

Description

Technical Field

[0001] The present invention relates to a noise control apparatus and noise control method for actively controlling noise.

Background Art

[0002] Conventionally, a technique of actively controlling noise (active noise control; hereinafter referred to as ANC) has been known and widely used in noise control for cars and copiers (for example, see Patent Literature 1 and Patent Literature 2).

ANC cancels noise in a noise reduction region (region that is a target for noise control; this definition applies to the following description) by emitting a noise reduction signal with the same strength but with a phase that is the inverse of that of a noise signal and causing the noise signal and the noise reduction signal to interfere with each other.

Citation List

Patent Literature

[0003]

Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2007-302134

Patent Literature 2: Japanese Patent No. 4078368

Summary of Invention

Technical Problem

[0004] Noise control in real time on a noise signal that is propagating to a closed space or open space (opened space) and varying its frequency component in real time requires feedforward control for accurately detecting the signal component from a noise source and reducing noise in a bandwidth for noise reduction. The feedforward control needs a sensor device for searching for a noise source, a sensor device for determining a noise reduction region, and a speaker device for generating a noise reduction signal. An algorithm for controlling these devices is also necessary.

[0005] In cases where a microphone is used as each of the sensor devices, if the microphone and a speaker device that are, for example, consumer products are adjacent to each other, a wavelength issue arising due to the proximity of the devices causes feedback. Accordingly, to avoid such a wavelength issue occurring with the proximity, it is important to preliminarily examine a sound field environment in a noise reduction region and determine a variation in the sound field environment in the noise reduction region during noise control.

[0006] Such an operation for determining an acoustic property in a noise reduction region is referred to as "identification operation." An identification operation determines the size of a noise reduction region and the effects of an object that reflects a signal on the basis of the time from emission of an audio signal with a certain sound pressure and a certain frequency for a certain period of time from a control speaker to input of the sound reflection from the control speaker directly or indirectly into the sensor device.

[0007] Conventionally, this identification operation is carried out before noise control starts. If some kind of change occurs in an unknown sound field environment during noise reduction operation or a sudden movement arises in a control speaker or a sensor device, the state of an acoustic environment in the noise reduction region changes. This change makes the noise control inefficient.

[0008] For an identification operation, a signal that contains all frequency bands, including white noise and pink noise, is emitted from a control speaker to grasp frequency characteristics in a noise reduction region to determine an acoustic environment in the noise reduction region. At this time, it is necessary to temporarily halt noise control in order to emit the signal with a sound pressure that is equal to or more than a sound level of noise to be reduced. In addition, the signal emitted in this identification operation may cause a "noise" state in the noise reduction region.

[0009] The present invention is made to address the above-described issues and is directed to provide a noise control device and noise control method capable of controlling noise in response to a change of an acoustic property in a noise reduction region.

Solution to Problem

[0010] A noise control apparatus according to the present invention includes one or more reference sensors for detecting a noise signal produced by a noise source, one or more sound emitting sources for emitting a noise reduction signal and an identification signal, an error sensor for detecting the noise signal, noise reduction signal, and identification signal, identification means for carrying out an identification operation of identifying an acoustic property in a noise reduction region based on the identification signal detected by the error sensor, and noise reduction signal generating means for generating the noise reduction signal by adaptive signal processing based on the detection by at least one of the reference sensors and the detection by the error sensor. The identification means carries out the identification operation while at least one of the sound emitting sources emits the noise reduction signal.

Advantageous Effects of Invention

[0011] With the noise control apparatus according to the present invention, an identification operation for a

noise reduction region is carried out during noise control. Accordingly, even if a change of an acoustic property in the noise reduction region is caused by an environmental variation, appropriate noise control in response to the change can be achieved.

Brief Description of Drawings

[0012]

[Fig. 1] Fig. 1 is a functional block diagram for describing a noise control apparatus according to an embodiment.

[Fig. 2] Fig. 2 is a functional block diagram for describing another example of the noise control apparatus according to the embodiment.

[Fig. 3] Fig. 3 is an illustration for describing an identification signal used in an identification operation carried out during noise control according to the embodiment.

Description of Embodiments

Embodiment

[0013] An embodiment of the present invention is described below with reference to the drawings. For the present embodiment, a case in which a noise control apparatus according to the present invention is incorporated in an air-conditioning system that includes a duct is described as an example. The noise control apparatus suppresses propagation of noise produced by, for example, a fan of air-conditioning equipment through a fan duct and emission of the noise to a room to be air-conditioned.

[0014] As previously described, noise control requires a sensor device for searching for a noise source, a sensor device for determining a noise reduction region, and a speaker device for generating a noise signal. The noise control can be classified into two types: single-channel control for a case where the number of each of these devices is one and multi-channel control for a case where the number of at least one of these devices is more than one. The noise control apparatus according to the present invention is applicable to both the single-channel control and the multi-channel control. An arrangement for the single-channel control and an arrangement for the multi-channel control are described below in sequence.

[0015] Fig. 1 is a functional block diagram for describing a noise control apparatus 100 according to the present embodiment. Fig. 1 illustrates an example of the noise control apparatus 100 for single-channel control. A duct 10 is a passage for air issuing from air-conditioning equipment (not illustrated), with a noise source 11 at the upstream side, and has an opening portion 10a opened toward an air-conditioning target region at the downstream side. This noise control system suppresses propagation of noise produced by the noise source 11 at the

upstream side through the duct 10 and emission of the noise to the air-conditioning target region. That is, the air-conditioning target region positioned downstream of the duct 10 is a noise reduction region.

[0016] For the present embodiment, the noise source 11 is a rotational mechanism, such as a fan or motor.

[0017] The noise control apparatus 100 includes a reference sensor 2, a secondary sound source 3, an error sensor 4, and a computation processor 5.

[0018] The reference sensor 2 is a sensor for detecting an acoustic signal component from the noise source 11 that propagates through the duct 10 and transmitting the detected value to the computation processor 5. For the present embodiment, a case in which a microphone for catching a propagating sound that is travelling in the space is used as the reference sensor 2 is described as an example. The reference sensor 2 is disposed in the vicinity of the noise source 11 so as to detect an acoustic property of the noise source 11. A path of a plurality of input signals from the reference sensor 2 is represented as an input-signal path R(N).

[0019] An example that can be used as the reference sensor 2 other than a microphone is a vibration sensor for detecting a signal caused by vibration. In this case, the vibration sensor can be directly placed on the noise source 11, for example, a fan or motor, to directly detect vibration, or alternatively, it can be fixed to a structure in which the noise source 11 is placed, such as the duct 10, in accordance with the fixation of the noise source 11 to indirectly detect vibration.

[0020] The secondary sound source 3 emits a noise reduction signal under the control of the computation processor 5. For the present embodiment, a case in which a speaker is used as the secondary sound source 3 is described as an example. In the following description, the secondary sound source 3 is referred to as the control speaker 3. The control speaker 3 is placed at a given location downstream of the reference sensor 2 in the duct 10.

[0021] The error sensor 4 is placed at a given location downstream of the control speaker 3 and is a sensor for detecting an acoustic signal component and transmitting the detected value to the computation processor 5. For the present embodiment, a case in which a microphone is used as the error sensor 4 is described as an example. A transfer path of a plurality of input signals from the error sensor 4 (hereinafter referred to as error signals e(N)) is represented as an error-signal path E(N). The acoustic signal component detected by the error sensor 4 indicates noise at the location where the error sensor 4 is placed. Accordingly, the noise control apparatus 100 aims at minimizing the error signals e(N) (rendering them zero as close as possible).

[0022] The computation processor 5 includes an inverse filter stage 8, a computation stage 6, and an adaptive filter stage 7 and performs signal processing and filter processing to control noise. Specifically, the computation processor 5 performs adaptive-signal process-

ing of generating a noise reduction signal for reducing the acoustic property of noise on the basis of signals detected by the reference sensor 2 and the error sensor 4.

In Fig. 1, the computation processor 5 corresponds to noise reduction signal generating means and identification means in the present invention.

[0023] Next, signal propagation and noise control processing performed in noise control by the computation processor 5 are described.

For the present embodiment, the vicinity of the opening portion 10a is a noise reduction region. The acoustic property of this noise reduction region is unknown.

[0024] A transfer path 20 is one through which an acoustic component connecting the control speaker 3 and the error sensor 4 is transferred. The transfer path 20 has a signal transfer characteristic C, and the signal transfer characteristic C is represented by a transfer function A.

A transfer path 30 is one through which an acoustic component connecting the reference sensor 2 and the control speaker 3 is transferred. The transfer path 30 has a signal transfer characteristic F, and the signal transfer characteristic F is represented by a transfer function B.

[0025] Before noise control starts, temporal characteristics of the transfer function A and the transfer function B are obtainable by emitting a given signal from the control speaker 3 for a given period of time and detecting the given signal by the use of the reference sensor 2 and the error sensor 4. The locations where the reference sensor 2 and the error sensor 4 are placed and the number thereof can also be determined.

[0026] The inverse filter stage 8 convolves an input signal input from the reference sensor 2 through the input-signal path R(N) and generates a signal having a phase that is the inverse of that of the input signal. The signal with the inverted phase is transmitted to the adaptive filter stage 7 and is used in updating the filter characteristics of the adaptive filter stage 7. The signal with the inverted phase is also transmitted to the computation stage 6.

[0027] The computation stage 6 performs computation based on the least squares method for minimizing the error signal $e(N)$ input from the error sensor 4. The result of the computation by the computation stage 6 is transmitted to the adaptive filter stage 7 and is used in updating the filter characteristics of the adaptive filter stage 7.

The computation stage 6 performs computation for rendering the signal component with the inverted phase generated by and transmitted from the inverse filter stage 8 to zero as close as possible.

The computation stage 6 compares the phase characteristics of the acoustic signal transmitted from the inverse filter stage 8 against the phase characteristics of the error signal $e(N)$ transmitted from the error sensor 4. In this way, among signals propagating to the noise reduction region and input to the error sensor 4, signals other than ones from the noise source 11 can be identified

as extraneous signals. The extraneous signals can be considered to be an environmental change factor that varies the acoustic property in the noise reduction region. The extraneous signals are transmitted to the adaptive filter stage 7 and are used in updating the filter characteristics of the adaptive filter stage 7.

[0028] The adaptive filter stage 7 is a filter having the filter characteristics set to generate a noise reduction signal. The adaptive filter stage 7 performs adaptive-signal processing for updating the filter characteristics at the appropriate times to cancel an ever-changing noise signal from the noise source 11.

The adaptive filter stage 7 updates the filter coefficient on the basis of the signal with the inverted phase to the input signal generated by the inverse filter stage 8, the result of the computation at the computation stage 6, and the extraneous signals, which are described above. The use of the extraneous signals enables stable noise reduction operation that takes effects of the extraneous signals (environmental change factor for the noise reduction region) into consideration.

[0029] The acoustic signal component of the noise reduction signal generated by the adaptive filter stage 7 is transmitted to the control speaker 3 and emitted from the control speaker 3. In this way, an audio signal component of the noise reduction signal emitted from the control speaker 3 cancels the audio signal component from the noise source 11.

[0030] Next, a fundamental configuration for the multi-channel control is described.

Fig. 2 is an example functional block diagram for describing control operation of the noise control apparatus 100 and illustrates a configuration for the multi-channel control. In Fig. 2, some elements illustrated in Fig. 1, such as the duct 10 and the noise source 11, are not illustrated, and only the functional blocks are shown. The noise control operation for the multi-channel control is described with reference to Fig. 2, and the description focuses on differences from the configuration illustrated in Fig. 1. In Fig. 2, the same reference numerals are used for the same or corresponding elements in Fig. 1.

[0031] The multi-channel control illustrated in Fig. 2 generates an M-channel noise reduction signal on the basis of a K-channel input from the reference sensor 2 and exercises control for minimizing an L-channel error signal $e(N)$ detected by the error sensor 4. Each of K, L, and M is one or more. A transfer path of a noise reduction signal from the control speaker 3 (not illustrated in Fig. 2) to the error sensor 4 is represented by an error path C(N).

[0032] A computation processor 9 performs computation for updating the filter characteristics of an adaptive filter stage 7a on the basis of a signal input from the reference sensor 2 through the input-signal path R(N) and an error signal $e(N)$ from the error sensor 4.

The adaptive filter stage 7a includes an adaptive filter W supporting a plurality of channels and generates a noise reduction signal. The adaptive filter stage 7a includes

one or more input channels and one or more output channels and is connected to the control speaker 3.

The noise reduction signal generating means and the identification means in the present invention correspond to the computation processor 9 and the adaptive filter stage 7a in Fig. 2.

[0033] The acoustic signal component of the noise reduction signal generated by the adaptive filter stage 7a is transmitted to the control speaker 3 (not illustrated in Fig. 2) and emitted from the control speaker 3. In this way, the audio signal component of the noise reduction signal emitted from the control speaker 3 cancels the audio signal component from the noise source 11.

[0034] The fundamental operations for the single-channel control and the multi-channel control are described above with reference to Figs. 1 and 2.

Next, an identification operation according to the present embodiment is described. As previously described, conventionally, an identification operation has been carried out before noise control. In contrast, for the present embodiment, an identification operation is carried out during noise control, in addition to before the noise control.

[0035] An identification operation carried out during noise control is described below.

The noise control apparatus 100 emits a noise reduction signal and an acoustic signal component for use in an identification operation (hereinafter referred to as identification signal) from the control speaker 3 in such a way that they are superimposed. The identification signal is an impulse signal and has a sound pressure level lower than that of the noise reduction signal by 3 dB or more. The identification signal is emitted for a certain period of time at certain intervals.

[0036] Fig. 3 is an illustration for describing an identification signal used in an identification operation carried out during noise control. As illustrated in Fig. 3, an identification signal whose emission period is 0.5 seconds or less is emitted at intervals of approximately 3 seconds. This period of the identification signal is in the minimum time relation for minimizing effects on human perception to sound reflection. The period of emission of the identification signal (i.e., period of the identification operation) for each operation can be between one minute and five minutes inclusive, for example.

As the frequency component of the identification signal, a component in the range from a given low-frequency component required for noise reduction (e.g., 5 Hz) to a frequency component of low sensitivity in human hearing characteristics (e.g., 1 kHz or less) can be used. In this way, the identification signal is not perceptible to humans, and thus the discomfort sensed by humans caused by the identification operation can be suppressed.

[0037] Next, signal propagation and related control processing in an identification operation are described with reference to Figs. 1 and 2. In Figs. 1 and 2, transfer paths of identification signals are represented by identification-signal paths D(N); for the sake of the description, the identification-signal paths D(N) are distinguished into

transfer paths 40 to 44.

[0038] First, description is provided with reference to Fig. 1.

In Fig. 1, an identification signal generated by the adaptive filter stage 7 is transmitted to the control speaker 3 through the transfer path 40 and emitted from the control speaker 3. The identification signal emitted from the control speaker 3 is input to the error sensor 4 through the transfer path 41. The identification signal input to the error sensor 4 is transmitted to the adaptive filter stage 7 through the transfer path 42. The adaptive filter stage 7 convolves the acoustic property of the transmitted identification signal and acquires a change in the frequency characteristics as a change in the noise reduction region. The change in the noise reduction region is monitored by comparing the acoustic property obtained in the identification operation during noise control and the acoustic property obtained before the noise control.

[0039] The adaptive filter stage 7 reflects the change in the noise reduction region acquired at the previous stage in the above-described processing of generating the noise reduction signal. In this way, the noise reduction signal generated by the use of the filter characteristics in response to the change in the noise reduction region can be emitted from the control speaker 3. Accordingly, even if a change in the sound field characteristics is caused by an environmental variation in a noise reduction region, stable noise control can be achieved.

[0040] Next, description is provided with reference to Fig. 2.

In Fig. 2, an identification signal generated by the adaptive filter stage 7a is emitted from the control speaker 3 and input to the error sensor 4 through the transfer path 43. The identification signal input to the error sensor 4 is input to the computation processor 9 through the transfer path 44. The computation processor 9 performs computation on the transmitted identification signal on the basis of a predetermined algorithm and acquires a change in the frequency characteristics as a change in the noise reduction region. The change in the noise reduction region is monitored by comparing the acoustic property obtained in the identification operation during noise control and the acoustic property obtained before the noise control.

[0041] The adaptive filter stage 7a reflects the change in the noise reduction region acquired at the previous stage in the above-described processing of generating the noise reduction signal. In this way, the noise reduction signal generated by the use of the filter characteristics in response to the change in the noise reduction region can be emitted from the control speaker 3. Accordingly, even if a change in the sound field characteristics is caused by an environmental variation in a noise reduction region, stable noise control can be achieved.

[0042] Such an identification operation during noise control can be repeated at given times in a control process in a day, for example. For instance, the identification operation can be carried out three times at specified times

in the morning, noon, and evening, or alternatively, it can be carried out twice at specified times in the morning and evening. In this way, an environmental variation in the noise reduction region can be determined. Also, because the identification operation is carried out during noise control, the noise reduction signal in response to the noise reduction region that has varied can be emitted without having to halt the noise control operation for the noise reduction region.

[0043] As described above, with the noise control apparatus 100 according to the present embodiment, the identification operation for the noise reduction region is also carried out during noise control. Accordingly, the noise control in response to the sound field characteristics in the noise reduction region can be achieved. In addition, because the identification operation and the noise control are carried out simultaneously, it is not necessary to halt the noise control for the noise reduction region.

[0044] The identification signal used in the identification operation during noise control is lower than the sound pressure level of the noise reduction signal by 3 dB or more. Accordingly, the identification signal substantially does not affect the noise reduction signal. Alternatively, the identification signal used in the identification operation during noise control can have an energy component that is half the sound pressure level of the noise reduction signal. Even with this, substantially the same advantageous effects are obtainable.

[0045] The identification signal used in the identification operation during noise control has a frequency of low sensitivity in human hearing characteristics (e.g., 5 Hz or more, 1 kHz). Accordingly, the discomfort to humans existing in a noise reduction region caused by the identification signal can be suppressed.

For the identification operation during noise control, the identification signal whose emission period is 0.5 or less seconds is emitted at intervals of approximately 3 seconds. Accordingly, the effects on the human perception by the identification signal can be suppressed.

[0046] For the present embodiment, the case in which the noise control apparatus according to the present invention is applied to a closed space that is an air-conditioning apparatus including a duct is described as an example. The noise control apparatus according to the present invention is also applicable to an open space, and also in this case, substantially the same advantageous effects are obtainable.

For the present embodiment, an example in which noise emitted from a rotational mechanism, such as a fan or motor, is controlled is described. The present invention is also applicable to noise control for noise emitted from a moving mechanism, such as a car or machine tool, and also in this case, substantially the same advantageous effects are obtainable.

Reference Signs List

[0047] 2 reference sensor, 3 control speaker (secondary sound source), 4 error sensor, 5 computation processor, 6 computation stage, 7 adaptive filter stage, 7a adaptive filter stage, 8 inverse filter stage, 9 computation processor, 10 duct, 10a opening portion, 11 noise source, 20 transfer path, 30 transfer path, 40 transfer path, 41 transfer path, 42 transfer path, 43 transfer path, 44 transfer path, 100 noise control apparatus, A transfer function, B transfer function, C signal transfer characteristic, C(N) error path, D(N) identification-signal path, E(N) error-signal path, F signal transfer characteristic, R(N) input-signal path, W adaptive filter

Claims

1. A noise control apparatus comprising:

one or more reference sensors that detects a noise signal produced by a noise source;
one or more sound emitting sources that emit a noise reduction signal and an identification signal;
an error sensor that detects the noise signal, the noise reduction signal, and the identification signal;
identification means that carries out an identification operation of identifying an acoustic property in a noise reduction region based on the identification signal detected by the error sensor; and
noise reduction signal generating means that generates the noise reduction signal by adaptive signal processing based on the detection by at least one of the reference sensors and the detection by the error sensor,
wherein the identification means carries out the identification operation while at least one of the sound emitting sources emits the noise reduction signal.

2. The noise control apparatus of claim 1, wherein the identification signal is an impulse signal.

3. The noise control apparatus of claim 2, wherein the impulse signal is emitted so as to have a sound pressure level lower than a sound pressure level of the noise reduction signal emitted from at least one of the sound emitting sources by 3 dB or more, or an energy component that has a level that is half that of an energy component of the noise reduction signal emitted from the at least one of the sound emitting sources.

4. The noise control apparatus of claim 2 or claim 3,

wherein an operation period of the identification operation for each operation is between one minute and five minutes inclusive, and
 in the identification operation for each operation, the impulse signal is emitted for an emission period of 0.5 seconds or less and the emission is repeated at intervals of approximately 3 seconds. 5

5. The noise control apparatus of any one of claim 2 to claim 4, wherein a signal component of the impulse signal includes a frequency component between 5 Hz and 1 kHz inclusive. 10

6. The noise control apparatus of any one of claim 1 to claim 5, wherein the identification means identifies the acoustic property in the noise reduction region based on the acoustic property identified in the identification operation carried out while the at least one of the sound emitting sources emits the noise reduction signal and an acoustic property identified in an identification operation carried out while the sound emitting sources do not emit the noise reduction signal. 15 20

7. The noise control apparatus of any one of claim 1 to claim 6, wherein the noise reduction signal generating means generates the noise reduction signal in consideration of the acoustic property in the noise reduction region identified in the identification operation carried out while the at least one of the sound emitting sources emits the noise reduction signal. 25 30

8. A noise control method comprising the steps of: 35
 outputting a noise reduction signal cancelling noise in a noise reduction region that is a target for noise reduction;
 outputting an identification signal for use in identifying an acoustic property in the noise reduction region; and 40
 outputting the noise reduction signal and the identification signal in such a manner that they are superimposed. 45

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FIG. 1

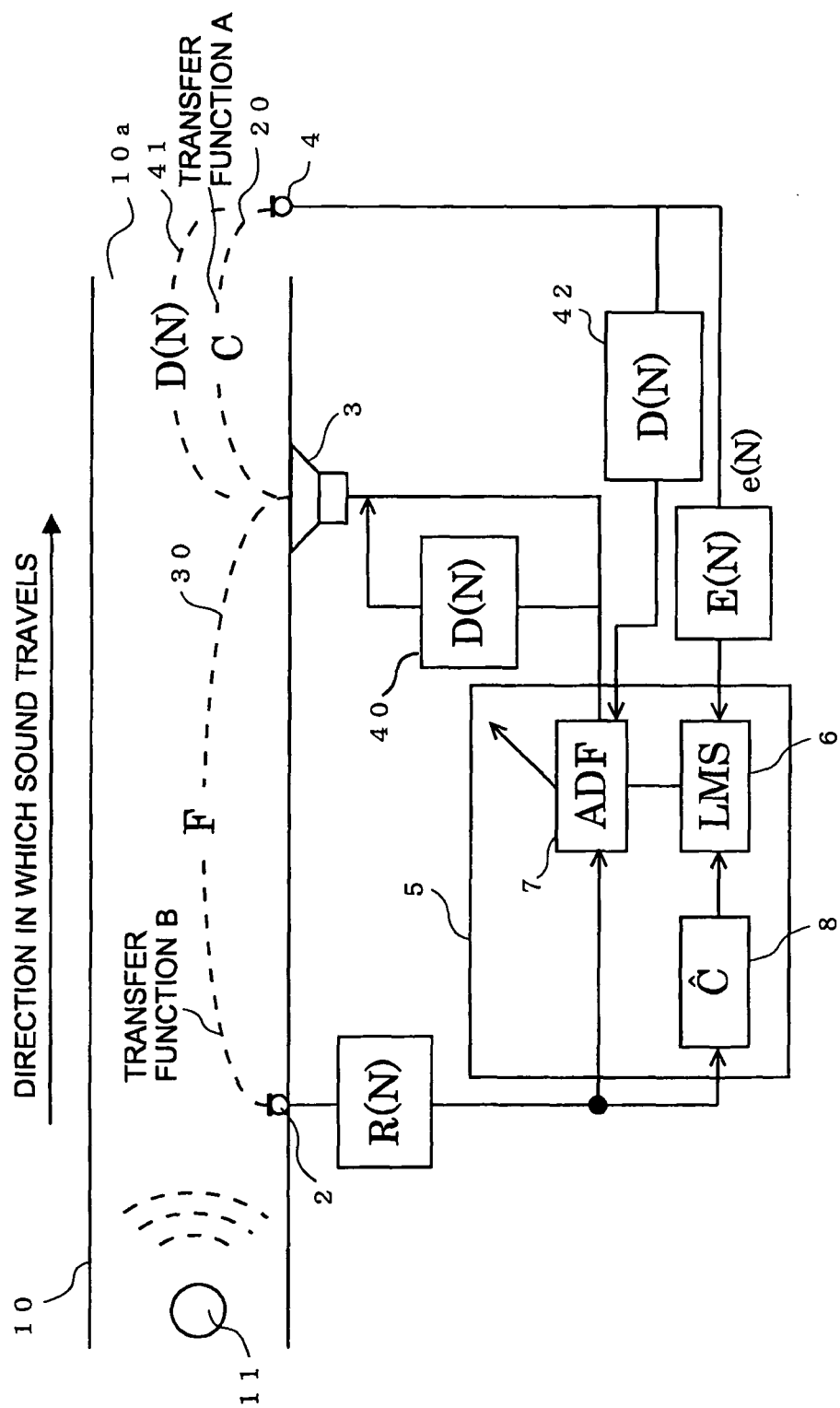


FIG. 2

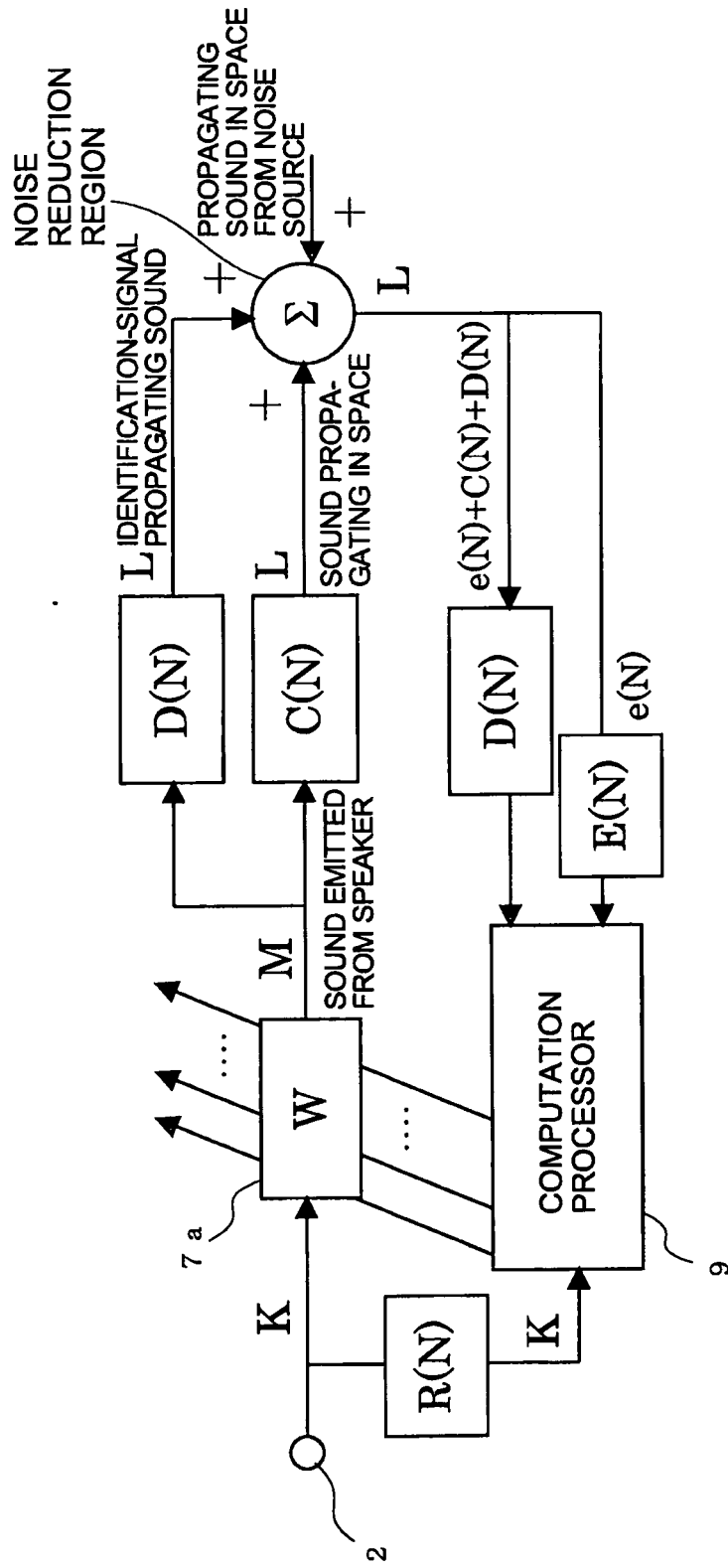
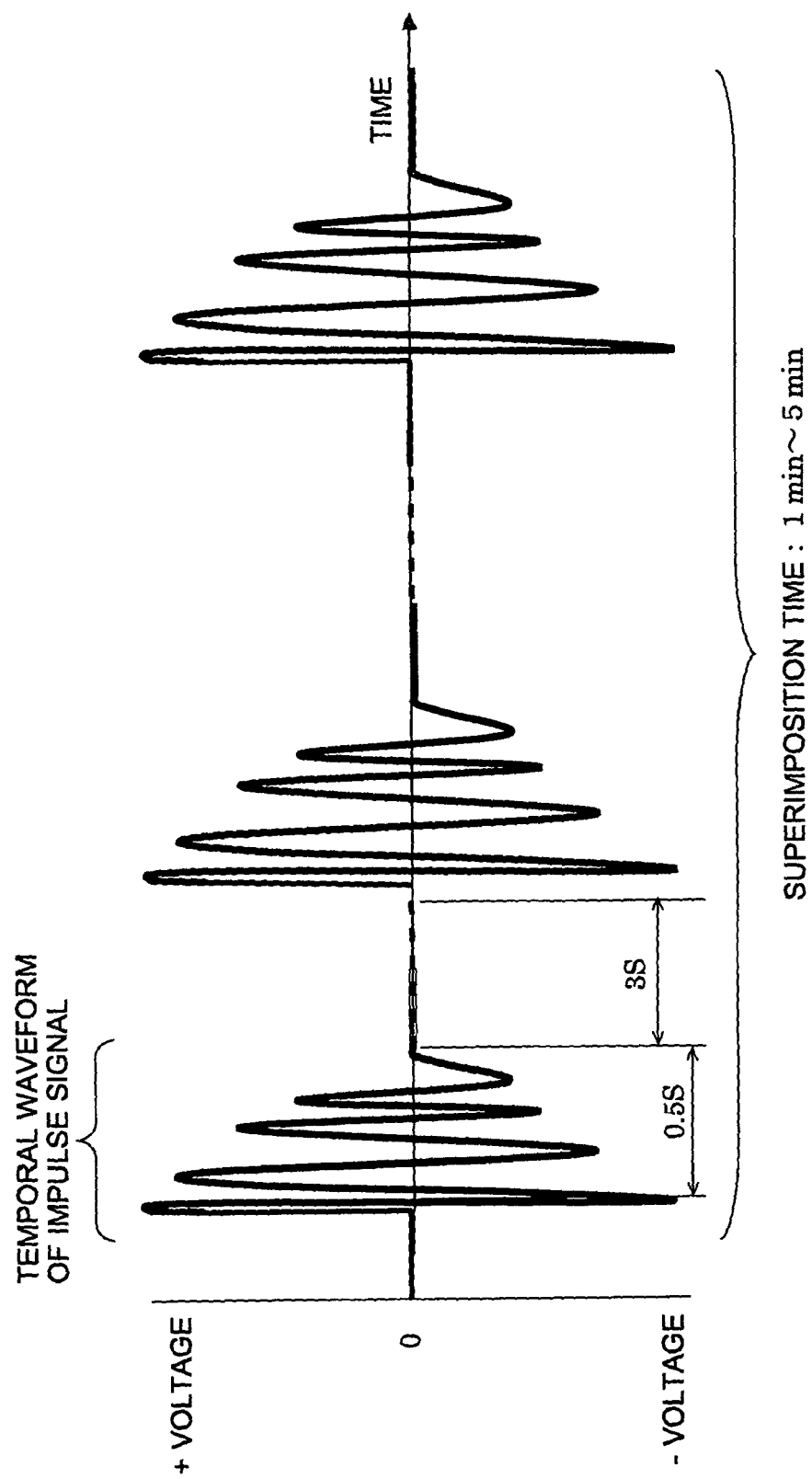


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/066506

A. CLASSIFICATION OF SUBJECT MATTER

G10K11/178(2006.01) i, G10K11/16(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)

G10K11/178, G10K11/16

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2009
Kokai Jitsuyo Shinan Koho	1971-2009	Toroku Jitsuyo Shinan Koho	1994-2009

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 6-272684 A (Toshiba Corp.), 27 September 1994 (27.09.1994), paragraphs [0052] to [0056], [0068] to [0072], [0085]; fig. 1 to 4 & US 005517571 A1 & EP 000616314 A2 & DE 069424587 D & KR 10-0133259 B	1-4, 6-8 5
X Y	JP 10-254459 A (TOA Corp.), 25 September 1998 (25.09.1998), paragraphs [0045], [0054] to [0055]; fig. 3 (Family: none)	1, 7-8 5
X	JP 2008-15046 A (Yanmar Co., Ltd.), 24 January 2008 (24.01.2008), paragraphs [0024] to [0069]; fig. 1 to 9 (Family: none)	1, 7-8

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search
19 November, 2009 (19.11.09)Date of mailing of the international search report
01 December, 2009 (01.12.09)Name and mailing address of the ISA/
Japanese Patent Office

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/066506

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 8-123446 A (Alpine Electronics, Inc.), 17 May 1996 (17.05.1996), paragraphs [0025] to [0044]; fig. 1 to 5 (Family: none)	1, 7-8

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2007302134 A [0003]
- JP 4078368 B [0003]