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Determination and Enlarging of the Acoustic Sweet-Spot in an Auditorium

Abhiram Lg, Aman Tayyab, Ankith V
PES Institute of Technology, Bangalore, India
Abram.krishna@gmail.com, amantayyab.2494@gmail.com, arcotankith@gmail.com

Abstract: The sweet spot is described to be the focal point between two speakers, where an individual is fully capable of hearing the stereo audio mix the way it was intended to be heard by the mixer. In the case of surround sound, this is the focal point between four or more speakers. Beyond this area, the spatial perception collapses and the since the signal arrives both louder and sooner, the stereo image moves to the nearer speaker. Different static methods exist to broaden the area of the "sweet spot". Alternatively, the "sweet spot" can be adjusted dynamically to the actual position of the listener. Sweet spot studies would be pursued using acoustic interference and sound theory involving the alignment of the focal points of the surround speaker systems and achieve a wide area of perfect hearing in an auditorium. This paper focuses on the alignment of the focal points of the sound sources to achieve a wide area of perfect hearing.

Key Terms: Dirichlet Boundary Condition, Mur's Boundary Condition, Leapfrog Scheme, Sweet-Spot.

I. INTRODUCTION

The sweet spot is described to be the focal point between two speakers, where an individual is fully capable of hearing the stereo audio mix the way it was intended to be heard by the mixer. In the case of surround sound, this is the focal point between four or more speakers.

Figure 1: Representation of sweet spot

II. LITERATURE SURVEY

Present methods to broaden the "sweet spot" can be separated into two types: Adjusting the radiation pattern of the speaker directly or adjusting the delay between the speakers. One of the early studies was published by Bauer [1]. He proposes a system, where the angle between the loudspeaker axes is approximately 120° to 130°. In such a system, the dB level difference between the loudspeaker signals remains almost constant over a wide area. If the listener is moving away from the symmetry axis, the signal from the nearer loudspeaker will arrive earlier but the signal from the further loudspeaker will become louder. This is due to the path difference between the two sound waves. However Merchel [2] suggests loudspeaker signals have to be adjusted according to the x-y position of the listener. The delay is calculated in such a manner that the signals of both loudspeakers arrive at the center of the listener's head at the exact same time (corresponding to the "sweet spot"). Additionally, the amplitudes of the loudspeaker signals are adjusted to reduce the level difference at the listening position. However this only creates a small region of the sweet-spot which is dependent on the position of a single listener.

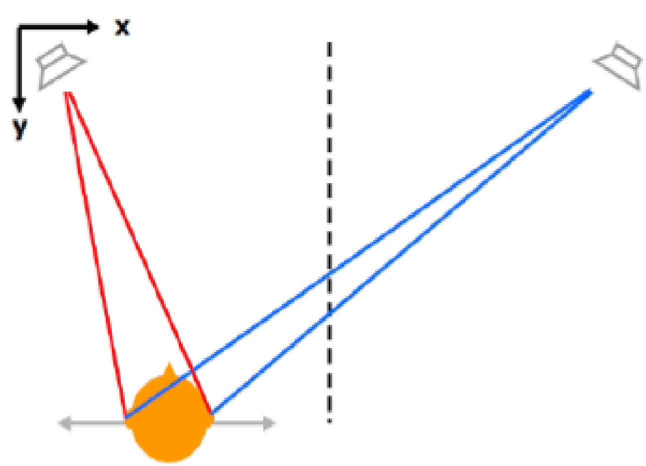


Figure 2: Asymmetric signal paths between loudspeakers and ears for an eccentric listening position.

Additional sound theory and auditorium acoustic were also Studied. [3, 4, 5, 6]

III. ONE SOURCE SYSTEM

A sample room was considered and the dimensions of the room were assumed to be 10m x 10m. The room was divided into a 100x100 grid by setting the grid size of 0.1m in both X and Y. These parameters were used as inputs in the simulation. Two simulations with absorbing (Mur's BC) and reflecting (Dirichlet BC) boundary conditions were done. The total time of simulation was set to be 15 seconds which equates to about 30ms in real time. The speed of propagation of sound was set as 343 ms-1. The Mach number is set to 1. The source was placed in the center of the room and a sinusoidal input wave given from the point source. The wave equation was solved using the numerical approach of Leapfrog Scheme [7] represented below:

$$\frac{u_{i,j}^{n+1} - 2u_{i,j}^{n} + u_{i,j}^{n-1}}{\Delta t^2} = v^2\left(\frac{u_{i+1,j}^{n} - 2u_{i,j}^{n} + u_{i-1,j}^{n}}{\Delta x^2} + \frac{u_{i,j+1}^{n} - 2u_{i,j}^{n} + u_{i,j-1}^{n}}{\Delta y^2}\right)$$

IV. TWO SOURCE SYSTEM

A. Numerical Approach

The dimensions of the room are set to the actual size of a recording room i.e 6.06m x 4.27 m. Rest of the input parameters remain the same as the one source condition. Two simulations with absorbing (Mur's BC) and reflecting (Dirichlet BC) boundary conditions were done. The total time of simulation was set to be 15 seconds which equates to about 17.5 ms in real time. The speed of propagation of sound was set as 343 ms-1. Three cases of point source inputs are assumed –

- Sine Wave
- Square Wave
- Exponentially Decreasing Wave

B. Experimental Approach

A recording studio of 6.06 m x 4.27 m was used for the next stage of the project. The speakers were placed 1.08m apart and at an angle of 600. The room was divided into number of points and a grid pattern was created. The dB levels at each point was measured and tabulated. The schematic of the experimental setup is shown

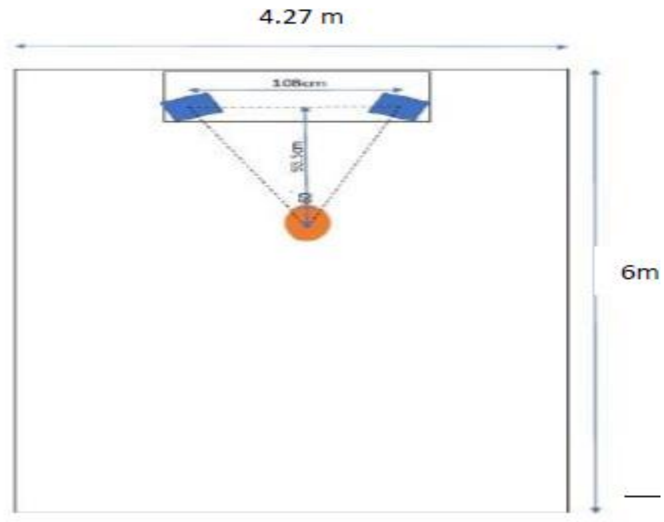


Figure 3: Schematic of the Experimental Setup

V. FOUR SOURCE SYSTEM

A. Numerical Approach

The dimensions of the room are set to the actual size of a recording room i.e. 6.06m x 4.27 m. Rest of the parameters remain the same as the two source condition. Two simulations with absorbing (Mur's BC) and reflecting (Dirichlet BC) boundary conditions were done. Four point sources are used in this study.
Three cases of point source input assumed are –

- Sine Wave
- Exponentially Decreasing Wave
- Square Wave

The main objective of the project is to enlarge the determined sweet spot. The radiation pattern is changed in order to study the behavior of sound wave propagating through the room. Hence two configurations of the sound wave are studied.
The two configurations are-

- X Configuration of sources
- Plus Configuration of sources

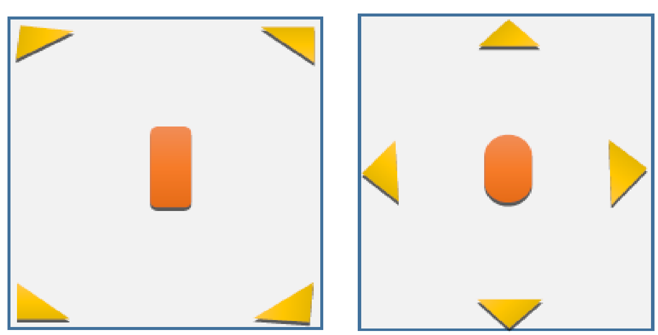


Figure 4: X-Configuration and Plus Configuration

B. Experimental Approach

A recording studio of 6.06 m x 4.27 m was used for the Stage II of our project. The room was divided into number of points and a grid pattern was created.

- The four speakers were placed at the corners of the room (distance from wall) and at an angle of 60_0.
- The four sources were placed at the mid points of the room and at right angles to each other.

The dB levels at each point was measured and tabulated.

C. Experimental Approach

A recording studio of 6.06 m x 4.27 m was used for the Stage II of our project. The room was divided into number of points and a grid pattern was created.

- The four speakers were placed at the corners of the room (distance from wall) and at an angle of 600.
- The four sources were placed at the mid points of the room and at right angles to each other.

The dB levels at each point was measured and tabulated.

VI. SIMULATIONS AND EXPERIMENTAL RESULTS

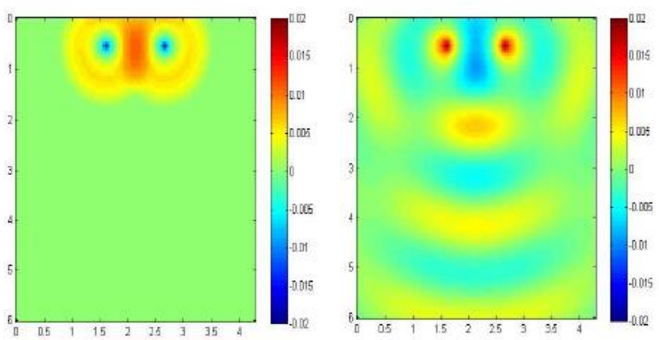
The simulations and experiment were carried out for the above mentioned systems. The plot of particle displacement with position was obtained. The relationship between particle displacement and pressure is given by

$$p = v \times \omega \times \rho \times \delta$$

Where,

- p is the pressure
- v is the velocity of the wave
- ω is the angular velocity of the wave
- ρ is the density of the medium
- δ is the particle displacement

A. Two Source System



T = 1s T=15s

Figure 5: Two Sources

Table 1 Two Sources

Y-distance(m)	X-distance(m)	Decibel Level
1	2.135	83
1	2.935	78
1	3.735	70
1	1.335	76
1	0.535	69
1.8	3.735	71
1.8	2.935	75
1.8	2.135	79
1.8	0.535	70
1.8	1.335	75
2.6	2.135	74
2.6	2.935	72
2.6	3.735	71
2.6	1.335	72
2.6	0.535	70
3.4	2.135	72
3.4	2.935	71
3.4	3.735	70
3.4	1.335	71
3.4	0.535	68

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B. Four Source System- X configuration

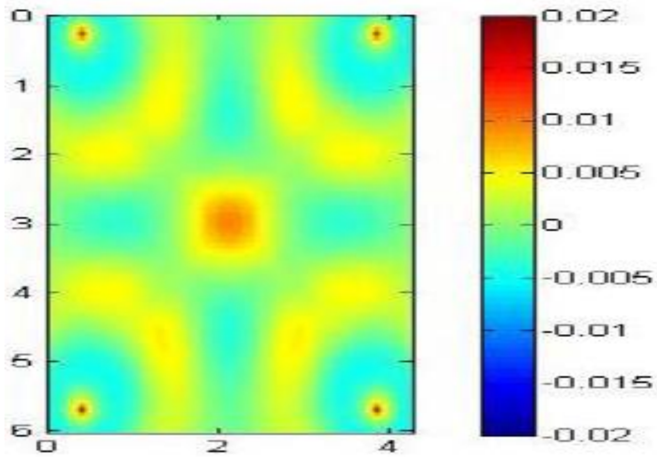

Figure 6: Four Sources X-Configuration

C. Four Source System- Plus configuration

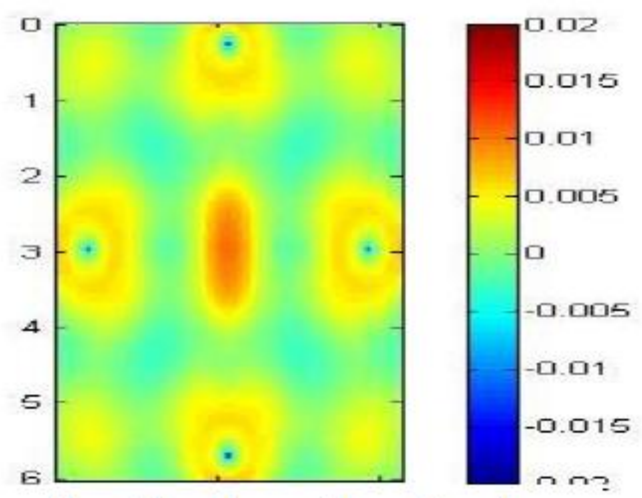

Figure 7: Four Sources Plus-Configuration

VII. CONCLUSION

After an extensive study it was concluded that for a two source system the sweet spot is found to be at the apex of the equilateral triangle when the angle between the speakers have been kept at 60° and we get the maximum constructive interference of the sound wave at this point. The experimental values were found in accordance with simulation. However for a four source system, a satisfactory result was obtained which showed that the plus configuration would be the preferred choice to get a larger area of the sweet spot as compared to the X configuration which has been compared and shown for the Particular acoustic room taken into consideration. The configuration to be used is dependent on the dimensions of the room so as to obtain a large area of sweet spot.

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