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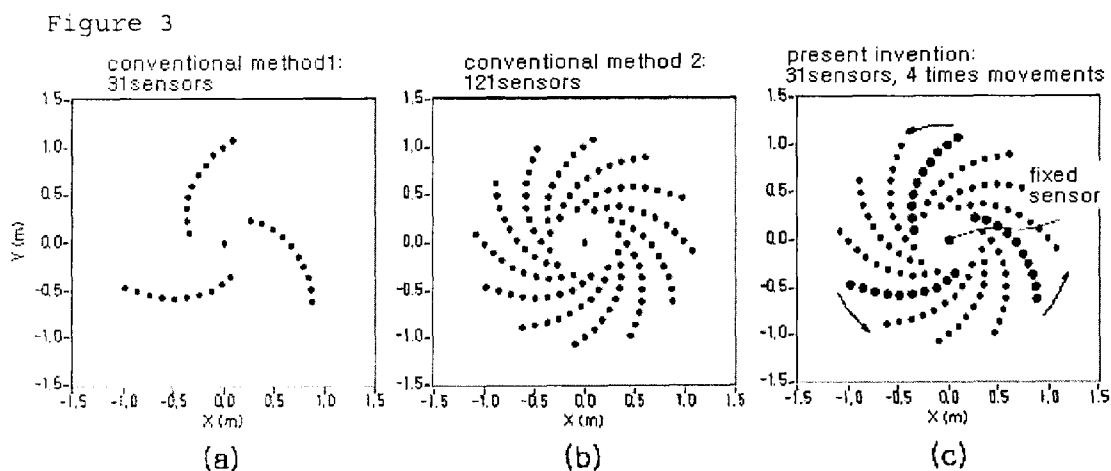
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(57) Abstract: Disclosed is an enhanced sound source localization technique, which can overcome a limitation of a conventional beamforming method using a fixed microphone array by applying a movable microphone array and an analytic algorithm related to the movable microphone array. An object of the present invention is to provide an enhanced sound source localization system and method by using a movable microphone array, wherein a sound source is measured by moving a limited number of microphones, and a signal processing method capable of synchronizing the microphones, so that measurement accuracy can be improved. According to the present invention, a sound source is measured by moving a limited number of microphones, the number of sensors required to evaluate measured values in a range of desired measurement accuracy can be considerably decreased, and therefore, measuring cost can be remarkably saved.

【DESCRIPTION】**【Invention Title】**

ENHANCED SOUND SOURCE LOCALIZATION SYSTEM AND METHOD BY
USING A MOVABLE MICROPHONE ARRAY

【Technical Field】

The present invention relates to an enhanced sound source localization system and method by using a movable microphone array.

Sound characteristics of various products, such as automobiles and electric home appliances, are recognized as main performance indicators. From this reason, efforts for more quiet products continuously made from the beginning of their development stage. For the noise reduction of product, a method is generally used as follow. In first, it is found where sound is generated from and what cause of that sound. And then, through the design change of product, low noise product can be developed. To this end, a measuring method for localizing a sound source is primarily required.

Currently, there are two available source localizing method, one is a sound intensity measuring method using an intensity probe and the other is a sound source localization method using a microphone array beamforming method. Fig. 1 illustrates examples of a microphone array measuring method

applied to various types of research and development. In the microphone array method which has recently been developed, several microphones are used for measuring sensors, and the power distribution of a sound source in a space is calculated through the signal processing using a phase difference of measured signal based on distances between a sound source and the measuring sensors. Then, from the distribution map, the location of maximum strength of power can be accepted as a sound source location. In this microphone array method, the measurement accuracy depends on the number of sensors in used. It is known that larger number of sensors give more accurate results.

【Background Art】

In a conventional microphone array beamforming method, the procedure of sound source localization is as follows.

1) Sound waves $u(t)$ generated from a sound source are measured using a plurality of microphones. Then, a cross spectrum matrix having cross spectra A_{ij} between i -th and j -th microphones, defined by the following Equation 1, is calculated using a frequency analysis. At this time, an ensemble average is taken to improve measurement accuracy. The ensemble averaged cross spectrum matrix is referred to as $\langle A \rangle$.

$$A_{ij} = \frac{1}{T} \int_0^T u_i(t) u_j^*(t) dt$$

2) A steering vector which can be defined differently depending on wave propagation characteristics is used to apply the microphone array beamforming method. The steering vector
 5 is calculated from positions of a sound source and measuring sensors. In the case of sound source which has square wave propagation characteristics, the steering vector between m -th sound source and n -th measuring sensor is defined by the following Equation 2. The matrix having steering vectors of
 10 all the sensors from the m -th sound source, calculated as described above, is designated by a steering vector matrix $\vec{C}_m$.

$$C_{nm} = \alpha \frac{e^{jk_0 r_{nm}}}{r_{nm}}$$

Where, $\alpha = \frac{1}{\sqrt{\sum_{n=1}^N r_{nm}^2}}$, $k_0 = 2\pi f/c$, and r_{nm} denotes a distance

15 from the m -th sound source to the n -th sound source.

3) Using the cross spectra and steering vector matrix obtained through measurement, the beam power map that means the intensity distribution of a sound source in a space can be evaluated as follows. A beam power b_m at the m -th sound source
 20 can be calculated by the following Equation 3.

$$b_m = \vec{C}_m^H \langle A \rangle \vec{C}_m$$

At this time, $\overline{C_m}^*$ is a Hermitian conjugate. Accordingly, in order to calculate the beam power map, a grid of virtual sound source is determined at an expected location of that sound source, and beam powers at each grid point are calculated. Then, the calculated beam powers are shown in a space, thereby obtaining a beam power map.

The measurement accuracy in a microphone array measuring system is depending on the number and relative location of sensors in used. It can be quantitatively evaluated by a beam width and a side-lobe rejection, which are defined as follows. When a single sound source exists in a space, a beam power map can be obtained by the arrangement of microphones used in measurement as shown in Fig. 2. At this time, a beam width is defined by a width of a beam in the space at a point corresponding to a level of -3dB from a main lobe corresponding to the position of the sound source. A side-lobe rejection is defined by a level difference between side and main lobes, shown in a position at which the sound source does not exist. Therefore, accurate measurement system requires narrow beam width and high side-lobe rejection capability. Fig. 2 illustrates an accuracy difference in a microphone array measuring system depending on the number of sensors used. 31 sensors are used in Fig. 2(a), and 121 sensors are used in Fig. 2(b). As shown in Fig. 2, it can be

seen that the performance is improved as the number of sensors used is increased.

The reason why a large number of sensors are required in the conventional method is that if the numbers of signal measured at different position is increased, the noise signal is attenuated more by summing up the measured signals, and therefore, performance is improved. Sound signals at different location can be measured by moving microphone array with a small number of sensors. However, in the beamforming method, a beam power map requires simultaneously measured signals from all the sensors being used. This is because a phase difference between the respective measured signals, i.e., a difference of times at which a sound signal reaches the respective sensors, is applied to the beamforming method.

Accordingly, in a measuring method using the conventional beamforming method, only the number of sensors is increased to improve its performance. Since the price of measuring sensors and data obtaining devices is very high, there is limitation in increasing the number of sensors. Therefore, it has been continuously required by those skilled in the art to develop a measuring method capable of improving measuring performance and saving costs.

[Disclosure]

【Technical Problem】

An object of the present invention is to provide an enhanced sound source localization system and method by using a movable microphone array, wherein a sound source is measured
5 by moving a limited number of microphones, and a signal processing method capable of synchronizing the microphones, so that measurement accuracy can be improved. More specifically, the present invention provides an enhanced sound source localization system and method by using a movable microphone
10 array, wherein one fixed sensor is used, and sound data is obtained at a larger number of measuring points by allowing the other sensors to be moved, so that independently measured signals can be corrected as simultaneously measured signals by applying a synchronizing method using a signal of the fixed
15 sensor.

【Technical Solution】

According to an aspect of the present invention, there is provided an enhanced sound source localization system by using
20 a microphone array beamforming method, which includes: a fixed sensor measuring a sound at a fixed point; a plurality of movable sensors spaced apart from the fixed sensor at a predetermined distance to measure the sound at a plurality of measuring points while moving along a predetermined path about

the fixed sensor; and an analyzer receiving sound data measured from the fixed sensor and the movable sensors to perform data analysis, wherein a measured result is obtained by synchronizing the sound data measured from the plurality of movable sensors with the sound data measured from the fixed sensor.

According to another aspect of the present invention, there is provided an enhanced sound source localization method by using the aforementioned sound source localization system, which includes the steps of: a) the analyzer obtaining an ensemble averaged cross spectrum matrix by using sound data measured from the one fixed sensor and the plurality of movable sensors; b) the analyzer repeating a predetermined times (K) an operation of moving the movable sensors to new positions, re-measuring sound data and obtaining an ensemble averaged cross spectrum matrix ($\langle A_{i,j,k} \rangle$) using the sound data; c) the analyzer correcting a difference of phases in the ensemble averaged cross spectrum matrix ($\langle A_{i,j,k} \rangle$), thereby obtaining a synchronized cross spectrum matrix ($\langle A'_{i,j,k} \rangle$); d) the analyzer rearranging the synchronized cross spectrum matrix ($\langle A'_{i,j,k} \rangle$) as a cross spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions; e) the analyzer obtaining unknown terms in the cross spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions by using characteristics of the cross spectrum matrix; and f)

the analyzer obtaining a synchronized beam power (b''_m) by using the cross spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions and a synchronized steering vector matrix ($\overrightarrow{C''_m}$).

In the step c), the analyzer may obtain the synchronized cross spectrum matrix by using the following equation;

$$\langle A''_{i,j,k} \rangle = \frac{\langle A''_{i,j,k} \rangle}{\langle A''_{1,1,k} \rangle} \langle A''_{1,1,k} \rangle$$

Here, i and j denote sensor numbers and are variables each having an integer between 1 to N when assuming that the total number of the fixed sensor and the plurality of movable sensors is N , and k denotes a measuring time and is a variable having an integer between 1 to K .

In the step e), the analyzer may obtain the unknown terms in the cross spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions by using the following equation;

$$\begin{aligned} \langle A''_{a,b} \rangle &= \langle X''_a \rangle \langle X_b \rangle \\ &= \frac{\langle X''_a \rangle \langle X_a \rangle}{\langle X''_i \rangle \langle X_a \rangle} \langle X''_i \rangle \langle X_b \rangle \\ &= \frac{\langle A''_{a,a} \rangle}{\langle A''_{i,a} \rangle} \langle A''_{i,b} \rangle \\ &= \frac{\langle A''_{a,a} \rangle}{\langle A''_{1,a} \rangle} \langle A''_{1,b} \rangle \end{aligned}$$

In the step f), the analyzer may obtain the synchronized

beam power (b''_m) by using the following equation;

$$b''_m = \overrightarrow{C''_m}^\dagger \langle A'' \rangle \overrightarrow{C''_m}$$

【Advantageous Effects】

5 Since measurement performance is determined by the number of high-priced measuring sensors, i.e., microphones when a sound source is measured using the conventional microphone array beamforming method, it is required to increase the number of measuring sensors for the purpose of high
10 measurement performance. However, in the present invention, a sound source is measured by moving a limited number of microphones, so that measurement accuracy can be improved. Particularly, since measurements are simultaneously performed in the conventional microphone array beamforming method, a
15 sound source cannot be measured by moving sensors. However, in the present invention, a sound source is measured by moving microphones, and a signal processing method capable of synchronizing the microphones is applied, thereby obtaining measurement results.

20 Accordingly, the number of sensors required to evaluate measured values in a range of desired measurement accuracy can be considerably decreased, and therefore, measuring cost can be remarkably saved.

【Description of Drawings】

The above and other objects, features and advantages of the present invention will become apparent from the following description of preferred embodiments given in conjunction with the accompanying drawings, in which:

Fig. 1 illustrates examples of a microphone array measuring method applied to various types of research and development;

Fig. 2 illustrates an accuracy difference in a microphone array measuring method depending on the number of sensors used;

Fig. 3 illustrates arrangements of sensors in verification through numerical simulation;

Fig. 4 illustrates comparison of beam power maps for respective measuring methods; and

Fig. 5 illustrates comparison of performance characteristics in accordance with frequencies for the respective measuring methods.

【Mode for Invention】

Hereinafter, an enhanced sound source localization system and method by using a movable microphone array according to embodiments of the present invention will be described in detail with reference to accompanying drawings.

1) First, like in the conventional microphone array

measuring method, sound wave signals generated from an arbitrary sound source is measured using N microphones positioned at difference places, and an ensemble averaged cross spectrum matrix is obtained. Then, the measurement is repeated K times in the state that only one of sensors used is disposed at a fixed position, and the other sensors are moved to new positions. Here, the fixed sensor is numbered by "1", and the obtained cross spectrum is referred to as $\langle A_{i,j,k} \rangle$. The obtained cross spectrum refers to an ensemble averaged cross spectrum obtained in a k -th measurement with respect to an i -th and j -th sensor.

2) Since the obtained cross spectra are not data obtained simultaneously, a difference between phases of the cross spectra exists. In order to correct the difference, a synchronized cross spectrum $\langle A'_{i,j,k} \rangle$ is calculated as follows by performing correction of phases.

$$\langle A'_{i,j,k} \rangle = \frac{\langle A_{i,j,k} \rangle}{\langle A_{1,1,k} \rangle} \langle A_{1,1,1} \rangle$$

Here, $\langle A_{1,1,1} \rangle$ and $\langle A_{1,1,k} \rangle$ denote auto spectra of the first microphone at first and k -th measurements, respectively. Through the correction process using Equation 4, the difference between phases measured at different measurement times can be corrected.

3) The $\langle A'_{i,j,k} \rangle$ is a three-dimensional matrix of a

synchronized $[N \times N \times K]$ and has data measured at different positions except the first microphone. Therefore, the $\langle A'_{i,j,k} \rangle$ can be rearranged as a cross spectrum matrix at independent positions as expressed in Equation 5. The cross spectrum matrix becomes a two-dimensional matrix of $[((N-1)K+1) \times ((N-1)K+1)]$.

$$\langle A' \rangle \equiv \begin{bmatrix} A'_{1,1,1} & A'_{2,1,1} & \cdots & A'_{N,1,1} & A'_{2,1,2} & \cdots & A'_{N,1,2} & \cdots & A'_{2,1,K} & \cdots & A'_{N,1,K} \\ A'_{1,2,1} & A'_{2,2,1} & \cdots & A'_{N,2,1} & & & & & & & \\ \vdots & \vdots & \ddots & \vdots & & & & & & & \\ A'_{1,N,1} & A'_{2,N,1} & \cdots & A'_{N,N,1} & & & & & & & \\ A'_{1,2,2} & & & & A'_{2,2,2} & \cdots & A'_{N,2,2} & & & & \\ \vdots & & & & \vdots & \ddots & \vdots & & & & \\ A'_{1,N,2} & & & & A'_{2,N,2} & \cdots & A'_{N,N,2} & & & & \\ \vdots & & & & & & & \ddots & & & \\ A'_{1,2,K} & & & & & & & & A'_{2,2,K} & \cdots & A'_{N,2,K} \\ \vdots & & & & & & & & \vdots & \ddots & \vdots \\ A'_{1,N,K} & & & & & & & & A'_{2,N,K} & \cdots & A'_{N,N,K} \end{bmatrix}$$

When the synchronized three-dimensional $\langle A'_{i,j,k} \rangle$ is rearranged as $\langle A''_{a,b} \rangle$, some terms of the matrix $\langle A''_{a,b} \rangle$, i.e., $A''_{N,1}, A''_{N+1,1}, \dots$ are set as unknown numbers. The terms can be calculated as follows with a diagonal term which is a known term from a first row and a first column, using characteristics of the cross spectrum.

$$\begin{aligned} \langle A'_{a,b} \rangle &= \langle X_a^* \rangle \langle X_b \rangle \\ &= \frac{\langle X_a^* \rangle \langle X_a \rangle}{\langle X_1^* \rangle \langle X_a \rangle} \langle X_1^* \rangle \langle X_b \rangle \end{aligned}$$

$$\begin{aligned}
&= \frac{\langle A_{a,a}'' \rangle}{\langle A_{1,a}'' \rangle} \langle A_{1,b}' \rangle \\
&= \frac{\langle A_{a,a}'' \rangle}{\langle A_{1,a}'' \rangle} \langle A_{1,b}' \rangle
\end{aligned}$$

4) The cross spectrum matrix obtained as described above has the same result as that obtained from $((N-1)K+1)$ sensors disposed at different positioned. Therefore, one synchronized beam power b_m'' can be calculated using the result obtained from independent measurements performed K times. At this time, the synchronized steering vector can be calculated from positions of the moved microphones.

$$b_m'' = \overrightarrow{C_m''}^\dagger \langle A'' \rangle \overrightarrow{C_m''}$$

When the measuring method of the present invention using a movable microphone array is applied, the same measurement accuracy as obtained using a plurality of high-priced sensors can be obtained only using a limited number of sensors. In order to verify that performance of the measuring method of the present invention is more improved than that of the conventional measuring method, the performance of the measuring method of the present invention was compared with that of the conventional measuring method through simulation using a numerical method.

Fig. 3 illustrates arrangements of sensors in verification through numerical simulation. Fig. 3(a)

illustrates an arrangement of 31 sensors for measuring using the conventional beamforming method as shown in Fig. 2(a). Fig. 3(b) illustrates an arrangement of 121 sensors for measuring using the conventional beamforming method as shown in Fig. 2(b). Fig. 3(c) illustrates an arrangement of movable 31 sensors for measuring using the measuring method of the present invention.

Fig. 4 illustrates numerical simulation results of beam power maps for the respective measuring methods of Fig. 3. As shown in Fig. 4, it can be seen that side-lobe rejections are remarkably improved as the number of sensors used is increased. In the measuring method of the present invention, 31 microphones are substantially used. However, it can be seen that the measuring method of the present invention has a result almost similar to that when 121 sensors are used in the conventional measuring method.

Fig. 5 illustrates graphs for comparison of performance characteristics in accordance with frequencies for the respective measuring methods, in which beam widths and side-lobe rejections are numerically compared for the purpose of numerical comparison of the aforementioned performance improvement. Regarding the entire frequency region of the measured sound, it can be seen that the measured result of the present invention has performance close to that using 121

sensors in the conventional measuring method, even though only 31 sensors are used in the measuring method of the present invention.

Those skilled in the art will appreciate that the
5 conceptions and specific embodiments disclosed in the foregoing description may be readily utilized as a basis for modifying or designing other embodiments for carrying out the same purposes of the present invention. Those skilled in the art will also appreciate that such
10 equivalent embodiments do not depart from the spirit and scope of the invention as set forth in the appended claims.

【Industrial Applicability】

When the measuring method of the present invention using
15 a movable microphone array is applied, the same measurement accuracy as obtained using a plurality of sensors can be obtained only using a small number of sensors, and measurement can be performed at a low cost. Accordingly, it is expected that environmental sound can be reduced as application of a
20 method for reducing sound is extended. Further, the measuring method of the present invention can be extended to various fields through modification of a steering vector in accordance with measurement conditions. Furthermore, the measuring method of the present invention can be applied to localization

of a sound source transmitted in the water in addition to a sound source transmitted in the air.

【CLAIMS】**【Claim 1】**

An enhanced sound source localization system by using a microphone array beamforming method, the system comprises:

5 a fixed sensor measuring a sound at a fixed point;

a plurality of movable sensors spaced apart from the fixed sensor at a predetermined distance to measure the sound at a plurality of measuring points while moving along a predetermined path about the fixed sensor; and

10 an analyzer receiving sound data measured from the fixed sensor and the movable sensors to perform data analysis,

wherein a measured result is obtained by synchronizing the sound data measured from the plurality of movable sensors with the sound data measured from the fixed sensor.

【Claim 2】

An enhanced sound source localization method by using the sound source localization system according to claim 1, the method comprises the steps of:

20 a) the analyzer obtaining an ensemble averaged cross spectrum matrix by using sound data measured from the one fixed sensor and the plurality of movable sensors;

b) the analyzer repeating a predetermined times (K) an operation of moving the movable sensors to new positions, re-

measuring sound data and obtaining an ensemble averaged cross spectrum matrix ($\langle A_{i,j,k} \rangle$) using the sound data;

c) the analyzer correcting a difference of phases in the ensemble averaged cross spectrum matrix ($\langle A_{i,j,k} \rangle$), thereby
5 obtaining a synchronized cross spectrum matrix ($\langle A'_{i,j,k} \rangle$);

d) the analyzer rearranging the synchronized cross spectrum matrix ($\langle A'_{i,j,k} \rangle$) as a cross spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions;

e) the analyzer obtaining unknown terms in the cross
10 spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions by using characteristics of the cross spectrum matrix; and

f) the analyzer obtaining a synchronized beam power (b''_m) by using the cross spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions and a synchronized steering vector matrix ($\overline{C''_m}$).

15

【Claim 3】

The method of claim 2, wherein, in the step c), the analyzer obtains the synchronized cross spectrum matrix by using the following equation;

$$20 \quad \langle A_{i,j,k} \rangle = \frac{\langle A_{i,j,k} \rangle}{\langle A_{1,1,k} \rangle} \langle A_{1,1,1} \rangle$$

wherein i and j denote sensor numbers and are variables each having an integer between 1 to N when assuming that the total number of the fixed sensor and the plurality of movable

sensors is N , and k denotes a measuring time and is a variable having an integer between 1 to K .

【Claim 4】

The method of claim 2, wherein, in the step e), the analyzer obtains the unknown terms in the cross spectrum matrix ($\langle A''_{a,b} \rangle$) at independent positions by using the following equation;

$$\begin{aligned}
 \langle A''_{a,b} \rangle &= \langle X_a^* \rangle \langle X_b \rangle \\
 &= \frac{\langle X_a^* \rangle \langle X_a \rangle}{\langle X_i^* \rangle \langle X_i \rangle} \langle X_i^* \rangle \langle X_b \rangle \\
 &= \frac{\langle A''_{a,a} \rangle}{\langle A''_{i,a} \rangle} \langle A''_{i,b} \rangle \\
 &= \frac{\langle A''_{a,a} \rangle}{\langle A''_{i,a} \rangle} \langle A''_{i,b} \rangle
 \end{aligned}$$

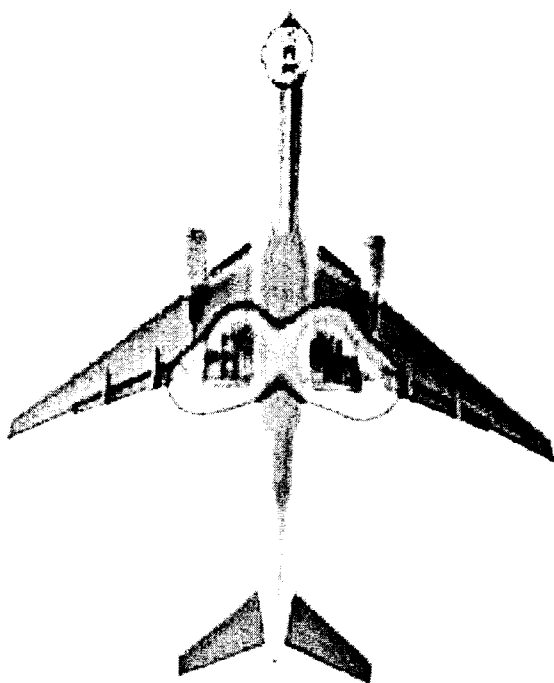
【Claim 5】

The method of claim 2, wherein, in the step f), the analyzer obtains the synchronized beam power (b''_m) by using the following equation;

$$b''_m = \overrightarrow{C''_m} \langle A'' \rangle \overrightarrow{C''_m}$$

【DRAWINGS】

【Figure 1】

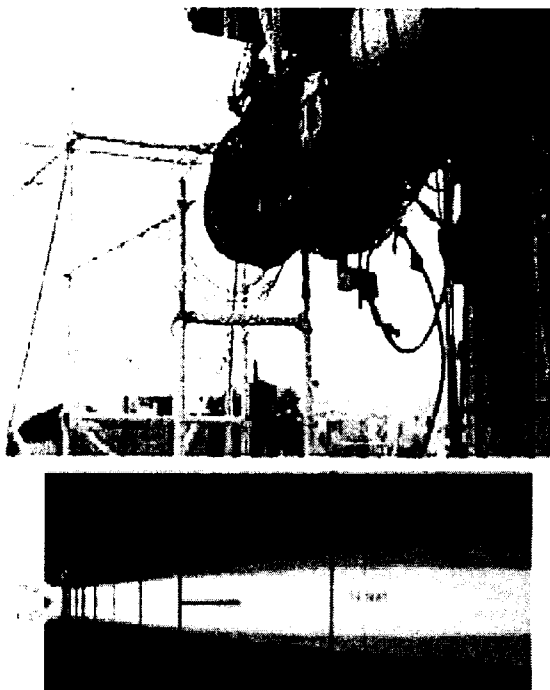


Boeing 777 flight test

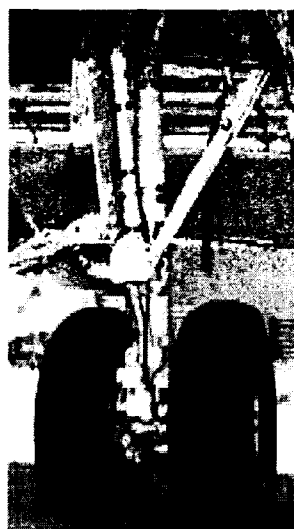


Engine Inlet Noise

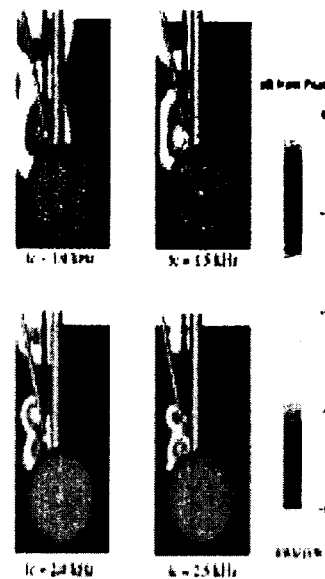
"Phased Array Beamforming for Aeroacoustics", AIAA Short Course, 2003



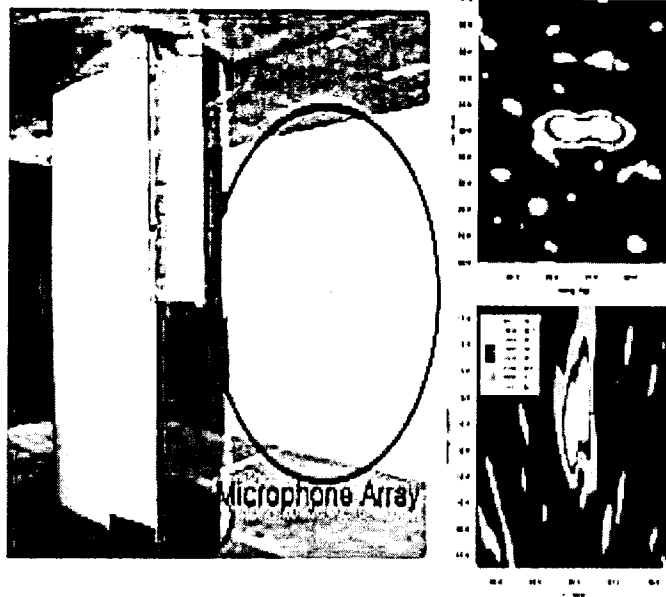
Jet Noise



Landing Gear Noise



"Phased Array Beamforming
for Aeroacoustics",
AIAA Short Course, 2003



Flap Noise Study in Wind-tunnel

"Boeing 18-Inch Fan
Rig Broadband Noise Test",
NASA/CR-1998-208704

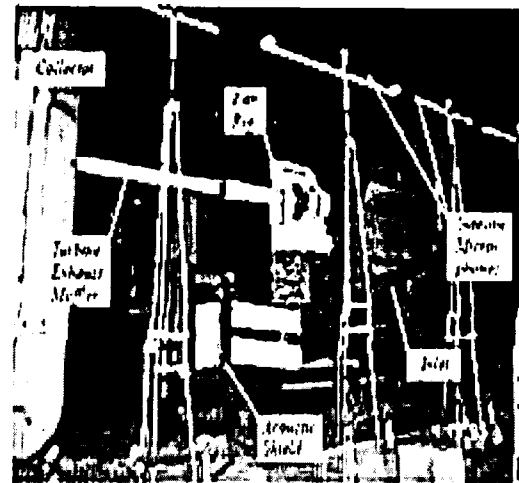


Fig. 1 The Boeing Low-Speed Aeroacoustic Facility

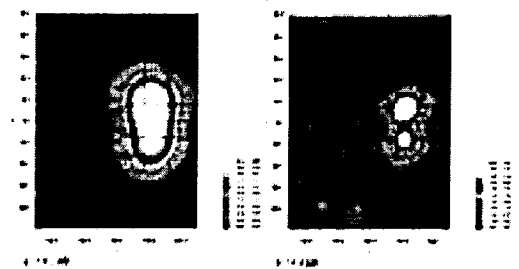
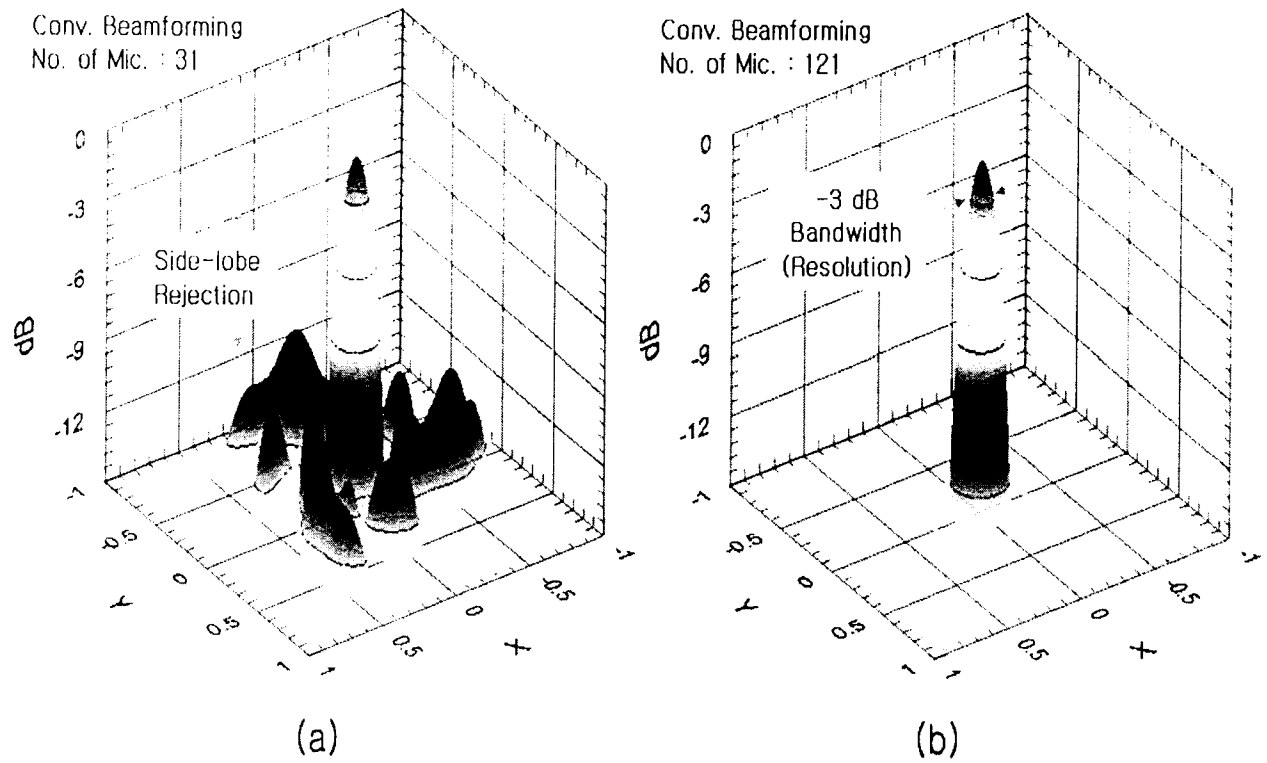


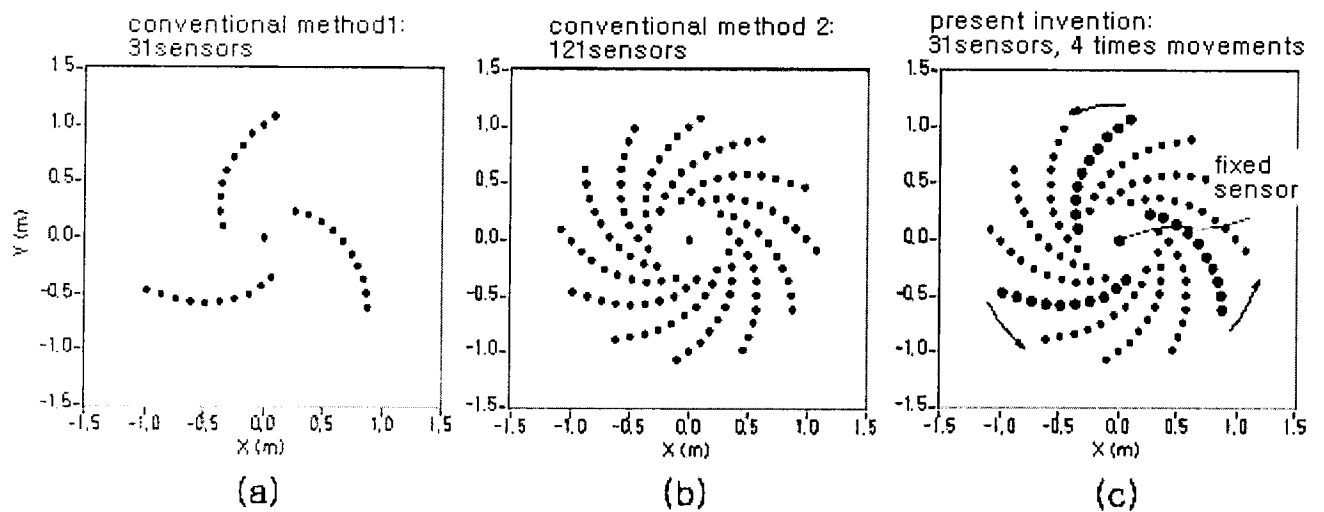
Fig. 3 Phased array beamforming of the Boeing 18-inch Fan Rig Broadband Noise Test (NASA Low-Speed Aeroacoustic Facility)

Jet Noise Study in Wind-tunnel

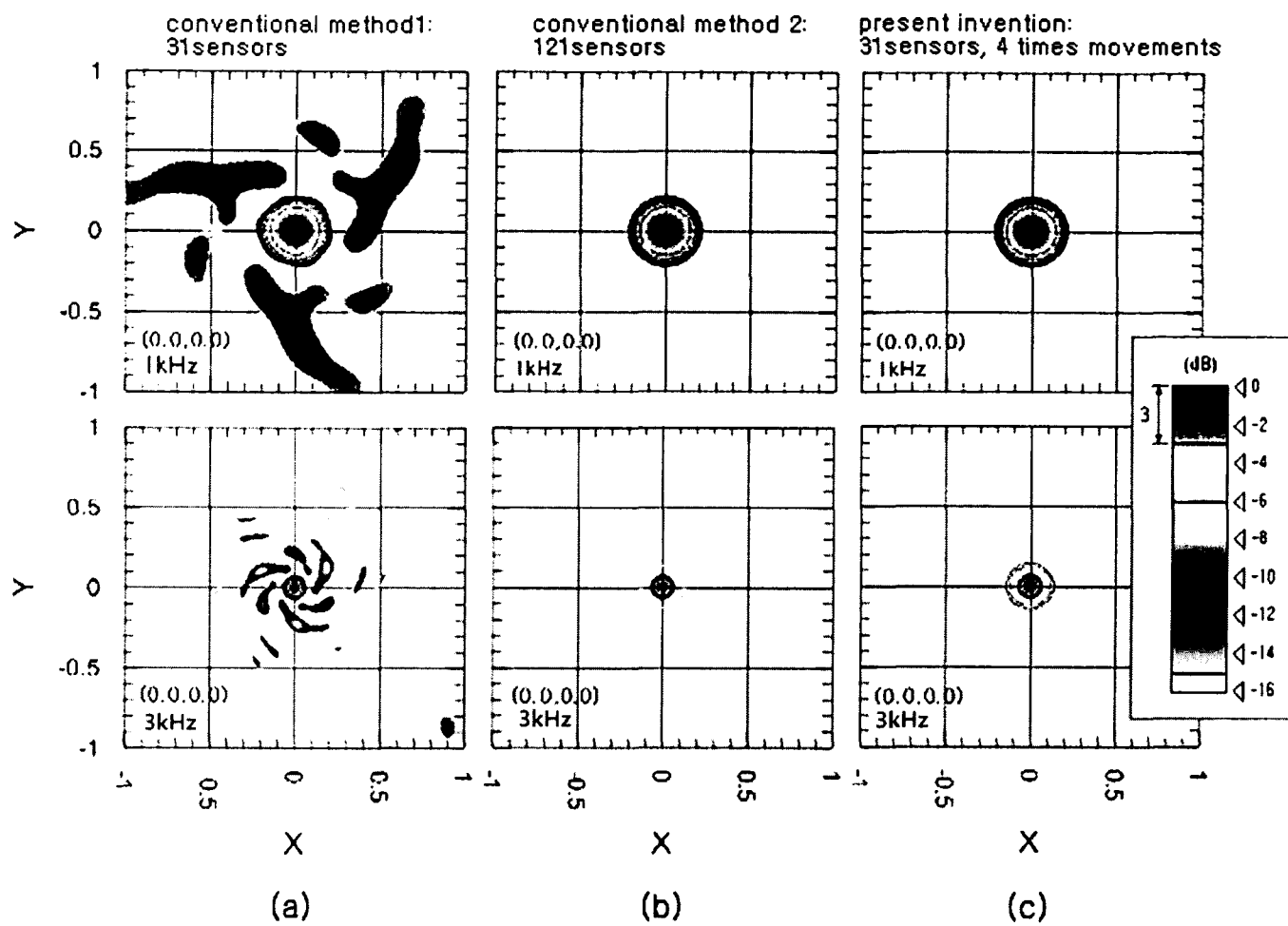
【Figure 2】



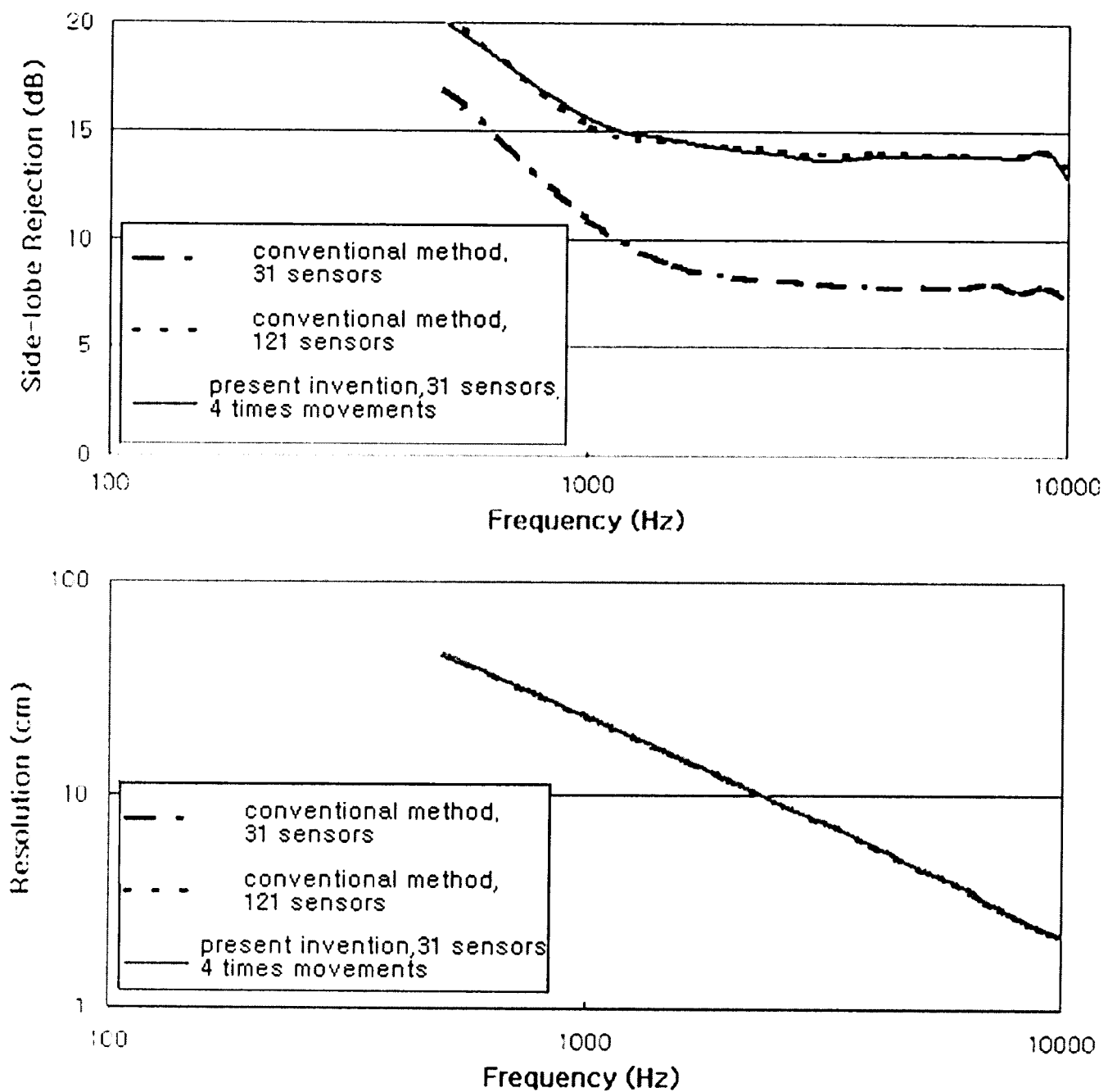
【Figure 3】



【Figure 4】



【Figure 5】



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2008/005969**A. CLASSIFICATION OF SUBJECT MATTER***G10L 15/20(2006.01)i*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC G10L, H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility Models since 1975

Japanese Utility models and applications for Utility Models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS(KIPO internal) & keywords: "Rotating", "Beamforming", "Source Localization", "microphone array"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RHEE WOOK et al. "Study for Visualization of Rotating Sound Source Using Microphone Array", Transaction of the Korea Society for Noise and Vibration Engineering, Vol.16, No. 6, pp.565-573, January 2006 See the abstract and section 2.	1-5
A	RHEE WOOK et al. "Study on De-Dopplerization Technique for Rotating Source Localization", In: The Korea Society for Noise and Vibration Engineering, 2005 fall conference, pp.200-204, November 2005 See the abstract and sections 2-3.	1-5
A	KR 10-2004-0079085 A (SAMSUNG ELECTRONICS CO., LTD.) 14 September 2004 See the abstract, claims 1-2,10-12 and figures 2-4.	1-5
A	KR 10-2003-0077797 A (SAMSUNG ELECTRONICS CO., LTD.) 04 October 2003 See the abstract, claims 1,10 and figures 3-4.	1-5



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2008/005969

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