Immersive Audio Rendering Algorithms

1. Research Team

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Industrial Partner(s): SPAWAR, STRICOM

2. Statement of Project Goals

A key issue that we are investigating in the area of immersive audio rendering has to do with optimizing the frequency response of the rendered sound for multiple listeners simultaneously. We seek to overcome the fundamental problems of room acoustics and equalization using a novel fuzzy logic approach. Previous work in this area has only focused on the single listener problem and has dealt with multiple listeners by simply averaging the responses at various locations. We have shown that our method significantly outperforms spatial averaging and are working towards a real-time stand-alone implementation based on DSP architecture.

3. Project Role in Support of IMSC Strategic Plan

Immersive audio is one of the critical elements in IMSC's vision of Immersipresence. The algorithms that we are developing will enable multiple listeners to be immersed in a remote environment simultaneously. We are looking to go beyond the individual in front of their PC, but rather to focus on the group experience. Using our algorithms, people can be transported from the middle of a presidential press conference to a sports event, a concert, or to a distant classroom exploring the human brain.

4. Discussion of Methodology Used

As we move away from single-person experiences in front of a desktop PC to group immersion in an educational or entertainment setting, the spatial uniformity of sound experience begins to suffer. This is a fundamental problem of room acoustics and is particularly evident in small rooms, which are dominated by standing waves at frequencies below about 250 Hz. The goal in this work is to provide significant improvement in both the measured and perceived audio quality for all listeners simultaneously in a typical listening room. Traditional methods for room equalization in the past have either focused on the single listener problem, or use spatial averaging of the magnitude responses to derive the inverse filter. We have developed a novel a statistical framework for clustering room acoustical responses bearing "similarity" to each other [1-5].

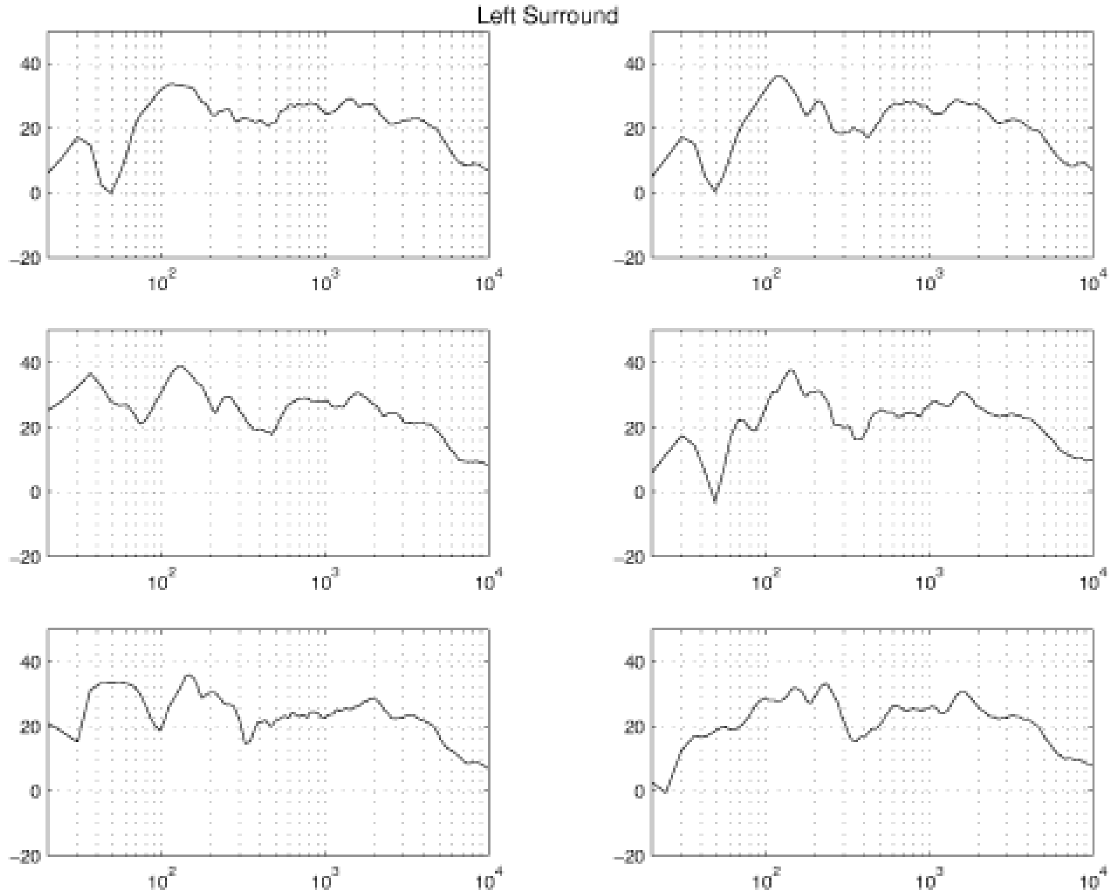

Figure 1 Measured frequency response (dB) as a function of frequency (Hz) at 6 seating locations in the listening room. Note the deviation from flatness in each response, as well as the lack of uniformity from position to position. The effects at the lower frequencies are inherent to living room size rooms and are due to standing waves and interactions with acoustical surfaces.

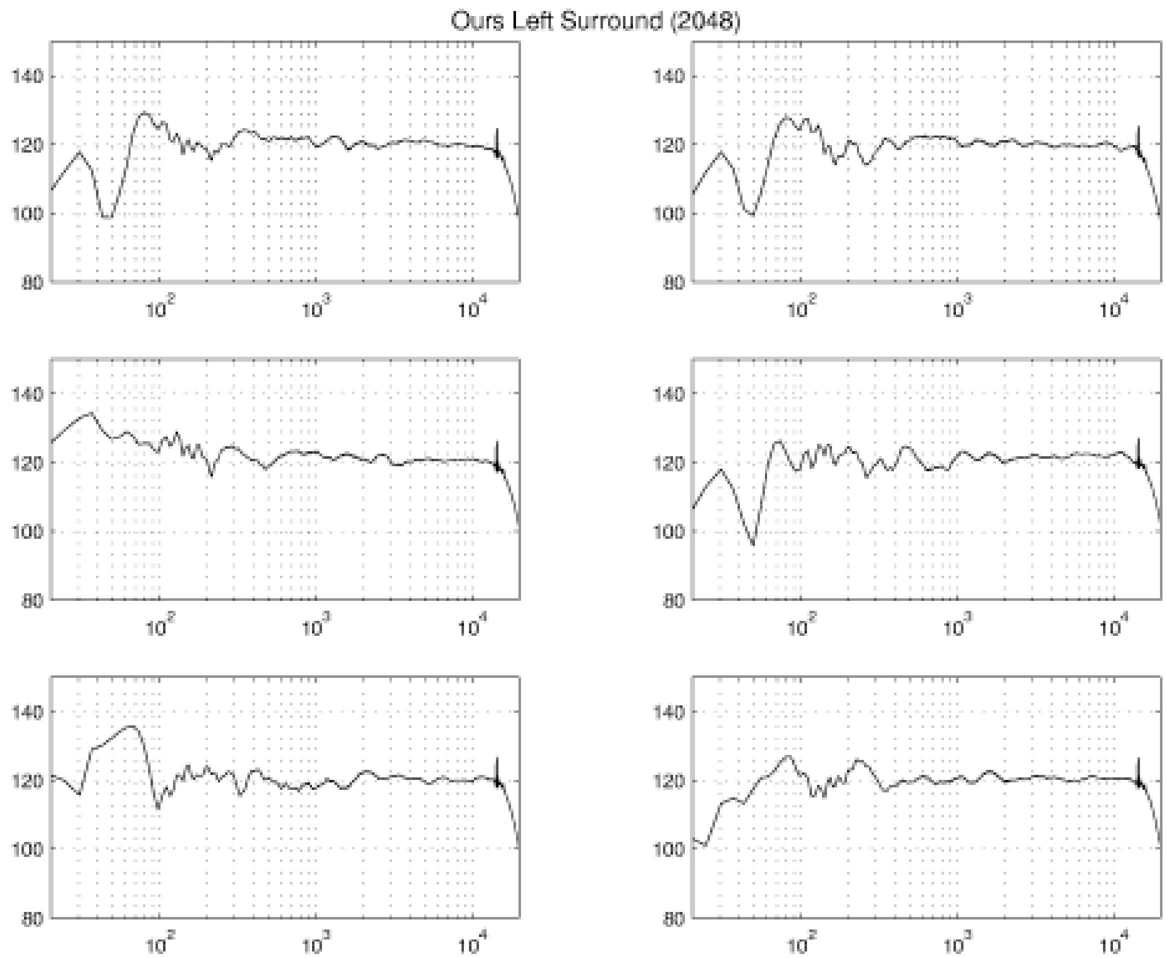

Figure 2 Measured frequency response (dB) as a function of frequency (Hz) at 6 seating locations in the listening room. Note that both the flatness (out to 10 kHz) and the uniformity have improved significantly. The improvement has also been verified through listening comparison tests.

The method used is *Fuzzy c-means clustering*, which allows degrees for clustering responses for clustering magnitude responses at the listeners. The centroids for the clusters are combined in a specific manner to form a model response that is inverted to form the equalization filter. The method has been shown to perform better than the spatial averaging method both from a perceptual, as well as from a computational efficiency viewpoint.

5. Short Description of Achievements in Previous Years

- Development of fuzzy c-means clustering method for room acoustics problem
- Software implementation for room response measurement and filter design
- Multiple publications outlining the work

5a. Detail of Accomplishments During the Past Year

- Implementation of psychoacoustical clustering and equalization that is motivated by the critical band filter model (Bark scale) [3]
- Porting of algorithms to real-time DSP architecture
- Operational system for demonstrations

6. Other Relevant Work Being Conducted and How this Project is Different

Traditional methods use spatial averaging of the magnitude responses. Also, LMS filters and CAPZ (common acoustical pole-zero) modeling have been used for this application [6].

7. Plan for the Next Year

We will investigate methods for efficient room response measurement, trade-offs in filter length vs. computational complexity, and the effects of including the non-minimum phase component of the response.

8. Expected Milestones and Deliverables

A stand-alone hardware/software solution for room equalization will be developed and demonstrated in the 2020Classroom and Distributed Performance projects as part of the local rendering system.

9. Member Company Benefits

These algorithms can be used in any immersive environment with multichannel sound including ones used in simulation, training, and mission rehearsal.

10. References

[1] S. Bharitkar and C. Kyriakakis, "Selective Signal Cancellation for Multiple-Listener Audio Applications Using Eigenfilters", accepted by IEEE Transactions on Multimedia. To appear February 2003.

[2] S. Bharitkar and C. Kyriakakis, "Perceptual Multiple Location Equalization with Clustering," in Proc. 36th IEEE Asilomar Conference on Signals, Systems, & Computers, Pacific Grove, CA, Nov. 2002.

[3] S. Bharitkar, P. Hilmes, and C. Kyriakakis, "Robustness of Spatial Averaging Equalization Methods: A Statistical Approach," in Proc. 36th IEEE Asilomar Conference on Signals, Systems, & Computers, Pacific Grove, CA, Nov. 2002.

[4] S. Bharitkar and C. Kyriakakis, "Visualization of Multiple Listener Room Response Equalization using Sammon Map," in Proc. IEEE Intl. Conf. on Multimedia & Expo (ICME 2002), Lausanne, Switzerland, Aug. 2002.

[5] S. Bharitkar, P. Hilmes, and C. Kyriakakis, "A Statistical Analysis of the Robustness of Room Equalization Using Spatial Averaging", Preprint No. 5669, presented at the 113th AES Convention, Los Angeles, CA, October, 2002.
[6] C. J. Liu, S. F. Hsieh. Common-acoustic-poles/zeros approximation of head-related transfer functions. *ASSP-2001 Proceedings*, vol. 5, pp. 3341–3344, 2001.