.J. Berkhout, D. de Vries, and P. Vogel, "Acoustic control by wave field synthesis," Journal of the Acoustic Society of America, vol. 93, no. 5, pp. 2764–2778, May 1993.

[3] Mathelier, Bertrand, et al. "Synthesis of Waveforms from Zero-Lag Cross-Correlation Matrix with Specified Constraints and Power Levels." *Ieeexplore.ieee.org*, IEEE Conference Publication, 2012

Naïve Approach

Using a four-channel interface, a sound event was recorded with microphone positions spanning an equally-spaced 5x4 subset of the holes in the above apparatus, varying the microphone positions four at a time. Five different sound event locations were recorded. Drivers were then placed in the microphone locations for one-to-one playback.



Figure 2: Recording Apparatus in the Anechoic Chamber

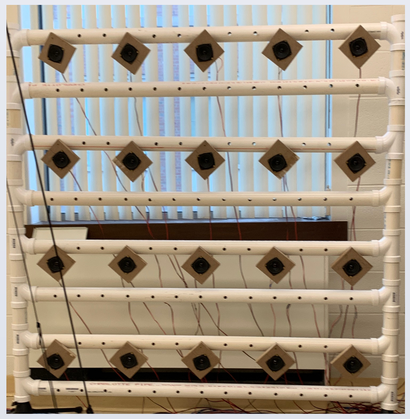


Figure 3: Playback Apparatus

Naive Approach Results	
Metric	**Accuracy**
Overall Left Spacialization	93.75 %
Overall Right Spacialization	100.0 %
Overall Center Spacialization	87.50 %
Overall Up Spacialization	93.75 %
Overall Down Spacialization	56.25 %
Overall Accuracy:	86.25%

Table 1: Results from Naïve Approach

Delay- and Amplitude-Panning Approach

The microphone locations in the room were measured, and the user can place a virtual source anywhere in the 'background' of the room. The output of each driver is a delayed mono source with an intensity difference commiserate of the distance from the virtual source to the driver.

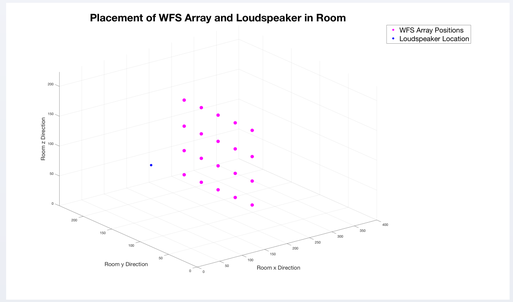


Figure 4: Virtual Source Location and Driver Locations

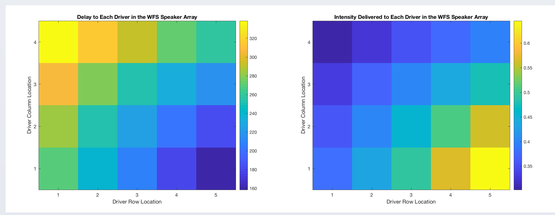


Figure 5: Relative Delay and Intensity of Drivers for Virtual Source Location in the Lower Left

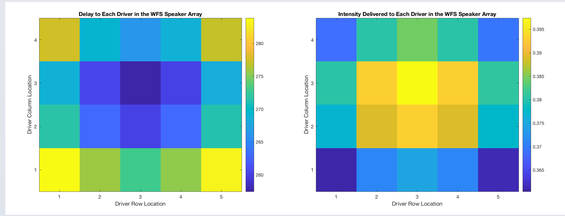


Figure 6: Relative Delay and Intensity of Drivers for Virtual Source Location in the Center

Delay/Intensity Approach Results	
Metric	**Accuracy**
Overall Left Spacialization	100.0 %
Overall Right Spacialization	93.75 %
Overall Center Spacialization	75.00 %
Overall Up Spacialization	93.75 %
Overall Down Spacialization	50.00 %
Overall Accuracy:	82.50 %

Table 2: Results from Delay/Amplitude Approach

Notes for Scalability

Our designed array uses 20 drivers, however state of the art WFS systems will use upwards of 750 drivers. In order to make our processes efficient at scale, we propose using Huygen's principle to limit the number of discrete arrays calculated by our system [2]:

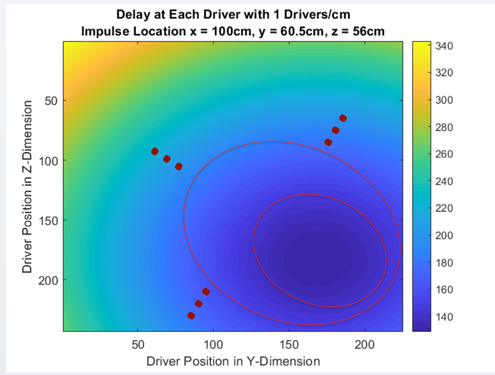


Figure 7: Efficient Rings of Constant Delay Employing Huygen's Principle

Additionally, to allow for one channel of audio to drive hundreds of channels, a synthesis technique borrowed from MIMO radar physics as proposed in [3] should be explored, whereby each output channel is synthesized from the input audio and the co-variance matrix describing the correlation between the channels in the array in the given environment.

Discussion and Conclusions

The spatialization in the left and right directions were more pronounced than moving the source vertically up and down. This is influenced by the limitations in the actual design of the microphone/transducer array, with no "true" center speaker since there were only four loudspeakers in the vertical direction versus five in the horizontal plane. If an extra row of loudspeakers were added to the design, the observed results would likely improve the distinction between vertical source localization, and compare equivalently with the horizontal experimental data.

However, in general the outcome of both experiments were relatively good, with the average listener being able to correctly locate the source upwards of eighty percent of time for both the naïve and synthesized wavefield synthesis attempts. This could be significantly improved if there were more transducers introduced, and higher quality devices were dedicated to the project including microphones, recording locations, array design, and signal processing equipment.

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