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ASSESSMENT OF SPATIAL RESOLUTION OF DIRECTIONAL MICROPHONES

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1. RESOLUTION OF MICROPHONES AND QUANTIZING OF THE SPACE

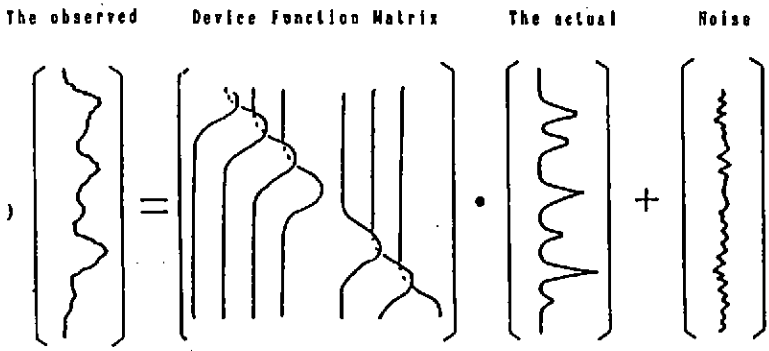
In general, the directivity stands for the directional characteristics of a microphone, but does not work enough, for example, to make difference in the direction of reflective sounds in acoustic measuring of auditorium. The resolution of a microphone which is defined as the characteristics of separating ability of 2 points sound sources in a spatial distance(or, simplified, with a horizontal angle) should be suitable for it. However there is no concepts to present resolution of microphones yet. A possible answer is "sampling and quantizing" of the space, in which each sound in a space is treated as a point source in a discrete direction. Let us make sampling a space, for example horizontal plane for simplified. The space direction is divided into N direction like as n1, n2, n3, , , , N in the order from the front direction. Therefore the sound distribution in a space is shown by the sample point sources like as a1 digit level impulse at n1, a2 digit level impulse at n2 and so on. That is, the sound distribution can be replaced by the digital responses which consist of each space impulse at digital direction.
Applying digital technique into the space problem, you might take great advantages just as the same as in the time domain one which digital technologies are successfully used. One example, in which digital technique into the study finding the relation between resolution and directivity of microphones is shown as following.

2. HOW TO MAKE DIFFERENCE TOW POINT SOURCES IN A SPACE

Remind a case of measuring the directivity of a microphone. At first, A point source locates at a direction and a microphone distant from the point source rotates horizontally. The characteristics of the microphone responses vs. directions show the directivity as you know. In digital space, a point source is regarded as a space impulse(sampled value of sound), so that the directivity shows a space impulse response with a sequence length of N.
At second, set microphone in the target sound field, take the responses in each digit direction. A measured total response means the result of convolutional operation between the microphone's space impulse response and the actual space impulses. Refer the pictorial presentation(EQ1) to show convolution operation, and the matrix equation(EQ2) for convolution is easily understood.
At third, to find actual space impulses(i.e., digital sound source), you should make deconvolution of a total response with measured values using microphone's impulse response, which is shown by matrix equation(EQ3). Another simple method of deconvolution is done by the transfer of the domain. Convolution in the

ASSESSMENT OF MICROPHONES

(E Q 1)



(E Q 2)

$$\underset{\text{The observed}}{\begin{vmatrix} x_0 \\ x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{n-1} \end{vmatrix}} = \underset{\text{Space Impulse Matrix of a Microphone}}{\begin{vmatrix} a_0 & a_{n-1} & a_{n-2} & \cdots & a_1 \\ a_1 & a_0 & a_{n-1} & \cdots & a_2 \\ a_2 & a_1 & a_0 & \cdots & a_3 \\ & \cdot & & & \\ & & \cdot & & \\ & & & \cdot & \\ a_{n-1} & a_{n-2} & a_{n-3} & \cdots & a_0 \end{vmatrix}} \cdot \underset{\text{Actual Space Impulses}}{\begin{vmatrix} e_0 \\ e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_{n-1} \end{vmatrix}}$$

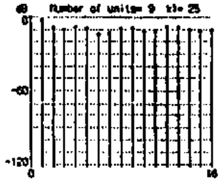
(E Q 3)

$$\underset{\text{Actual Space Impulses}}{\begin{vmatrix} e_0 \\ e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_{n-1} \end{vmatrix}} = \begin{vmatrix} a_0 & a_{n-1} & a_{n-2} & \cdots & a_1 \\ a_1 & a_0 & a_{n-1} & \cdots & a_2 \\ a_2 & a_1 & a_0 & \cdots & a_3 \\ & \cdot & & & \\ & & \cdot & & \\ & & & \cdot & \\ a_{n-1} & a_{n-2} & a_{n-3} & \cdots & a_0 \end{vmatrix}^{-1} \cdot \underset{\text{The observed}}{\begin{vmatrix} x_0 \\ x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{n-1} \end{vmatrix}}$$

Convolution and Deconvolution Operation

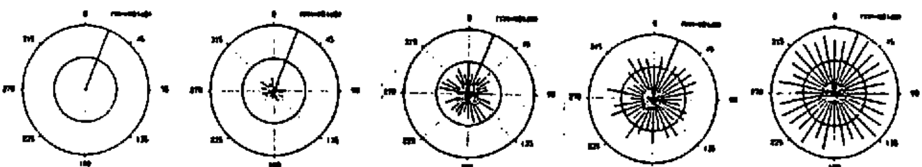
(c)Estimated point sources by line array type

(1)Space Spectrum (kl=25)



(2)Effects by noise level

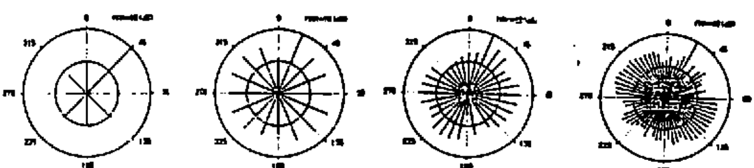
Sampling N=32, added noise from 0 dB to -80 dB



(a) -80dB (b) -60dB (c) -40dB (d) -20dB (e) 0dB

(3) Effects of Sampling N

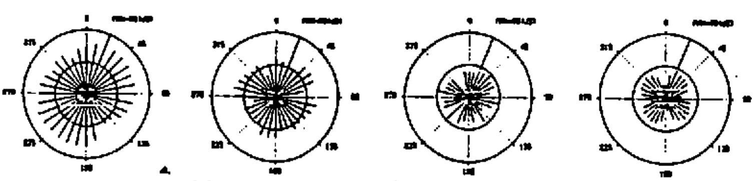
Added noise -40 dB, from N=8 to N=64



(a)n=8 (b)n=16 (c)n=32 (d)n=64

(4)Effects of Directivity(due to Various kl)

Added noise =-40 dB, from kl=5 to kl=53



(a)kl=5 (b)kl=11 (c)kl=25 (d)kl=53

6. SPACE SPECTRUM OF MICROPHONE AND SPACE SAMPLING NUMBER

Above simulations suggests that there could be a relation between the minimum value of space spectrum of the microphone's impulse response and maximum level of noises(ghost point sources) occurring at other digital directions.

sequence domain is done by division in the frequency domain, that is, spectral division. Get back to the resolution task. Like as time domain, if you want to find the fine distribution of sound, sampling number N might be increased. Is it true in case of microphones ?

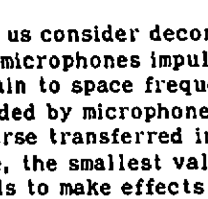
3. RESOLUTION OF MICROPHONES

Let us consider deconvolution further more. The total space response measured and microphones impulse response are transferred from the directional sequence domain to space frequency domain by FFT and the total response spectrum is divided by microphone's impulse response spectrum and again the result is inverse transferred into sequence domain to actual digital sound source. In this case, the smallest value of spectrum of microphone's space impulse response tends to make effects on the accuracy of mathematical operation. So if a value of microphone's spectrum gets smaller when N gets large, you realize that the characteristics of microphone's spatial spectrum(derived from the directivity) is a major factor affecting microphone's resolution accuracy.

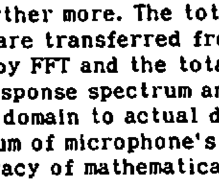
4. SPACE IMPULSE RESPONSE AND SPACE SPECTRUM

Assume that a point source on a circumstance of a microphone radiate impulsive sound at once N times and the microphone locate for digital direction step by step to pick up the impulse. Measured and calculated response and spectrum of some kind of microphones are shown.

(a)Uni-directional MIC(measured)

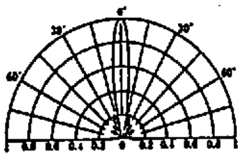


Impulse Response

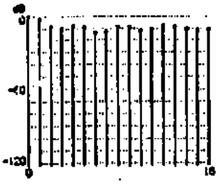


Space Spectrum

(b)Array MIC(calculated)

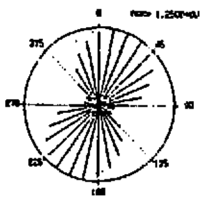


Impulse Response

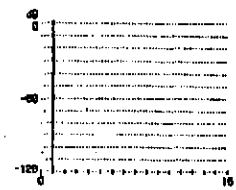


Space Spectrum

(c)Dipole MIC(calculated)



Impulse Response

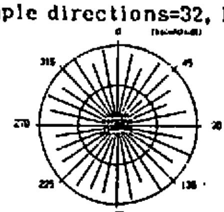


Space Spectrum

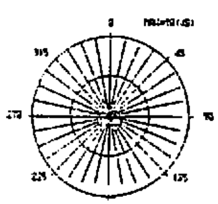
5. RESOLUTION LIMIT OF MICROPHONE

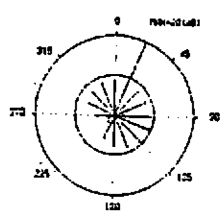
The resolutions of several microphones in deconvolution method are evaluated by simulation. A level(for example, S/N=-80, or -120 dB) of noise is added to each response for each digital direction at random. The estimated point source as the results of deconvolution are affected slightly or severely depending upon the type of microphones and sampling N.

(a)Estimated Point sources by Dipole type
Sample directions=32, Noise=-80dB

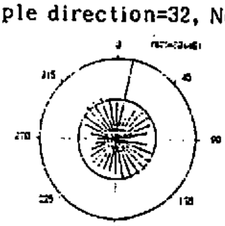


(b)Estimated point sources by Cardioid type
Sample directions=32, Noise=-80dB Sample directions=16, Noise=-80dB



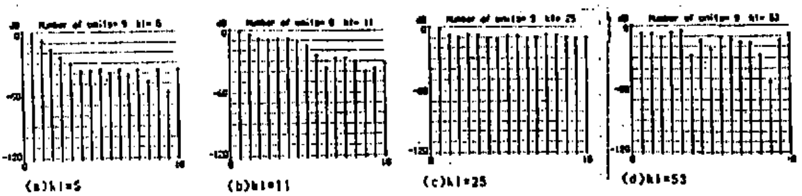


Sample direction=32, Noise=-120dB



(a)Half Value Band and Maximum Space Sampling Number Half value band(radian) at the sharpest peak of the directivity pattern of a microphone is measured for various kl. The limit sampling number is determined as the line number of the space spectrum which reaches -40 dB at first from 0 line. so called "-40 dB line number(LN[-40])".

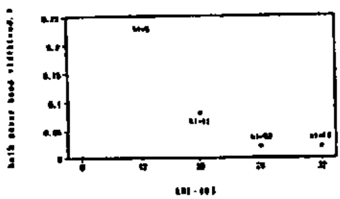
(a)Space spectrum in various kl
9 units linear array microphone, from kl=5 to kl=64,
space sampling N=32



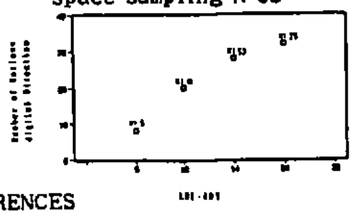
(b)Resolution and -40 dB Line Number(LN[-40])

Resolution is replaced by 2π/Nmax in which Nmax is the maximum space sampling number in keeping the ghost level within -40 dB from the target point source. So the value of Nmax shows the level of the resolution.

(1) Resolution versus LN[-40]
9 units linear array microphone, from kl=5 to kl=64,
space sampling N=32



(2) Maximum space sampling number versus NL[-40]
9 units linear array microphone, from kl=5 to kl=64,
space sampling N=32



7. REFERENCES

[1]K.Miura,A.Isogai,T.Gotoh,"An idea in qualification of directivity of microphones"(JPN),IEICE EA90-37 (1990)

[2]A.Isogai,K.Masuda,T.Gotoh,"Space deconvolution for determining the digital direction of the sound sources"(JPN),Report of ASJ,p427(Mar.1990)