(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 975 168 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
30.03.2022 Bulletin 2022/13

(21) Application number: **20198515.7**

(22) Date of filing: **25.09.2020**

(51) International Patent Classification (IPC):
G10K 11/178 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
G10K 11/17823; G10K 11/17825; G10K 11/17854; G10K 11/17879

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **Lavorosostenible S.r.l.**
00167 Rome (RM) (IT)

(72) Inventors:
- **ABBATECOLA, Tommaso**
00167 Rome (RM) (IT)
- **ABBATE, Carmine**
00167 Rome (RM) (IT)

(74) Representative: **Fezzardi, Antonio et al**
Studio Ferrario Srl
Via Collina, 36
00187 Roma (IT)

(54) A DEVICE FOR ACTIVE ATTENUATION AND CONTROL OF AMBIENT NOISE

(57) An active ambient noise attenuation and control device, which operates selectively by generating an ambient noise attenuation signal with 180° phase shift of the detected noise and, furthermore, means correcting the signal generated by the feedback of a residual noise signal.

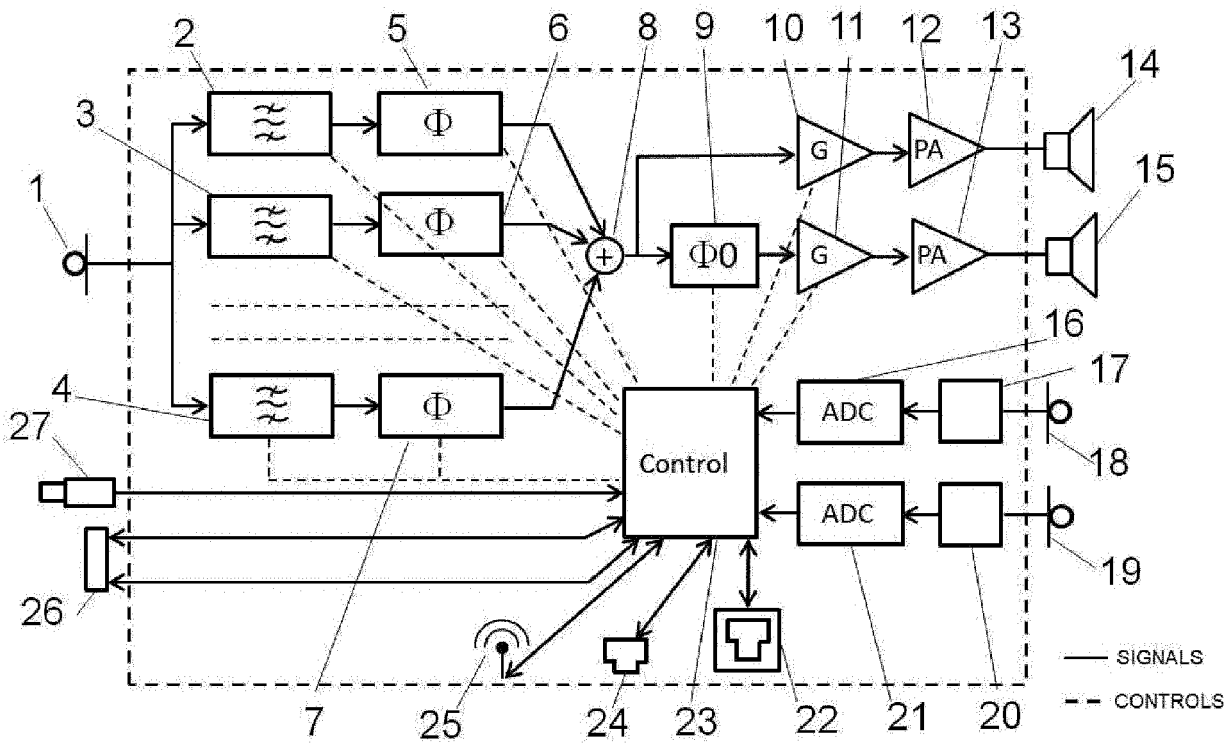

FIG.1

EP 3 975 168 A1

Description

Sector of the invention

[0001] The invention relates to a device for the active attenuation and control of noise sources and in particular a device for reducing the ambient noise in workplaces.

Prior art

[0002] It is known that, particularly in workplaces, noise produces significant damage to hearing, sometimes only detectable after many years, and that, although not being a direct cause of death, serious accidents have occurred in which the noise present in the work environment did not allow the prevention of the event. Detailed noise analysis carried out in factories, on critical workstations, revealed noise levels between 85 and 87 dB.

[0003] Such levels lead to social costs related to noise, which determines a deterioration in the quality of life, while costs related to occupational diseases arise in the long term.

[0004] Personal protective equipment ("PPE") is used to deal with these problems. However, it is a costly palliative that enterprises adopt essentially to comply with legal requirements, but which have little impact on the wellbeing of workers.

[0005] It is also known that technological evolution in digital signal and information management has now led to the development of active electronic noise reduction systems by virtue of real-time adaptive algorithms.

[0006] At present, however, electronic noise suppression systems are known which are available only for particular applications but are functionally critical when applied in a wider range of applications, highlighting limits in achieving and maintaining the results in terms of noise attenuation.

[0007] The technological limitations, in addition to limited social and cultural sensitivity, have limited the development of electronic noise suppression systems over the years, in practice favoring their application mainly in headphones and luxury cars.

[0008] Therefore, there is a need for an active noise reduction system, particularly in workplaces.

Object of the invention

[0009] It is a first object of the present invention to overcome the limits of the solutions available today and to suggest a device for active noise reduction capable of generating an opposite sound relative to the ambient noise source, thus reducing the perceived disturbance.

Summary of the invention

[0010] For these and other objects, a device was achieved for the active attenuation and control of noise according to any one of the appended claims.

[0011] According to a first aspect of the invention, the device works selectively by generating an ambient noise attenuation signal with 180° phase shift of the detected noise and also, by means of feedback of a residual noise signal, to correct the generated signal.

[0012] A first advantage of the invention is in that the device can ensure the correction of errors in the generated attenuation signal relative to the noise present, thereby solving the safety problems in work contexts related to the presence of noise also in dynamic conditions.

[0013] A further advantage of the invention is in that the signals detected by the device can allow, either directly or through the network, optimizations in the operation of machines present in the working environment with benefits on energy consumption, detection, and signaling of working anomalies which could compromise both product quality and machine reliability.

[0014] Furthermore, an advantage of the invention is that it can be configured to adapt to various applications, even the most complex, in both the industrial and service sectors.

[0015] A further advantage of the invention is in the possibility of providing a vibration sensor and to interconnect on Ethernet network (or as WiFi, RS232 option, etc.), allowing the control of further parameters and the connectability in 4.0 enterprise networks, allowing an enterprise resource planning system connected to the device (either on enterprise or machine level) to emit signals or to induce useful corrections to the provided processes.

[0016] For example, in case of vibrations, the enterprise resource planning system can signal or implement a different automatic processing mode.

[0017] Furthermore, in case of machines that produce vibrations, such as presses, the presence of a vibration control makes it possible to highlight, e.g. if the processed product is not ejected, a different noise that is linked to the presence of the residual piece. Therefore, in automatic operation, the machine stops thus avoiding damages and warns, through the enterprise resource planning system, that the machine has stopped even when there is no operator. Another application is that of machine tools, in which, in case of tool wear, the vibrations change, and through the suggested system it is possible to detect and highlight the anomaly with consequent signaling to the operator and the product quality control before subsequent phases or delivery to the customer.

[0018] A further advantage of the invention consists in the possibility of providing a modular structure which makes it possible to install the device aftermarket.

[0019] A further advantage of the invention is in that the device can be set to select the fundamental frequencies of the noise source to manage signal generation stably and avoid undesirable system operations which could thwart the achievement of the results.

List of drawings

[0020] These and further advantages will be better un-

derstood by a person skilled in the art from the description that follows and the accompanying drawings, provided by way of non-limiting example, in which:

- fig.1 diagrammatically shows a device according to the invention;
- fig. 2 shows the flow chart of a possible attenuation algorithm according to the invention.

Detailed description

[0021] With reference to the accompanying drawings, a device for the active attenuation and control of ambient noise according to the invention is described in Fig. 1. The device comprises an ambient microphone 1 which converts the detected ambient noise into a corresponding electrical, analog, or digital signal.

[0022] The electrical signal coming from the microphone is then shared and applied in parallel to various band-pass filters, e.g. three filters 2, 3, 4, with configurable frequency bands adaptable according to the noise signal and its predominant frequencies.

[0023] Advantageously, the predominant frequencies can be identified by means of preliminary ambient noise measurement, performed with specific meters or with the device itself used in ambient learning mode, followed by spectral analysis of the noise itself, performable by the same invention. The band-pass filters 2, 3, 4 are then centered on the predominant frequencies identified so that they can pass without appreciable attenuation, but with the elimination of the noise and off-band components which would cause errors in the exact identification of the disturbance.

[0024] Although in various embodiments of the device, the filters 2-4 can be either analog or digital, digital filters are preferable because they are easier to reconfigure.

[0025] Phase shifters 5,6,7, also configurable, are connected to the output of each band-pass filter and are adapted to introduce a suitable phase on the corresponding signal from each filter.

[0026] In particular, the phase to be introduced at the output of the individual filters will preferably be either equal or close to 180°, where the approximation takes into account the phase shifts of the downstream circuits, the phase shift as a function of frequency, and the spatial propagation delay after the electro-acoustic conversion.

[0027] As for the microphone and filters, the phase shifters can also be either analog or digital, providing they are configurable.

[0028] After the filtering operation by means of the filters 2-4 and the introduction of the correct phase by means of the phase-shifters 5-7, chosen according to the features of the noise signal to be reduced, the individual portions of the signal from the phase shifters are recombined in a sum node 8, which may also be either analog or digital.

[0029] The reproduced signal from the node 8 is then applied both to a variable gain preamplifier 10 followed by a first power amplifier 12 which drives the first loudspeaker 14 and to a further configurable phase shifter 9 followed by a second amplification chain comprising a second variable gain preamplifier 11 followed by a second power amplifier 13 which drives a second loudspeaker 15.

[0030] The loudspeakers 14, 15, fed by the input signals filtered, rephased, and amplified according to the features of the ambient noise detected by the microphone 1, thus emit an acoustic attenuation signal at the same frequencies and in counter-phase to the original ambient noise.

[0031] According to the invention, the remaining portion of ambient noise is then measured in two or more points by means of ambient feedback microphones 18,19, followed by the preamplification chain 17,20, and the respective analog digital converters 16, 21 necessary in case a digital control unit is chosen. Obviously, such converters are not present in the case of analog control units.

[0032] According to the invention, the signals from the feedback microphones 18, 19, are received by a control unit 23 (either analog or digital), which acquires and numerically processes the signals.

[0033] The unit 23, which is connected at least to the filters 2-4, the phase shifters 5-7 and 9, and the variable gain preamplifiers 10-11, as shown by the dashed connection lines in figure 1, is also in charge of controlling of the phase and amplitude selection of the attenuation signals, which is performed according to a control algorithm suggested for this purpose.

[0034] Advantageously, the use of configurable band-pass filters 2,3,4 makes it possible to apply and focus the noise reduction algorithm on the frequency band where it is predominant.

[0035] This makes it possible to optimize performance by avoiding the generation of spurious signals, which may constitute additional noise, in turn.

[0036] During operation, after having identified and selected the frequency band(s) in which the noise is predominant, the system sets the correct phase on the band(s) of interest to synthesize the correct signal to be sent to the external loudspeaker 14, after the appropriate amplification.

[0037] The signal produced in counter-phase relative to the noise signal, either reduces it or cancels it completely.

[0038] The ambient microphones 18,19 measure the residual noise level by providing information to the control unit which dynamically and in real-time corrects the phases on the individual bands, the output chain, and the signal amplitude to be applied on the main output 14.

[0039] The control unit selects microphones 18 or 19 according to the zone in which to focus the noise reduction. The number of such detectors may be arbitrary and positioned at various points in the space of interest.

[0040] The section which ends with the loudspeaker 15 is used if it is necessary to cancel the ambient noise

in a region of the space which is not orthogonal to the main loudspeaker 14.

[0041] For this purpose, by carefully selecting the phase shift 9 and preamplifier gain 11, it is possible to change the direction of the noise attenuation wave.

[0042] The invention may also provide the use of a higher number of outputs.

[0043] In a preferred embodiment, the device of the invention further provides one or more vibration sensors 27 to be able to intervene on the corresponding machine in the working environment, thus optimizing performance in terms of energy and sound.

[0044] Advantageously, the device will be able to communicate via an IP 22 interface, with the possibility of working in the Cloud and interacting operatively with other possible devices, either located in the same working environment or remotely.

[0045] A communication port may also be present, e.g. RS232-USB 24 and/or a WiFi module for wireless connection 25.

[0046] The device may also interact with other systems or machines using analog and/or digital input/output signals 26.

An attenuation algorithm usable according to the invention is described by way of example.

The suggested algorithm provides the following steps, summarized in the flow chart in Fig. 2:

1) frequency analyzing the noise components through an FFT (Fast Fourier Transform) on the signal from the microphone 1 performed by means of the invention suggested in ambient learning mode;
2) identifying the predominant noise frequency components, through the comparison with a predetermined threshold of the modules of components calculated in step (1);
3) setting the central frequencies of the band-pass filters 2,3,4 by the control unit 23 according to the analysis in step (2). In the numerical version, these are FIR (Finite Impulsive Response) filters in which the band is changed by changing the filter coefficients;
4) introducing a phase on each filtered line equal to 180° plus or minus a variable rate, the amount of which is proportional to the amplitude of the component of residual noise measured at that predetermined frequency;
5) recomposing as a sum 8 of the signals from the branches 2,3,4 to generate an attenuation signal;
6) amplifying with variable gain 10 the attenuation signal followed by power amplification 13 to drive the ambient loudspeaker 15;
7) acquiring the residual noise through the microphone 17;
8) processing the residual noise in step (7) by means of the control unit 23. Such processing, preferably carried out numerically, consists of a further frequency analysis using an FFT algorithm adapted to identify both the amplitude and phase of the residual noise frequency components. Said components, in stationary state, have frequencies similar to those selected as the central frequencies of the band-pass filters of step (3). If the difference between the frequencies identified in step (1) and those identified on the residual noise is greater than a predefined threshold, the control unit varies the central frequencies of the filters in step (3). In any operating case, such variation occurs with a time constant which is much slower than the typical processing time in the perspective to avoid the instability of the algorithm;
9) defining, by the control unit, the correct phases of the phase shifters 5,6,7 of the step (4) and of the amplification factor 10.

The addition or subtraction of a phase delta relative to the 180° of step (4) corresponding to the i-th bandpass line is proportional to the amplitude of the corresponding residual noise harmonic of steps (7) and (8). The gain coefficient G, 10 is calculated according to the amplitude of the residual noise signal measured at step (7).

[0047] In an advantageous aspect of the invention, the described device allows the optimization of the performance of the machines for industrial use operationally connected to it, with an increase in their reliability, the reduction of energy consumption, the increase in industrial productivity as well as the reduction of noise produced in the working environment.

[0048] By virtue of the possibility of interfacing the device with the machines involved in the production processes, the device itself can operate as a process interface to the enterprise resource planning system.

[0049] Indeed, the analysis of noise and vibration is useful information for controlling both the production process, e.g. to highlight drifts from the correct operation of the machine and/or machining tools. Furthermore, by interfacing the device which is the object of the invention appropriately with the machine, it is possible to optimize the working conditions and, given the network connection, to interface the machine itself in an industry 4.0 system. The communication protocols will be of standard type, such as MQTT or equivalent.

[0050] The components used and the construction logic also allow both software and hardware components to make the necessary configurations for optimizing and adapting the device to the specific purpose of use.

[0051] The described invention thus achieves important advantages.

[0052] A first advantageous aspect of the present invention is that the control system, by being able to interface both with the machines and with the enterprise resource planning system, can manage noise reduction efficiently and reliably by interacting with the machines and/or the enterprise network and makes it possible to optimize the operation of the machines themselves also relative to noise, and this both individually and in a more complex context.

[0053] Assuming an enterprise network, consisting of multiple machines and associating a device which is the object of the present invention with each machine, in addition to noise reduction, it is possible, through the enterprise resource planning system, to modulate the optimal management of each machine to improve production performance by reducing both noise and energy consumption, to the benefit of product quality and less machine wear.

[0054] A further advantageous aspect is that the device, with or without control of the enterprise resource planning system, can provide functional references to the PLC or CNC of a machine associated with it to vary the operating conditions of the machine itself within an appropriate range. Furthermore, if the machine allows it, it can transmit some fundamental information for control in industry 4.0 perspective to the enterprise resource planning system. In particular, if the device shows variations in noise or vibration, the available data can be used by the production control to prevent a faulty product from continuing in the production flow.

[0055] By virtue of the availability of different outputs, the invention further allows a spatial selectivity of noise abatement levels according to the areas of interest.

Experimental results

[0056] Laboratory tests carried out with stationary test signals, through instrumental measurements on a simulated station, showed a noise reduction of about 4.5 dB. Furthermore, on a machine operating in stationary mode, it was possible to generate an attenuation signal, also not electronically controlled, which produced a noise reduction of about 3.7 dB.

[0057] The simulations and field measurements allow the device presented herein, a noise reduction of between 3 and 6 dB with high reliability.

[0058] Therefore, the suggested device allows the use of lightweight earphones instead of headphones at these locations, thereby reducing the frequency of medical check-ups and reducing occupational hearing-related diseases.

[0059] For this reason, the minimum objectives set would be sufficient to achieve significant benefits for the wellbeing of workers.

[0060] Furthermore, the use of networked sensor-optimized adjustment controls on the motors of the processing machines has resulted in a reduction of about 2.8 dB in the produced noise.

[0061] In addition, it has been found in the motors of the processing machines that even a 10% speed reduction allows energy savings of 10% to 20% compared to normal conditions of use. This is because the machines themselves have adjustment time margins relative to expected productivity or product flow.

[0062] The present invention was described according to preferred embodiments, but equivalent variants may be devised without departing from the scope of protection of the invention.

Claims

1. An active ambient noise attenuation and control device, comprising:

   an ambient microphone (1) to detect an ambient noise comprising one or more predominant frequencies and convert the ambient noise detected into a corresponding electric attenuation signal,
   one or more band-pass filters (2, 3, 4) connected in parallel to said microphone (1) to receive the output electric signal from the microphone, wherein said filters (2, 3, 4) are centered on frequency bands which are configurable and adaptable according to the noise signal and the predominant frequencies thereof,
   one or more phase shifters (5, 6, 7), each connected at the output to a respective band-pass filter (2, 3, 4), wherein said phase shifters are configurable to introduce a phase on the corresponding signal output from each filter either equal or close to 180° and output corresponding shifted signals,
   a sum node (8) connected at the output to said phase shifters to recombine the respective signal rates and output a recombined signal,
   at least one recombined signal amplification chain, comprising a variable gain preamplifier (10, 11) followed by a power amplifier (12, 13), for outputting an amplified signal,
   at least one loudspeaker (14, 15) fed by said amplified signal to convert the amplified signal into an acoustic ambient noise attenuation signal,
   one or more feedback ambient microphones (18, 19) to detect a residual ambient noise rate and convert it into an electric feedback signal,
   at least one preamplification chain (17,20) to amplify said feedback signals,
   at least one control unit (23) configured to acquire said feedback signals and operatively connected to control the configuration of at least said filters (2-4), said phase shifters (5-7) and said variable gain preamplifier (10-11), wherein the control unit (23) is arranged to numerically process the acquired feedback signals and configure the phases and amplitudes of the attenuation signal according to an attenuation algorithm executed in response to the acquired feedback signal processing.

2. A device according to claim 1, wherein said node (8) is connected at the output to a further configurable phase shifter (9) followed by a second amplification

chain comprising a second variable gain preamplifier (11) followed by a second power amplifier (13), which drives a second loudspeaker (15) to convert the amplified signal into a further acoustic ambient noise attenuation signal, wherein said further phase shifter (9) and said second variable gain preamplifier (11) are operatively connected to said control unit (23) .

3. A device according to claim 1 or 2, comprising one or more vibration sensors (27) connected to said control unit (23) to send signals associated with the vibrational state of one or more machines present in the ambient.

4. A device according to one of the preceding claims, comprising an IP interface (22) connected to said control unit (23).

5. A device according to one of the preceding claims, comprising a communication port and/or a Wi-Fi module (25) for wireless connection.

6. A device according to one of the preceding claims, comprising input/output analog and/or digital signal lines (26) to interface with other devices or with other systems or machines.

7. A device according to any one of the preceding claims, wherein said control unit (23) is configured to execute an attenuation algorithm comprising the following steps:

frequency analyzing the noise components through an FFT transform on the signal from the microphone (1);
identifying the predominant noise frequency components, through the comparison with a predetermined threshold of the modules of components calculated during said step of frequency analyzing;
setting the central frequencies of the band-pass filters (2,3,4) according to the frequency components identified in said step of identifying;
introducing a phase on each filtered line equal to 180° plus or minus a variable rate, the amount of which is proportional to the amplitude of the component of residual noise measured at that predetermined frequency;
recomposing as a sum of the signals from the branches (2,3,4) and generating an attenuation signal;
amplifying with variable gain of the attenuation signal followed by power amplification in order to drive the ambient loudspeaker (15);
acquiring the residual noise through the microphone (17);
processing the acquired residual noise and identifying the residual noise frequencies;
if the difference between the frequencies identified in said step of frequency analyzing the noise components and those identified in said step of processing the acquired residual noise is greater than a predetermined threshold,

varying the central frequencies in said step of setting the central frequencies of the band-pass filters;
defining, in said step of introducing a phase on each filtered line, the correct phases of the phase shifters (5,6,7) and a correct amplification factor in said step of amplifying the attenuation signal.

8. A device according to claim 7, wherein in said step of introducing a phase on each filtered line, the addition or subtraction of a phase delta with respect to 180°, corresponding to the i-th band-pass line, occurs proportionally to the amplitude of the corresponding residual noise harmonic.

9. A device according to claim 7 or 8, wherein in said step of amplification, the gain coefficient is calculated according to the amplitude of the acquired residual noise signal.

10. A device according to any one of claims 7-9, wherein said residual signal is numerically processed by means of FFT algorithm frequency analysis adapted to identify both the amplitude and the phase of the residual noise frequency components.

11. A device according to one of claims 7-10, wherein said steps of frequency analyzing and identifying the predominant noise frequency components are preliminarily performed in ambient learning mode.

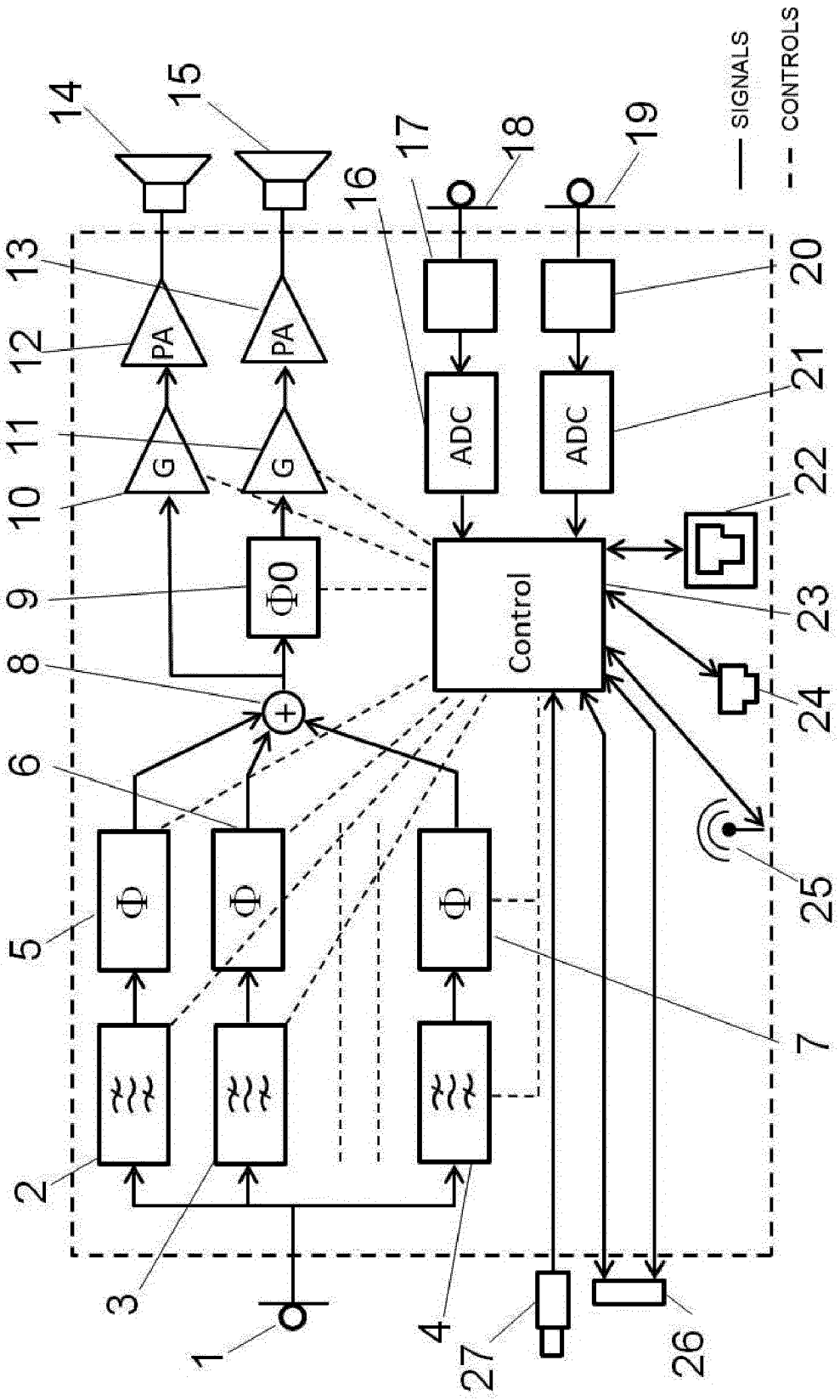
SIGNALS
CONTROLS
PA
PA
G
G
ADC
ADC
Control
Φ
Φ
Φ
Φ0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27

FIG.1

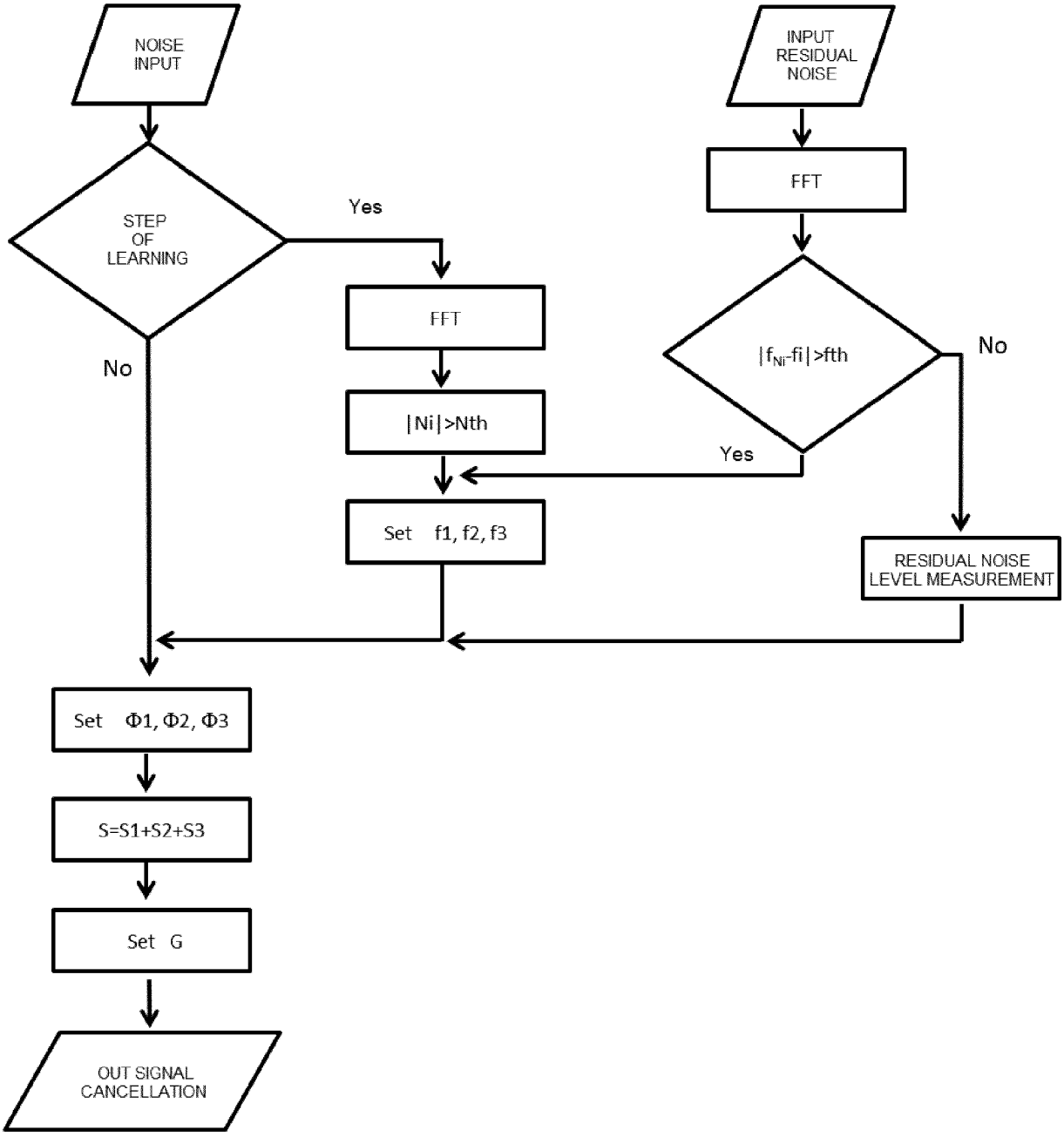
NOISE INPUT
STEP OF LEARNING
Yes
No
FFT
|Ni|>Nth
Set f1, f2, f3
INPUT RESIDUAL NOISE
FFT
|fNi-fi|>fth
No
Yes
RESIDUAL NOISE LEVEL MEASUREMENT
Set Φ1, Φ2, Φ3
S=S1+S2+S3
Set G
OUT SIGNAL CANCELLATION

FIG. 2

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 20 19 8515

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	US 10 565 979 B1 (CHRISTIAN JONATHAN [US] ET AL) 18 February 2020 (2020-02-18) * abstract; claims 1,5; figures 1,3,10,16 * * column 3, lines 56-59 * * column 4, lines 10-15 *	1-11	INV. G10K11/178
Y	US 2015/195646 A1 (KUMAR AMIT [US] ET AL) 9 July 2015 (2015-07-09) * abstract; claims 1,2; figure 9 * * paragraphs [0042], [0043] *	1-11	
Y	US 9 589 574 B1 (KLIMANIS GINTS [US] ET AL) 7 March 2017 (2017-03-07) * abstract; claim 1; figures 1,2,6B * * column 5, lines 50-60 *	4-6,11	
			TECHNICAL FIELDS SEARCHED (IPC) G10K

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	11 March 2021	Fernandes, Paulo

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 19 8515

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

11-03-2021

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 10565979 B1	18-02-2020	CN 111063332 A	24-04-2020
		DE 102019127820 A1	16-04-2020
		US 10565979 B1	18-02-2020
US 2015195646 A1	09-07-2015	US 2015195646 A1	09-07-2015
		US 2018053497 A1	22-02-2018
		US 2019043469 A1	07-02-2019
US 9589574 B1	07-03-2017	US 9589574 B1	07-03-2017
		US 2017142512 A1	18-05-2017
		US 2018330743 A1	15-11-2018
		US 2019037301 A1	31-01-2019

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82