National Institute of Information and Communications Technology

3D Sound Field Reproduction Using Directional Microphones

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Content of Talk

- First topic
  - 3D sound field reproduction system using
    - Directional microphones
    - Wave Field Synthesis (WFS) technique
- Second topic
  - 3D sound field reproduction system using
    - Directional microphones
    - Boundary Surface Control (BoSC) technique

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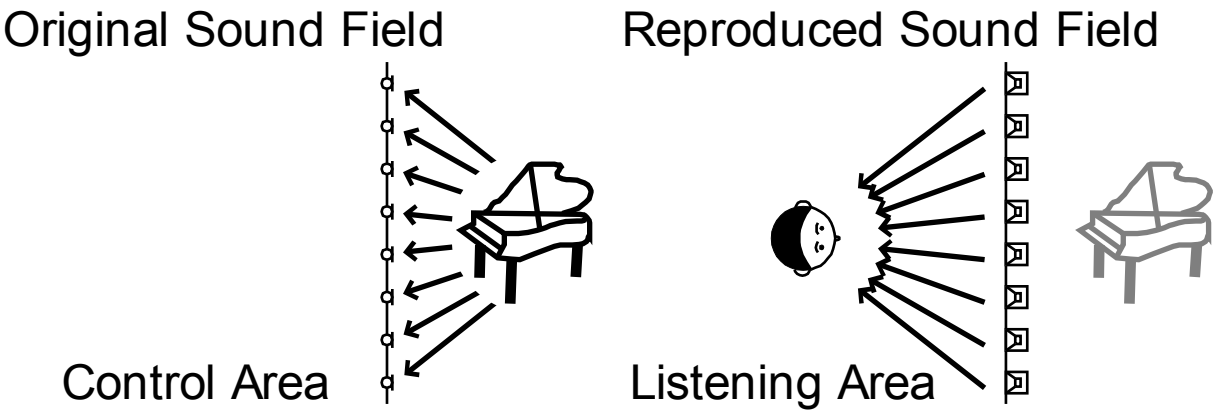
Wave Field Synthesis (WFS) Technique

- Original sound field
  - Sound is recorded by **planar** microphone array
- Reproduced sound field
  - Recorded sound is replayed by **planar** loudspeaker array
  - Wave fronts are accurately reproduced based on Huygens' principle



Problem of Surround System Using WFS

- Original sound field
  - **Surrounded** microphone array is used
- Reproduced sound field
  - Recorded sound comes from all directions
  - Listeners feel the reverberant sound field in spite of a free field
- It needs to use directional microphones

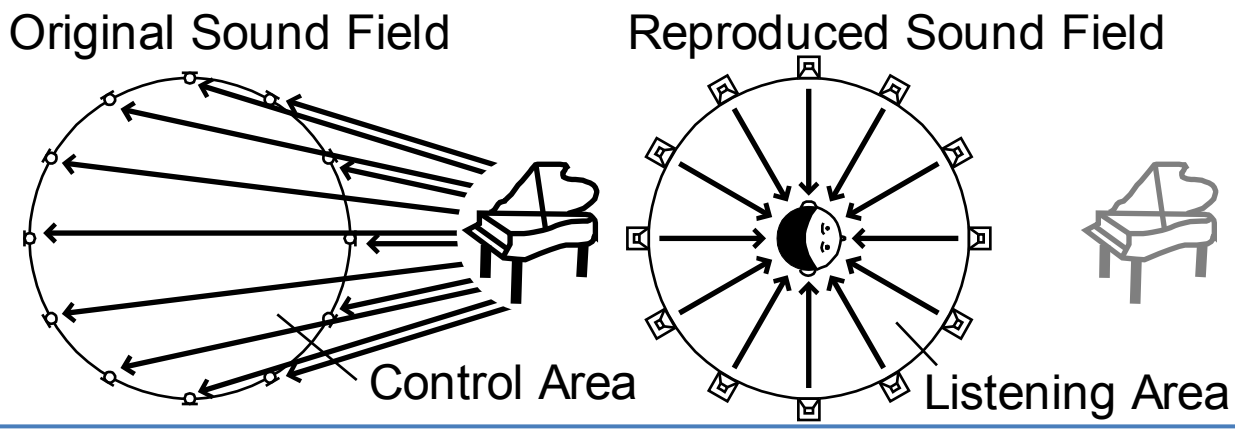


Diagram of Proposed System Using WFS (1)

- Directional microphones are placed and sound is recorded
  - Directional microphones are directed toward the outside of the control area

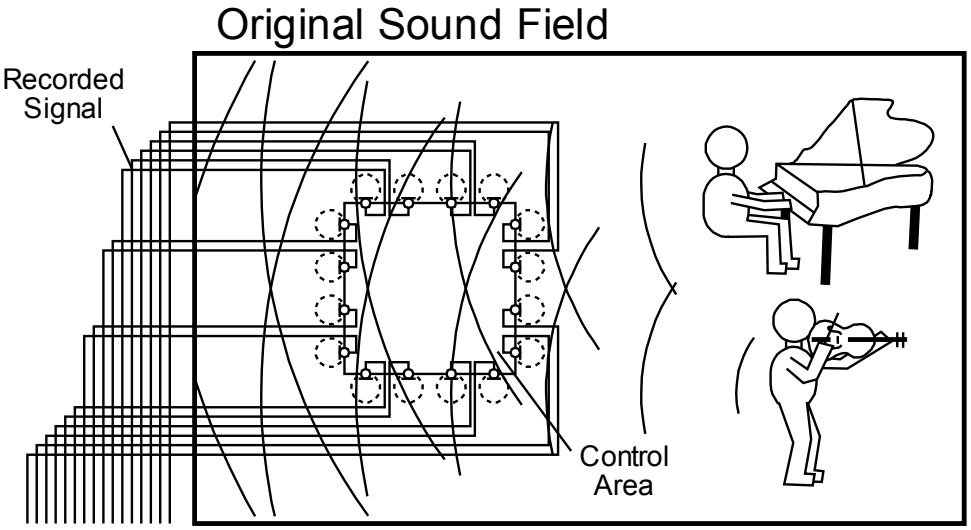
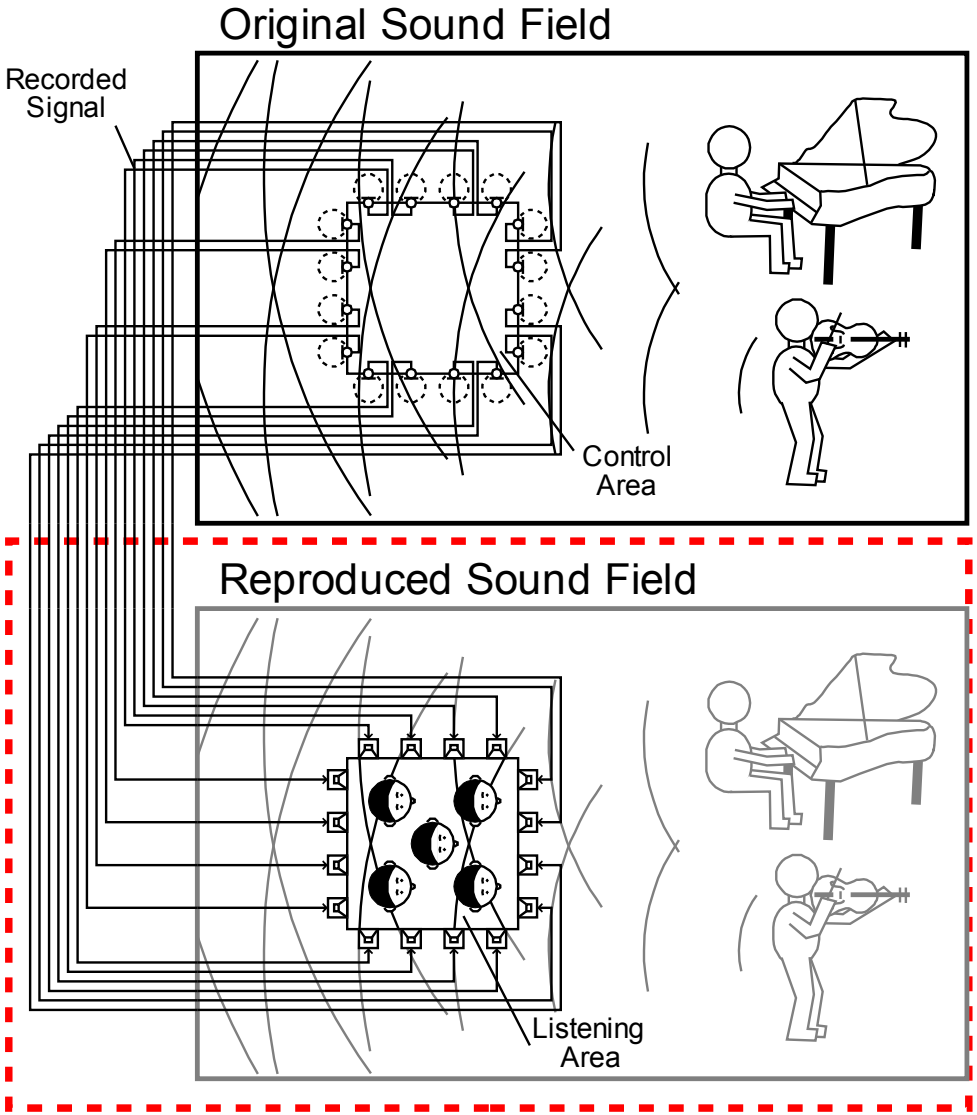


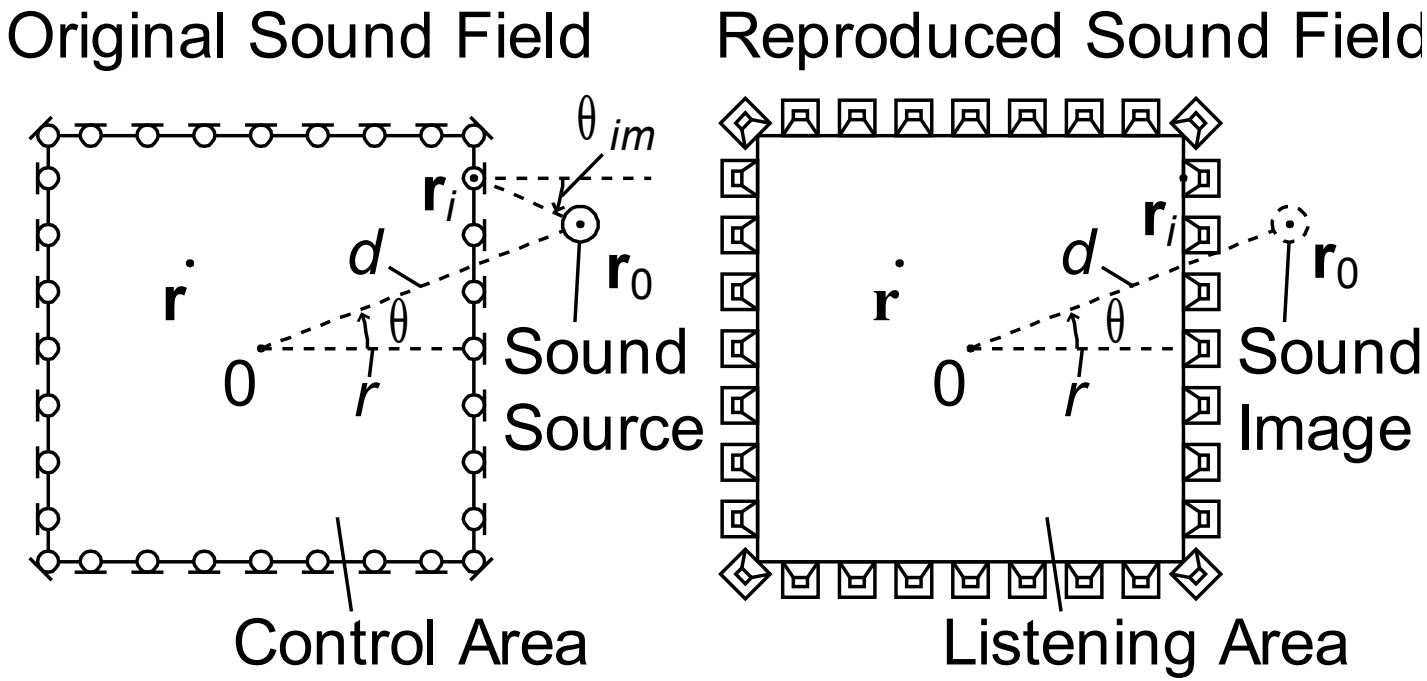
Diagram of Proposed System Using WFS (2)

- Recorded signals are played by loudspeakers
  - The position of loudspeakers are the same as the directional microphones
  - Listeners feel as if they are listening to the sound in the original sound field



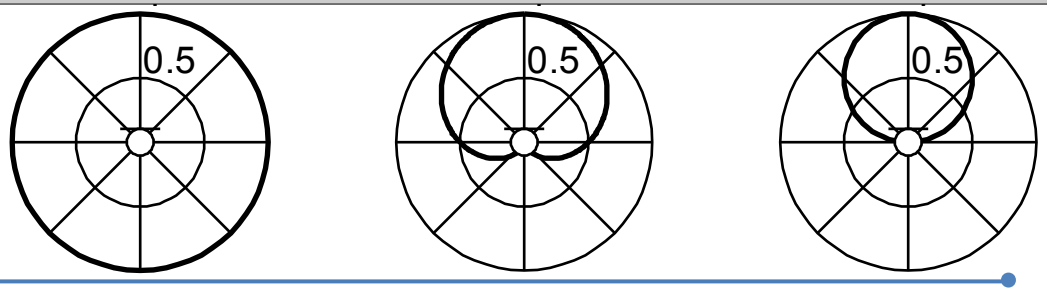
Sound Fields

- **Square** arrays (two-dimension)
- Sound fields: free field
- Directivity of Microphones
  - Toward the outside of control area



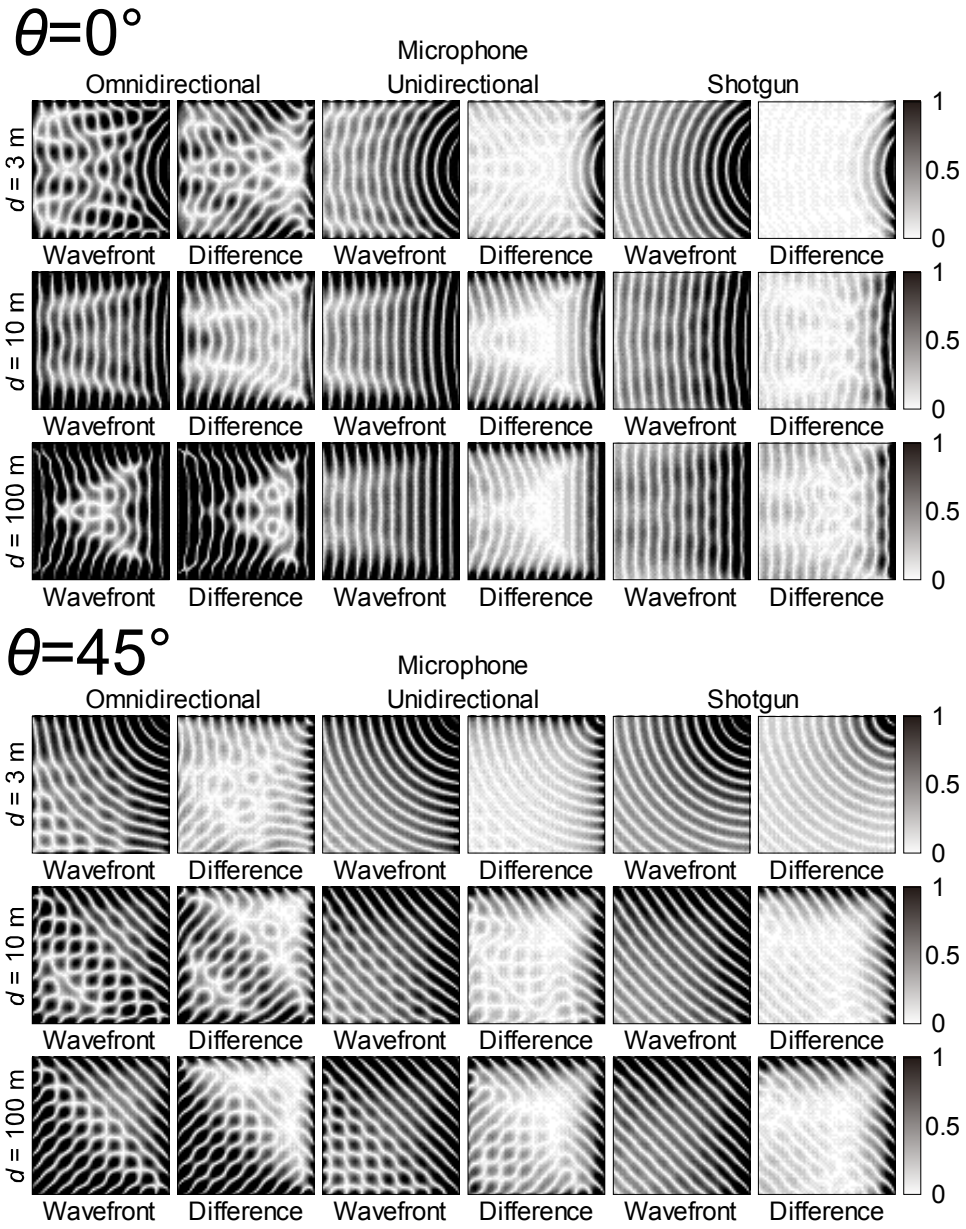
Parametric Condition

Source amplitude (A)	1
Source frequency (f)	125, 177, 250, 354, 500, 707, 1000,1414, 2000, 2828, 4000, 5657, 8000 Hz
Source distance (d)	3, 10, 100 m
Source azimuth (θ)	0, 45°
Sound velocity (c)	340 m/s
Radius of areas (r)	2 m
Microphone number (M)	800
Microphone directivity ($D_m(\mathbf{r}_0\|\mathbf{r}_i)$)	Omnidirectional, Unidirectional, Shotgun



Results of Proposed System Using WFS

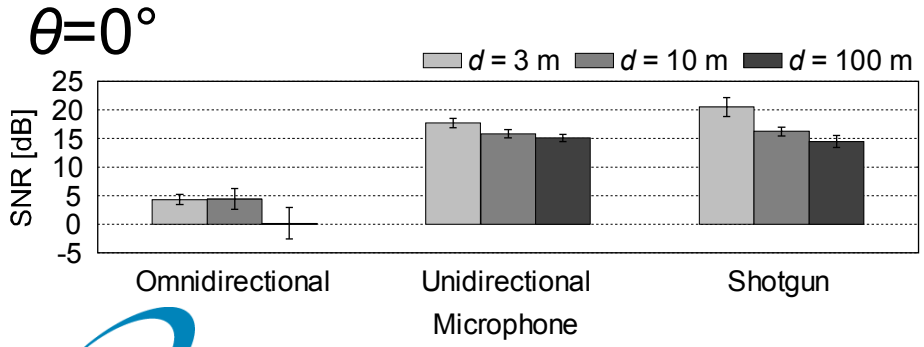
- Omnidirectional microphone
  - Differences are not white
- Unidirectional, shotgun microphone
  - Differences are white
  - Wave fronts are accurately reproduced

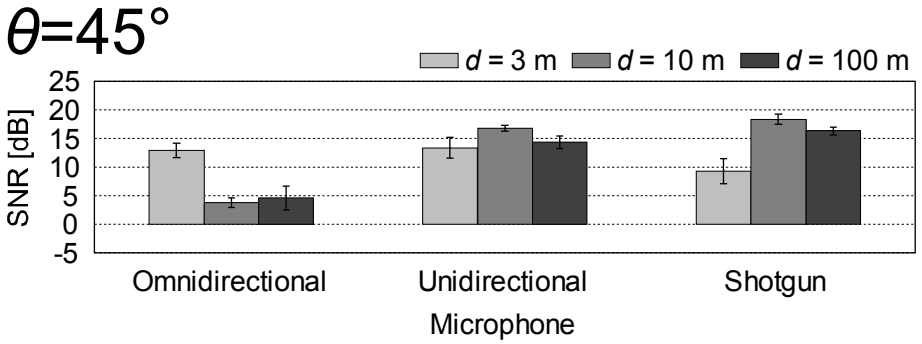


Results of Signal-to-Noise Ratios

$$\mathrm{SNR} = \frac{1}{F}\sum_{f}\left[10\log_{10}\frac{\sum_{\mathbf{r}}\left\{p_0(\mathbf{r},0)\right\}^2}{\sum_{\mathbf{r}}\left\{p(\mathbf{r},0)-p_0(\mathbf{r},0)\right\}^2}\right]$$

- Unifirectional, shotgun microphone
  - Higher than omnidirectional microphone
- Wave fronts can be more accurately reproduced by using unidirectional or shotgun microphones





Content of Talk

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Problem of Proposed System Using WFS

- Display should be placed for A-V system
  - On the surface
    - **Display cannot be placed**
  - Outside the surface
    - **Loudspeakers come into the listeners' field of view**
- It needs to develop another system

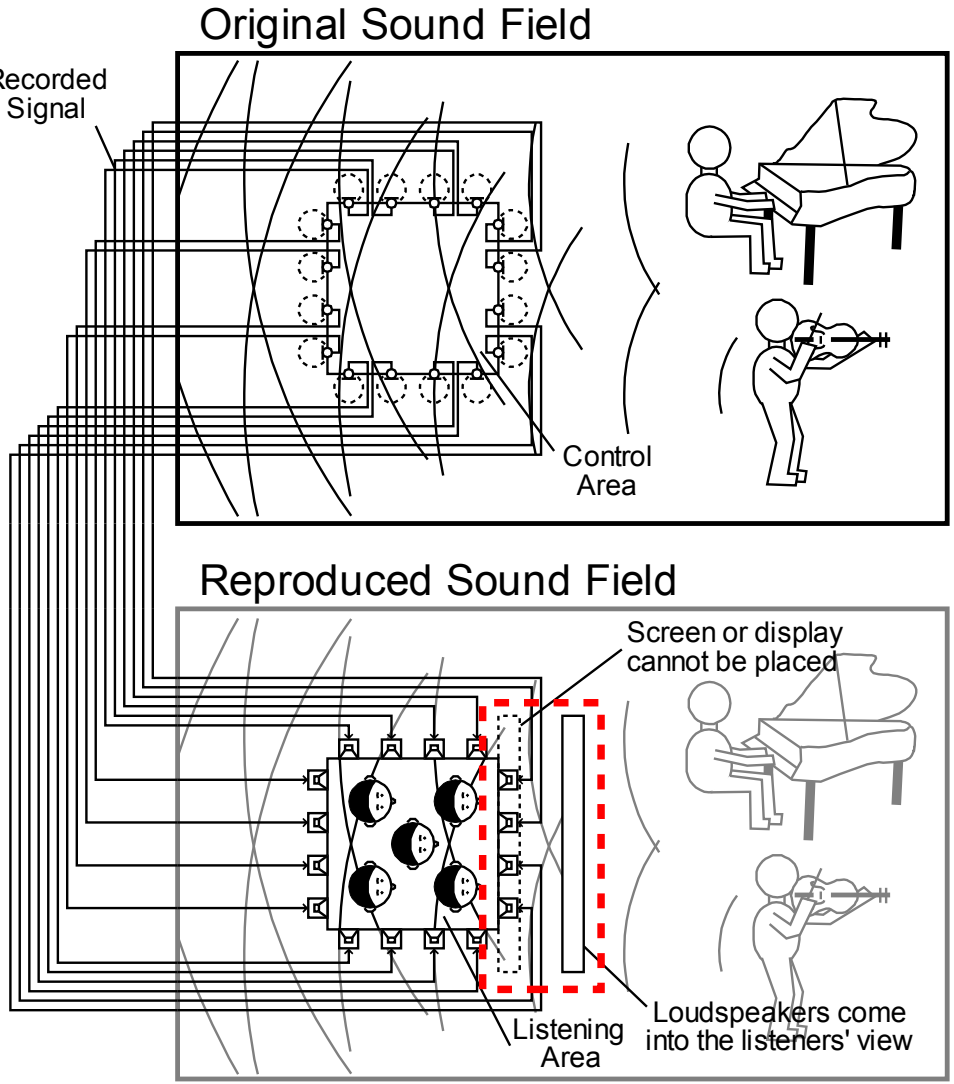


Diagram of Proposed System Using BoSC (1)

- Directional microphones are placed and sound is recorded
  - Directional microphones are directed toward the outside of the control area

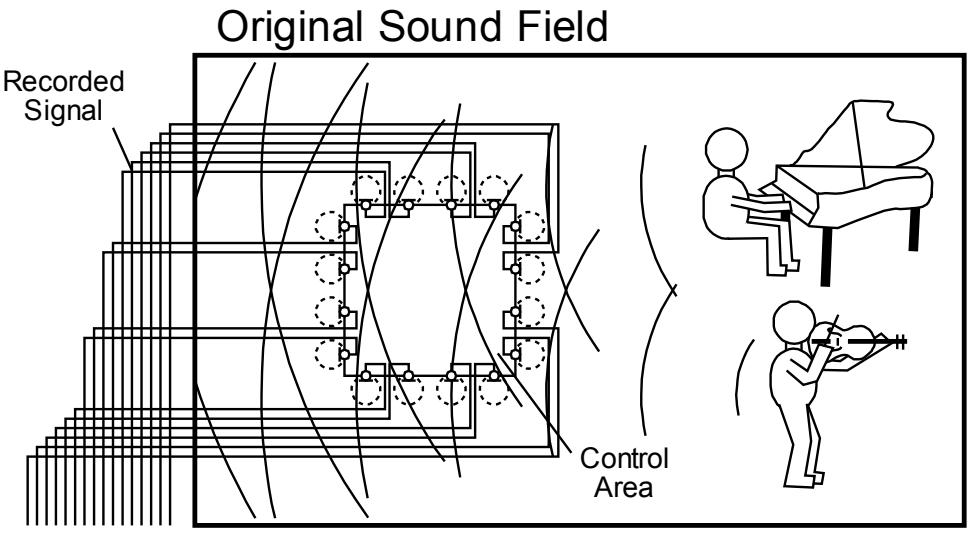


Diagram of Proposed System Using BoSC (2)

- Directional microphones and loudspeakers are placed
  - The position and direction of directional microphones are the same as in the recording
  - Loudspeaker array envelops microphone array

Reproduced Sound Field

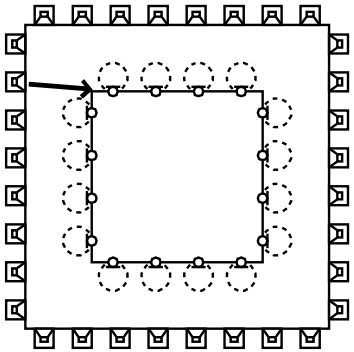


Diagram of Proposed System Using BoSC (3)

- Acoustic transfer functions are measured and the inverse filters are calculated

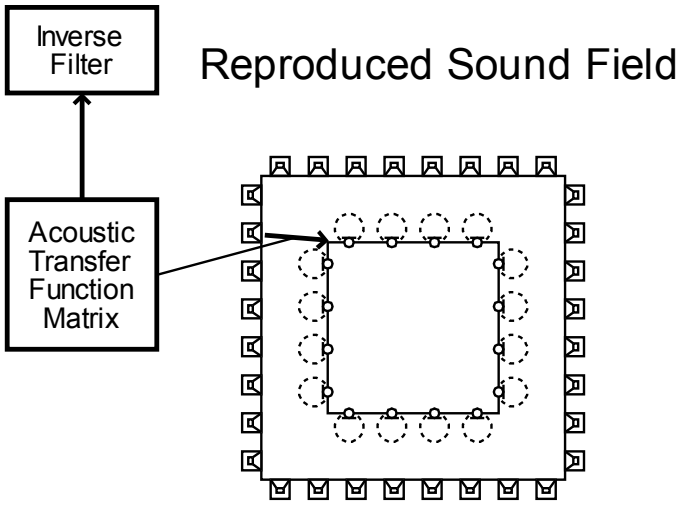


Diagram of Proposed System Using BoSC (4)

- Recorded signals are filtered by the inverse filters, and the filtered signals are played by loudspeakers
  - Listeners feel as if they are listening to the sound in the original sound field

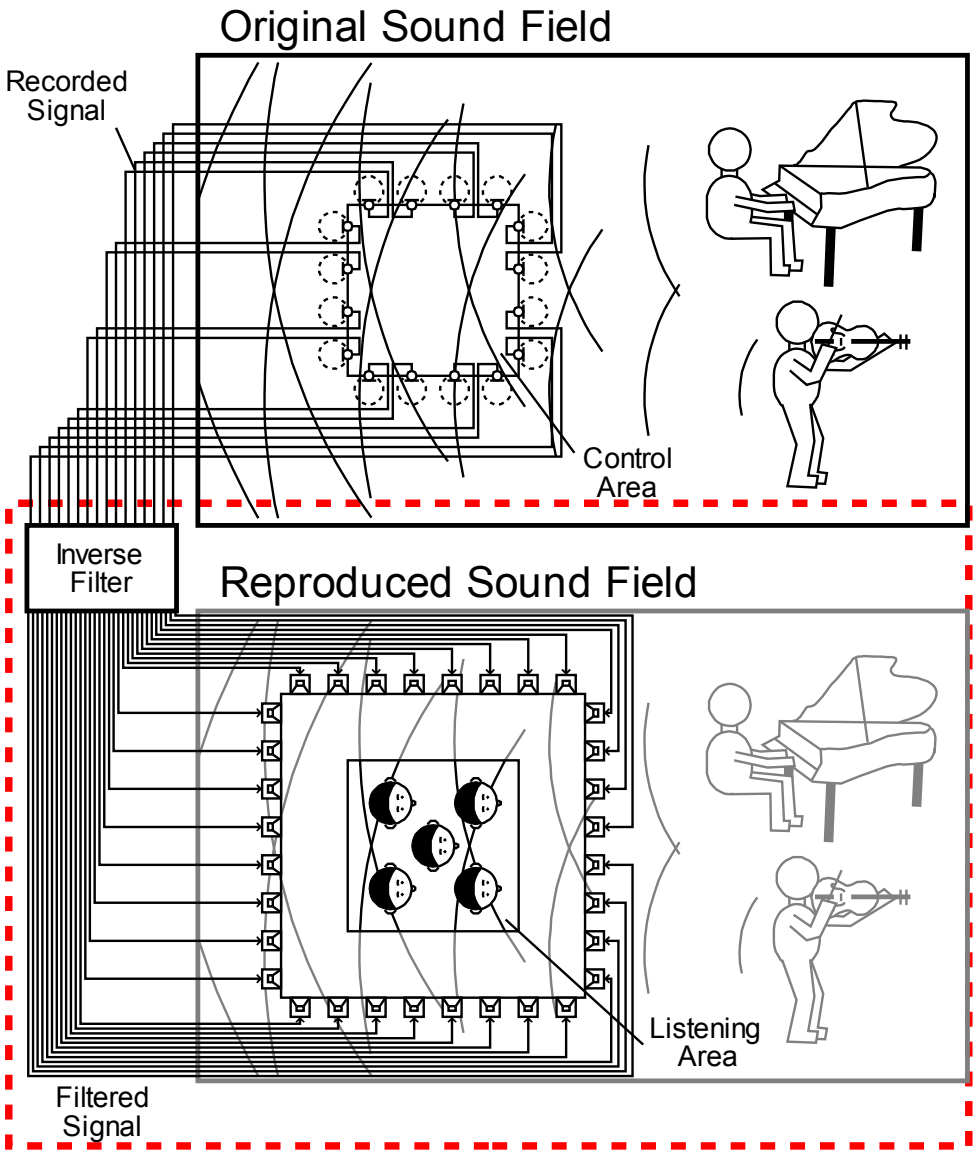
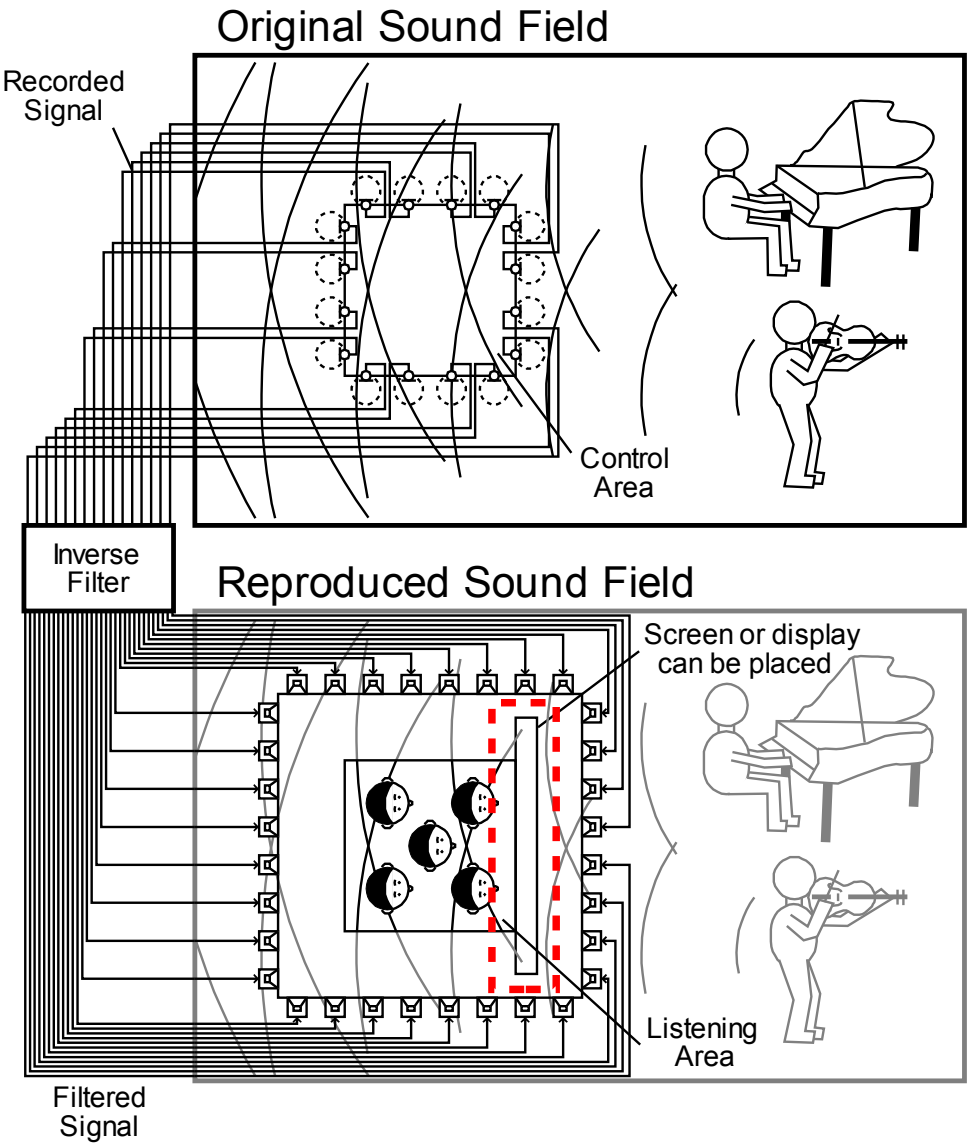


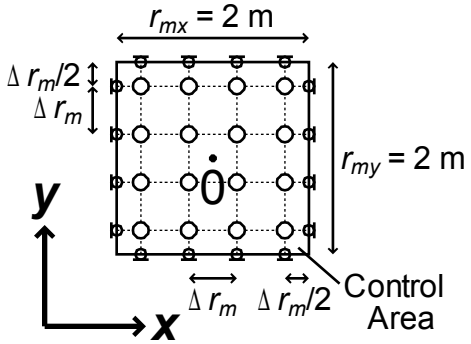
Diagram of Proposed System Using BoSC (5)

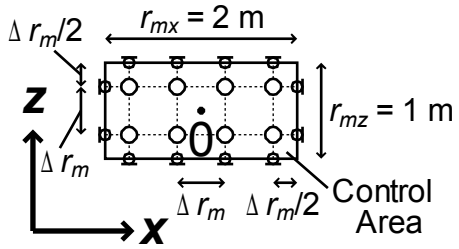
- It is possible to construct an audio-visual system
  - Screen or display of the visual system can be placed on or outside the boundary surface

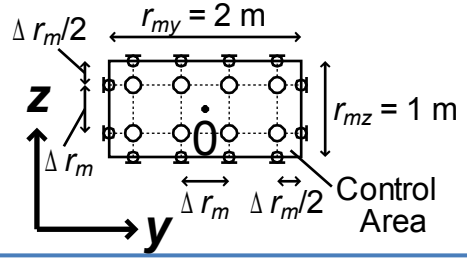


Original Sound Field

- **Square-prism** arrays (three-dimension)
- Control area
  - Size...2 m width, 2 m depth, 1 m height
- Microphone array (placed on 6 planes)
  - Size...2 m width, 2 m depth, 1 m height

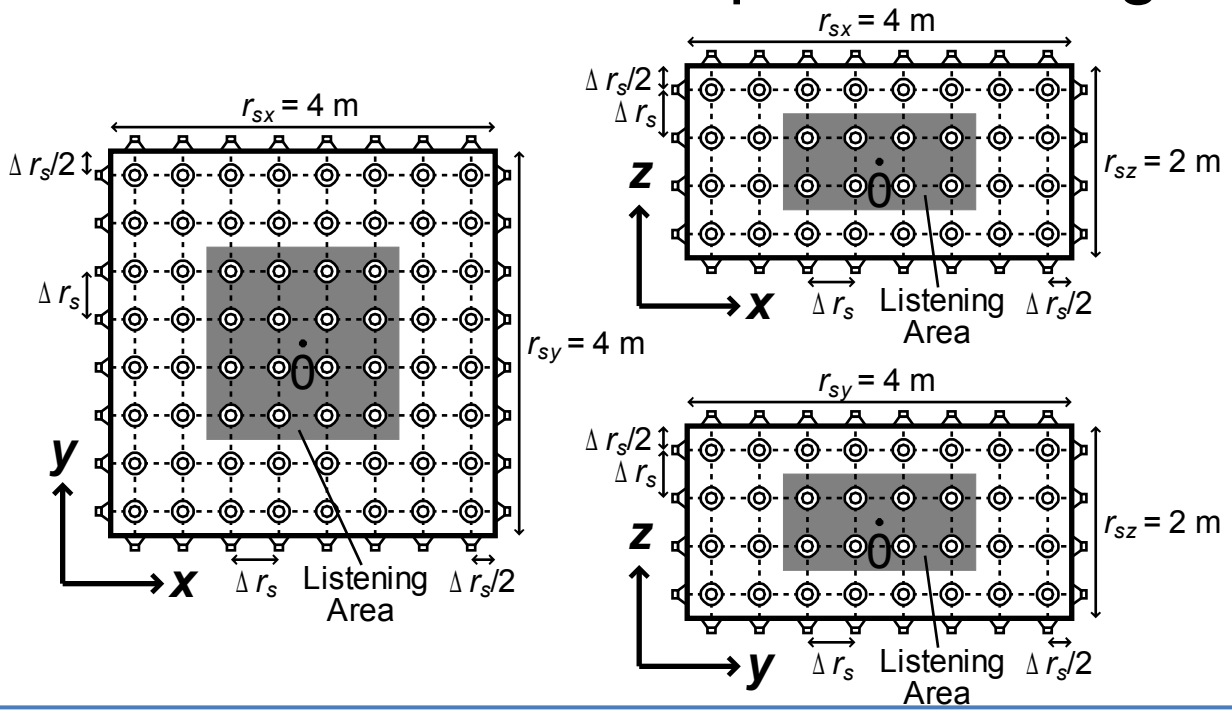






Reproduced Sound Field

- Listening area
  - Same size as control area
  - Size...2 m width, 2 m depth, 1 m height
- Loudspeaker array (placed on 6 planes)
  - Size...4 m width, 4 m depth, 2 m height

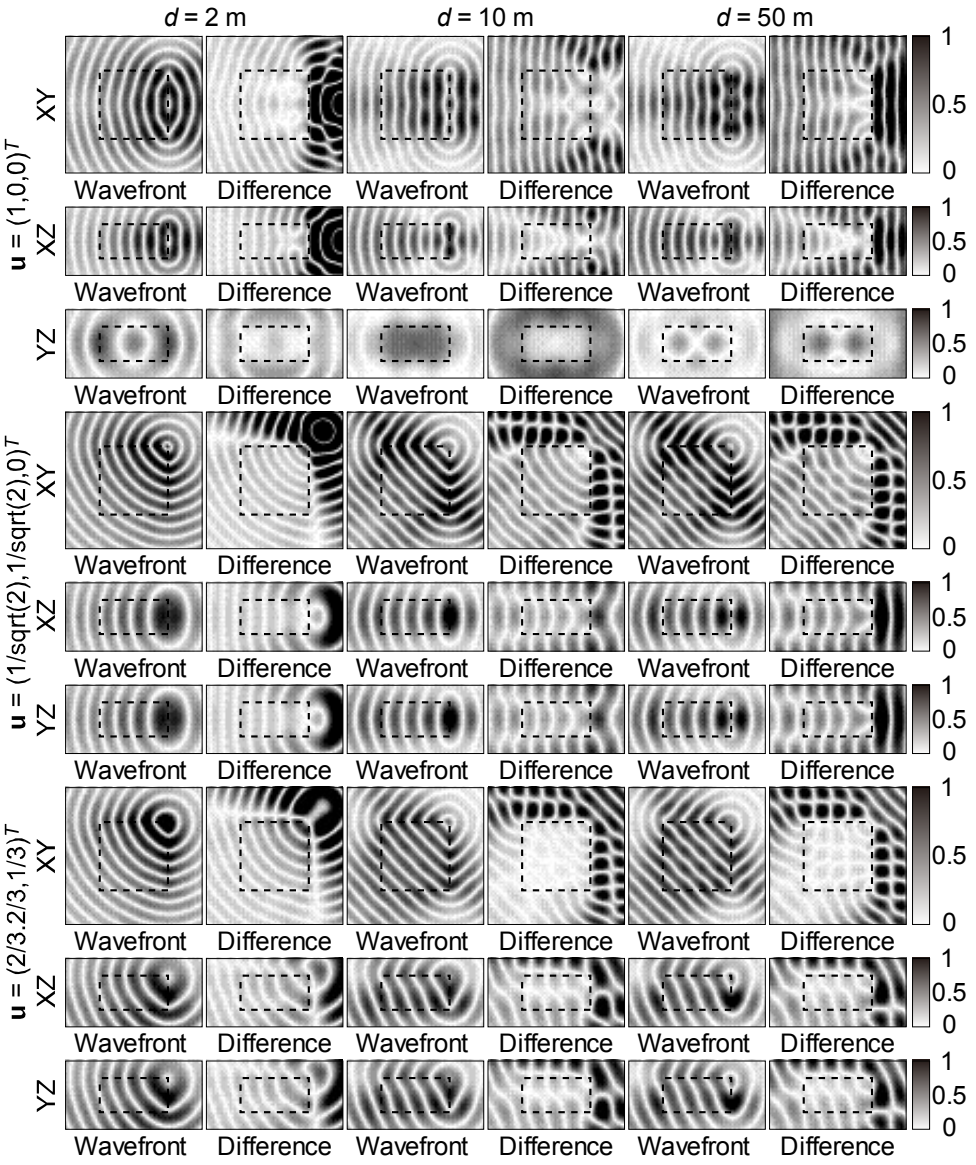


Parametric Condition

Source amplitude (A)	1
Source frequency (f)	63, 125, 250, 500, 1000 Hz
Source distance (d)	2, 10, 50 m
Source direction vector ($\mathbf{u}$)	$(1,0,0)^T (1/\sqrt{2},1/\sqrt{2},0)^T (2/3,2/3,1/3)^T$
Sound velocity (c)	340 m/s
Microphone directivity ($D_m(\mathbf{r}_0 \mid \mathbf{r}_i)$)	Shotgun
Microphone number (M)	576
Microphone interval (Δr_m)	0.1667 m
Loudspeaker number (N)	2304
Loudspeaker interval (Δr_s)	0.1667 m

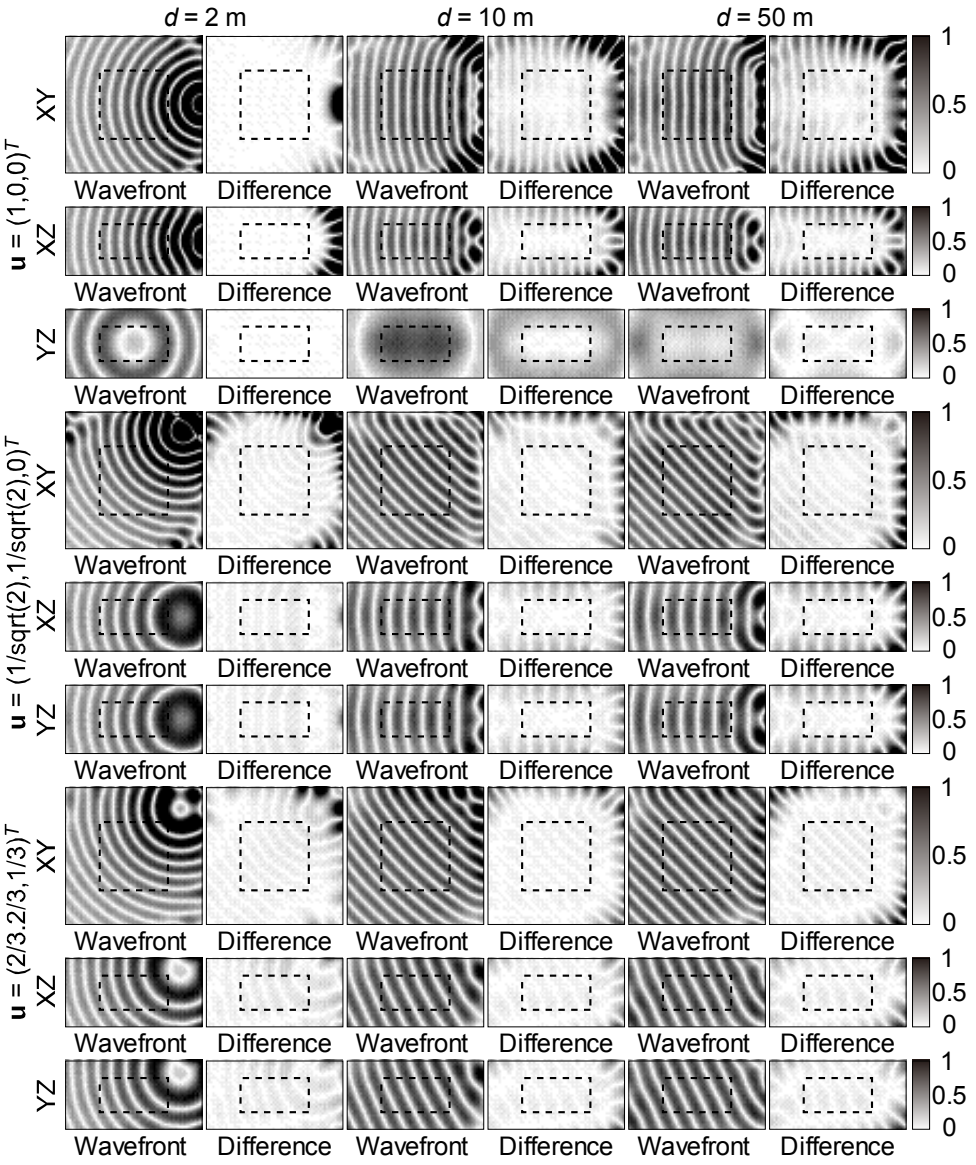
Results of Conventional System Using WFS

- Wave fronts are not accurately reproduced
  - Differences are not white



Results of Proposed System Using BoSC

- Wave fronts are accurately reproduced
  - Differences are white
- Proposed system using BoSC can reproduce more accurate wave fronts than conventional system using WFS

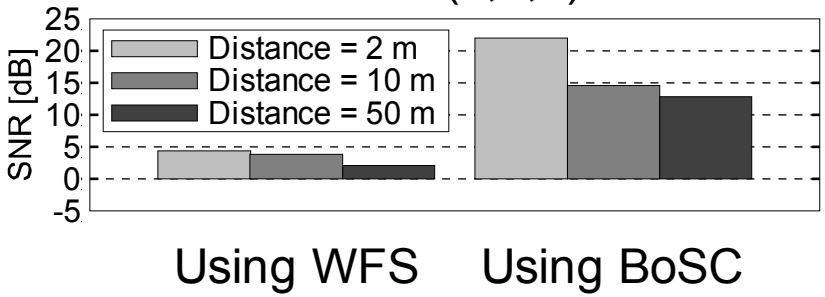


Results of Signal-to-Noise Ratios

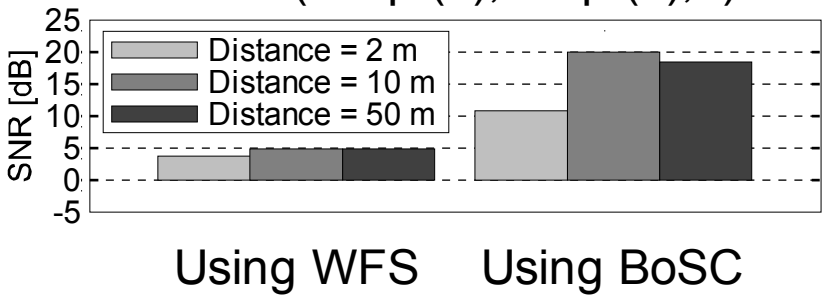
$$\mathrm{SNR} = 10\log_{10}\frac{\sum_f \sum_{\mathbf{r}} \left\{ p_o(\mathbf{r},0) \right\}^2}{\sum_f \sum_{\mathbf{r}} \left\{ p(\mathbf{r},0) - p_o(\mathbf{r},0) \right\}^2}$$

- Conventional system using WFS
  - Lesser than 5 dB
- Proposed system using BoSC
  - Greater than 10 dB
- System using BoSC can reproduce more accurate wave fronts

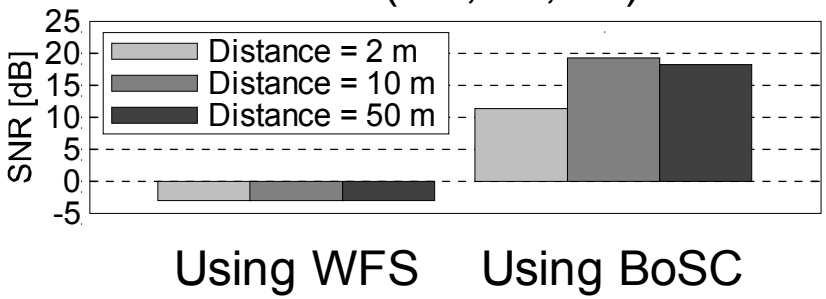
u = $(1,0,0)^T$



u = $(1/\sqrt{2},1/\sqrt{2},0)^T$



u = $(2/3,2/3,1/3)^T$



Conclusion

- 3D sound field reproduction system using directional microphones and Wave Field Synthesis (WFS) technique
  - Sound field can be accurately reproduced by using directional microphones
- 3D sound field reproduction system using directional microphones and Boundary Surface Control (BoSC) technique
  - Sound field can be accurately reproduced even if loudspeakers were not placed on the boundary surface