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(54) **ELECTRONIC SYSTEM HAVING HEAT DISSIPATION AND FEED-FORWARD ACTIVE NOISE CONTROL FUNCTION**

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CPC .. ***G10K 11/17883*** (2018.01); ***G10K 11/17854*** (2018.01); ***G10K 11/17881*** (2018.01)

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See application file for complete search history.

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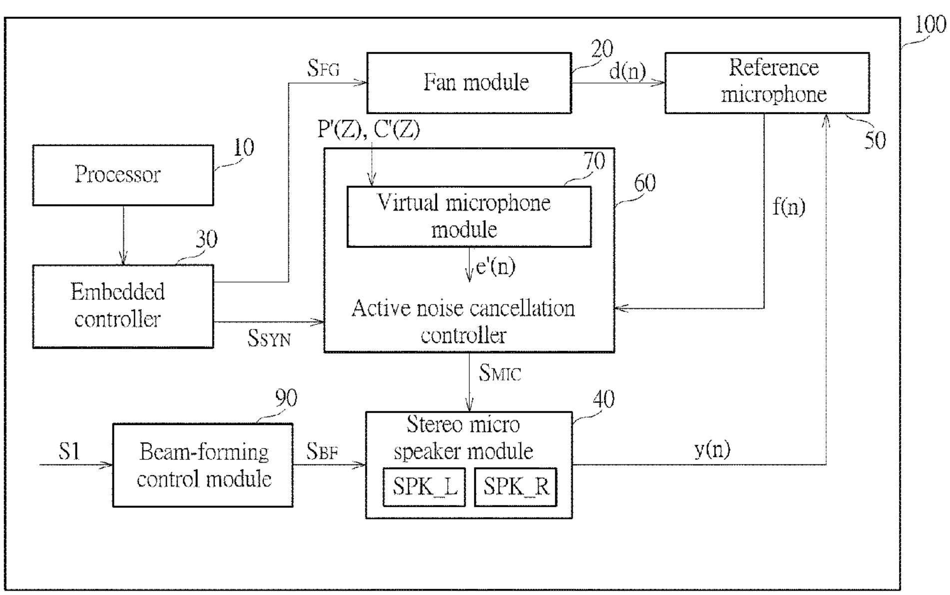
(57) **ABSTRACT**

An electronic system includes a fan module, an embedded controller, a reference microphone, a stereo speaker module, a beam-forming control module and an ANC controller. The beam-forming control module controls the orientation of the stereo speaker module, which provides a noise cancellation signal according to a speaker control signal. The reference microphone outputs a wide-band noise signal associated with the operation of the fan module. A virtual microphone module in the active noise cancellation controller outputs a virtual error signal according to a first transfer function between the reference microphone and a physical error microphone at a predetermined fan speed, a second transfer function between the stereo speaker module and the physical error microphone when the fan module is not in operation and the wide-band noise signal. The ANC controller provides the speaker control signal according to a synchronization signal, the wide-band noise signal and the virtual error signal.

20 Claims, 6 Drawing Sheets



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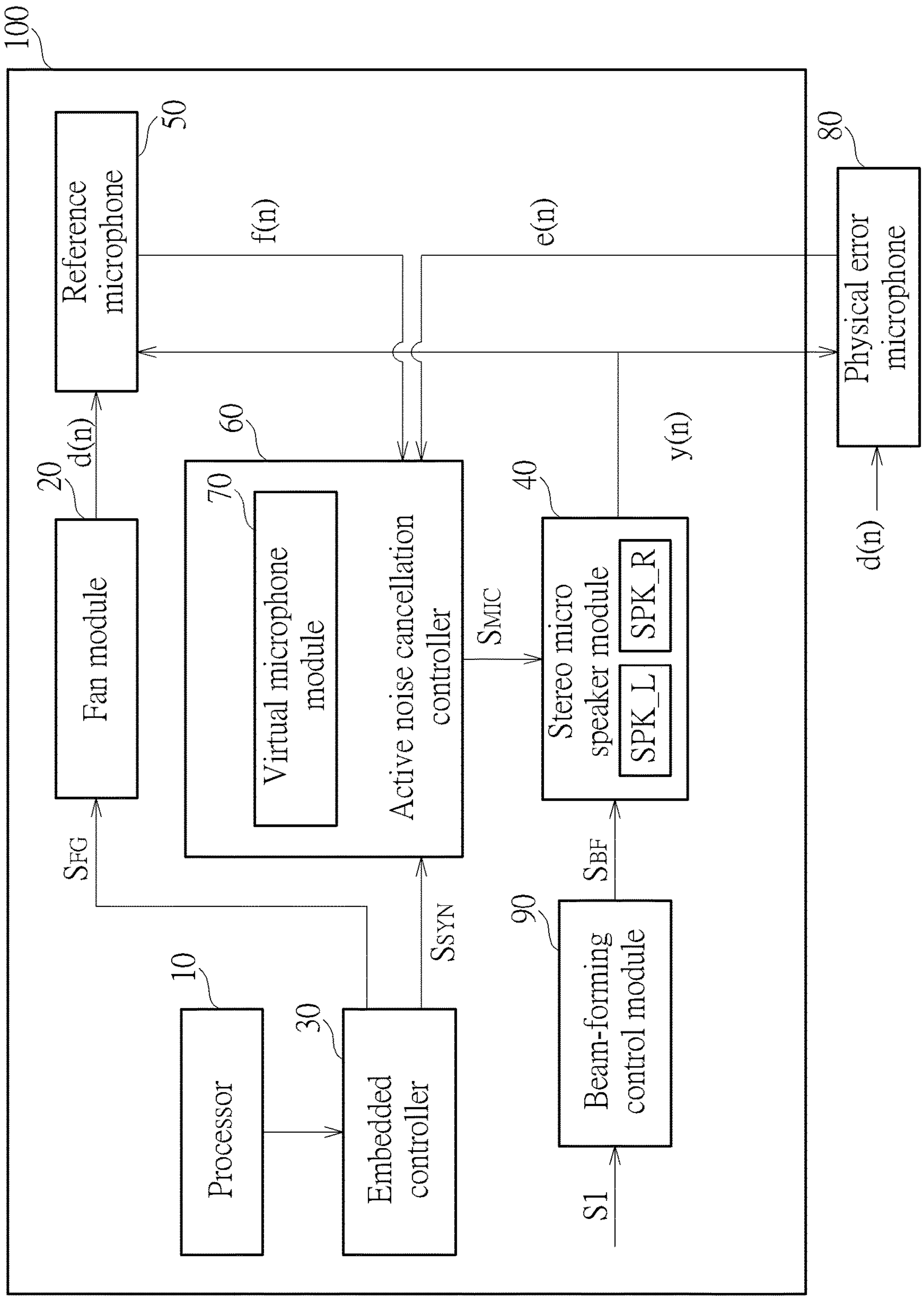

100
Reference microphone
50
f(n)
e(n)
80
Physical error microphone
d(n)
20
Fan module
60
70
Virtual microphone module
Active noise cancellation controller
40
Stereo micro speaker module
SPK_L
SPK_R
y(n)
S_{MIC}
S_{FG}
S_{SYN}
S_{BF}
10
Processor
30
Embedded controller
90
Beam-forming control module
S1
d(n)

FIG. 1

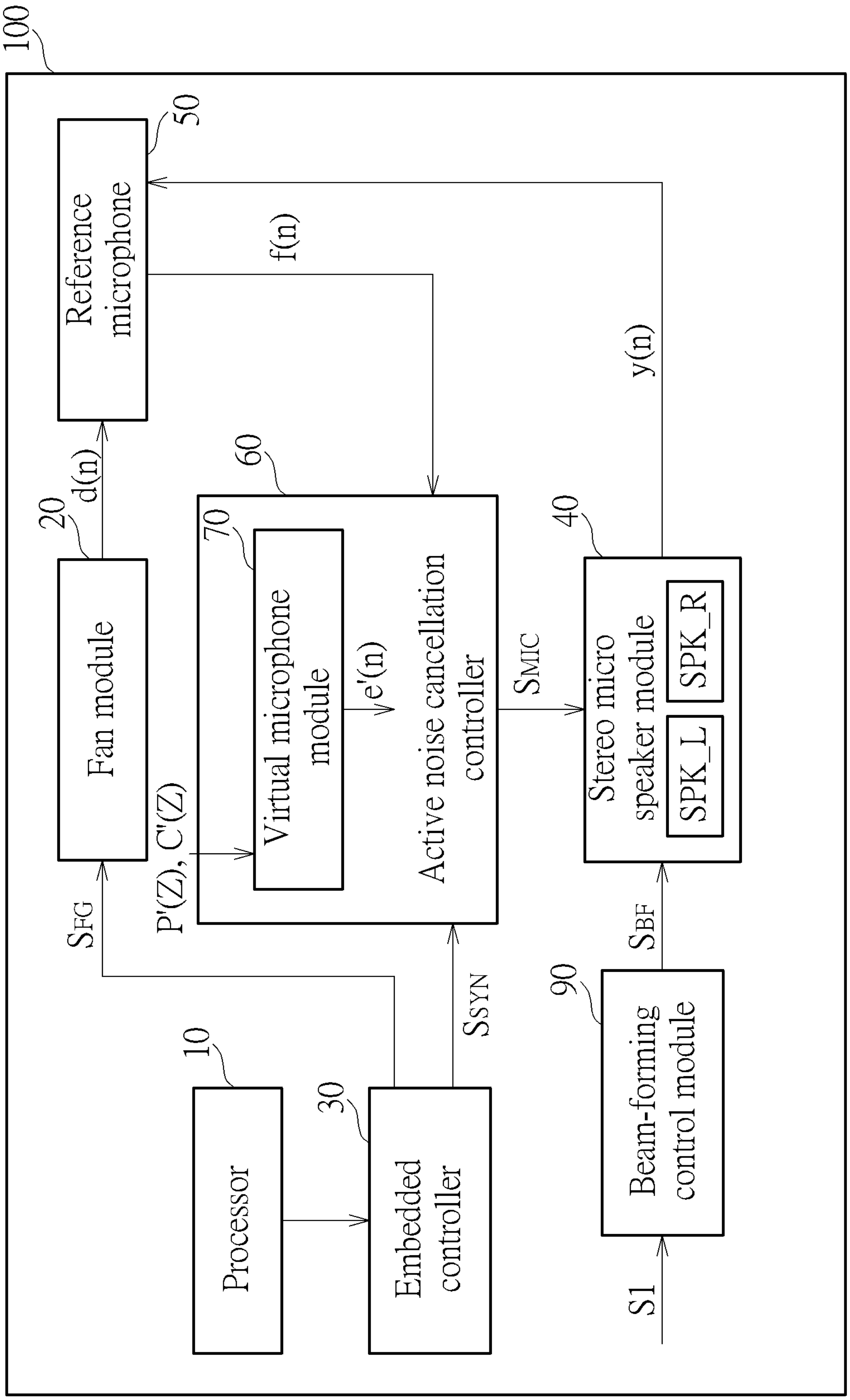
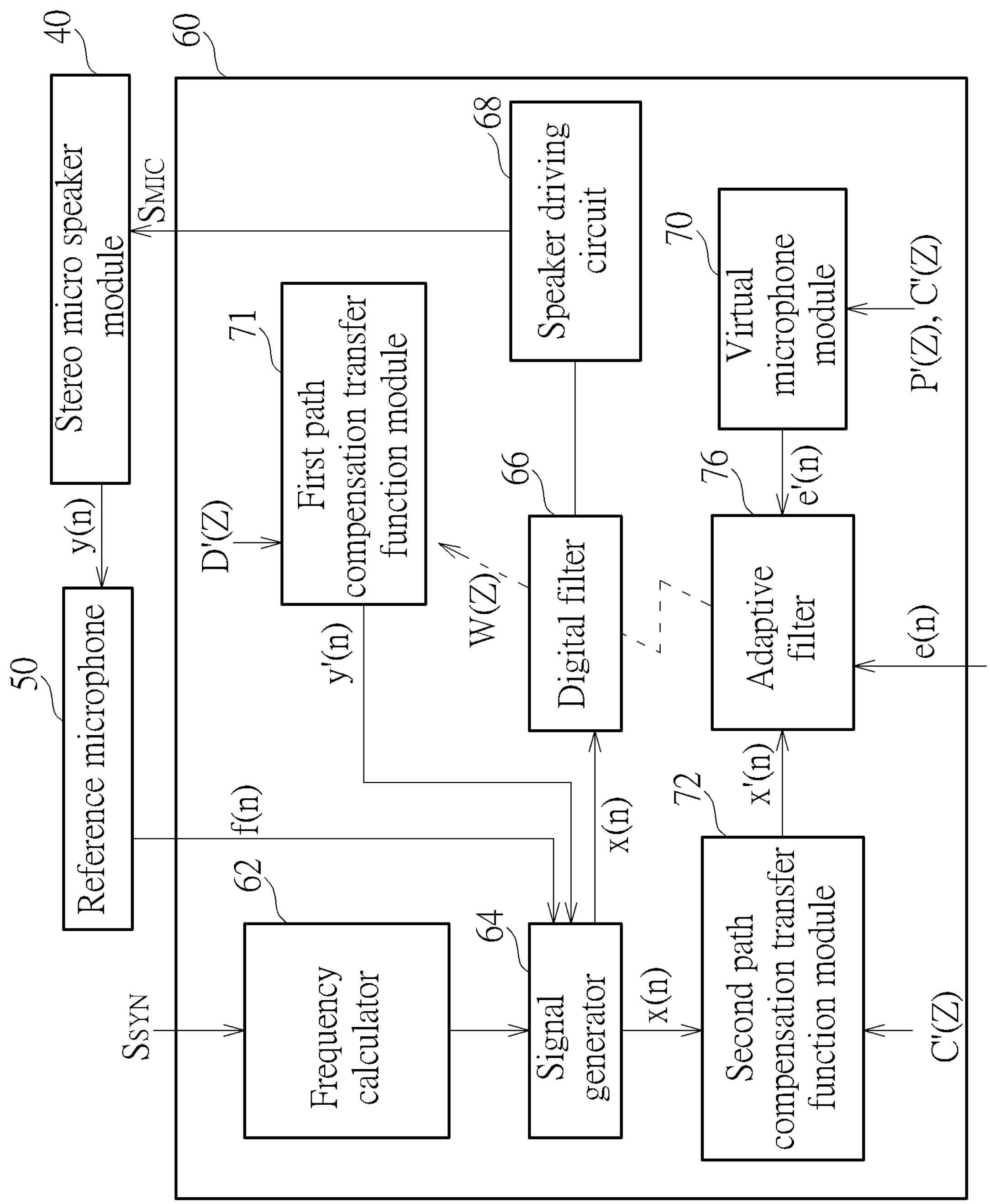

100
Reference microphone
50
f(n)
y(n)
d(n)
20
Fan module
60
70
Virtual microphone module
e'(n)
Active noise cancellation controller
S_{MIC}
40
Stereo micro speaker module
SPK_R
SPK_L
P'(Z), C'(Z)
S_{FG}
S_{SYN}
S_{BF}
90
Beam-forming control module
10
Processor
30
Embedded controller
S1

FIG. 2



40
Stereo micro speaker module
50
Reference microphone
60
62
Frequency calculator
64
Signal generator
66
Digital filter
68
Speaker driving circuit
70
Virtual microphone module
71
First path compensation transfer function module
72
Second path compensation transfer function module
76
Adaptive filter
SSYN
SMIC
y(n)
y'(n)
f(n)
x(n)
x'(n)
e(n)
e'(n)
D'(Z)
W(Z)
C'(Z)
P'(Z), C'(Z)

FIG. 3

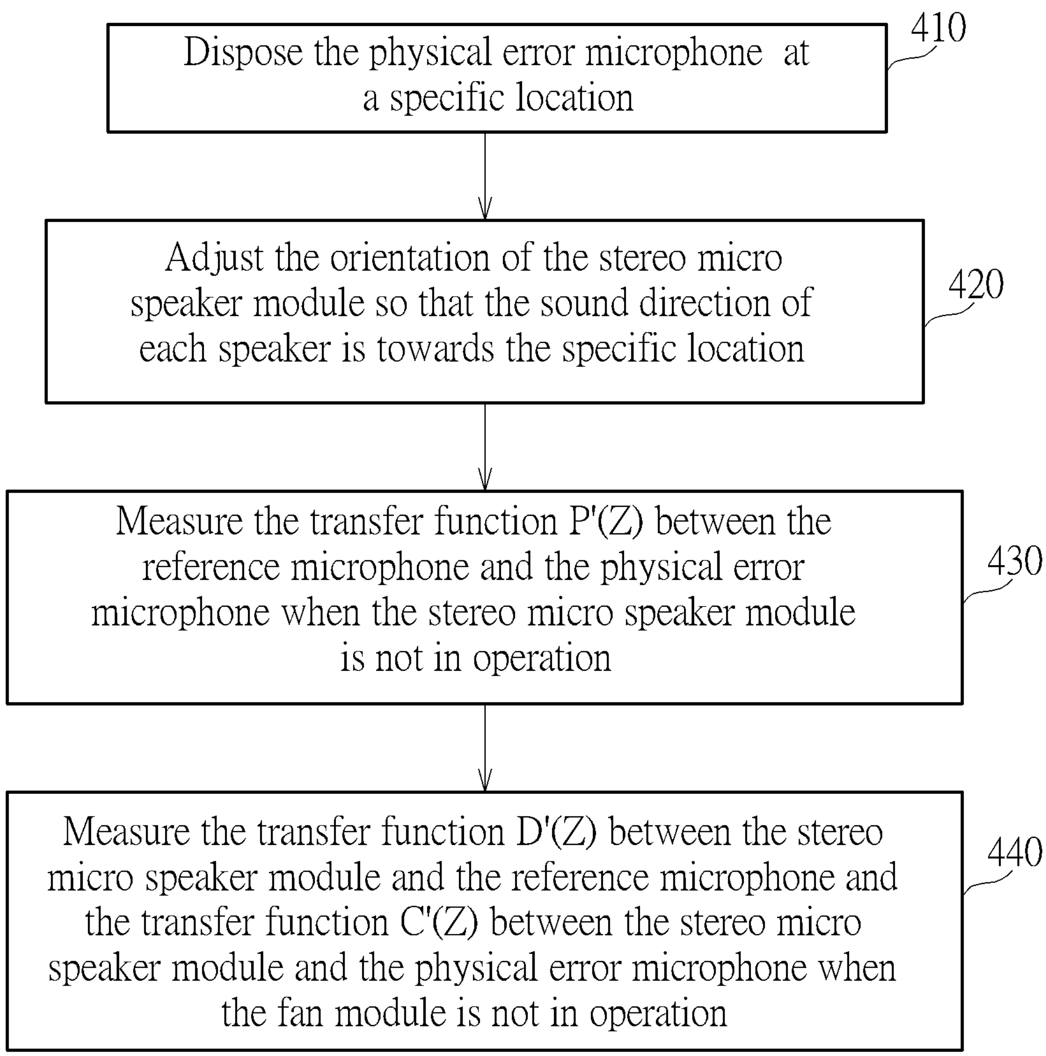

Dispose the physical error microphone at a specific location
410
Adjust the orientation of the stereo micro speaker module so that the sound direction of each speaker is towards the specific location
420
Measure the transfer function P'(Z) between the reference microphone and the physical error microphone when the stereo micro speaker module is not in operation
430
Measure the transfer function D'(Z) between the stereo micro speaker module and the reference microphone and the transfer function C'(Z) between the stereo micro speaker module and the physical error microphone when the fan module is not in operation
440

FIG. 4

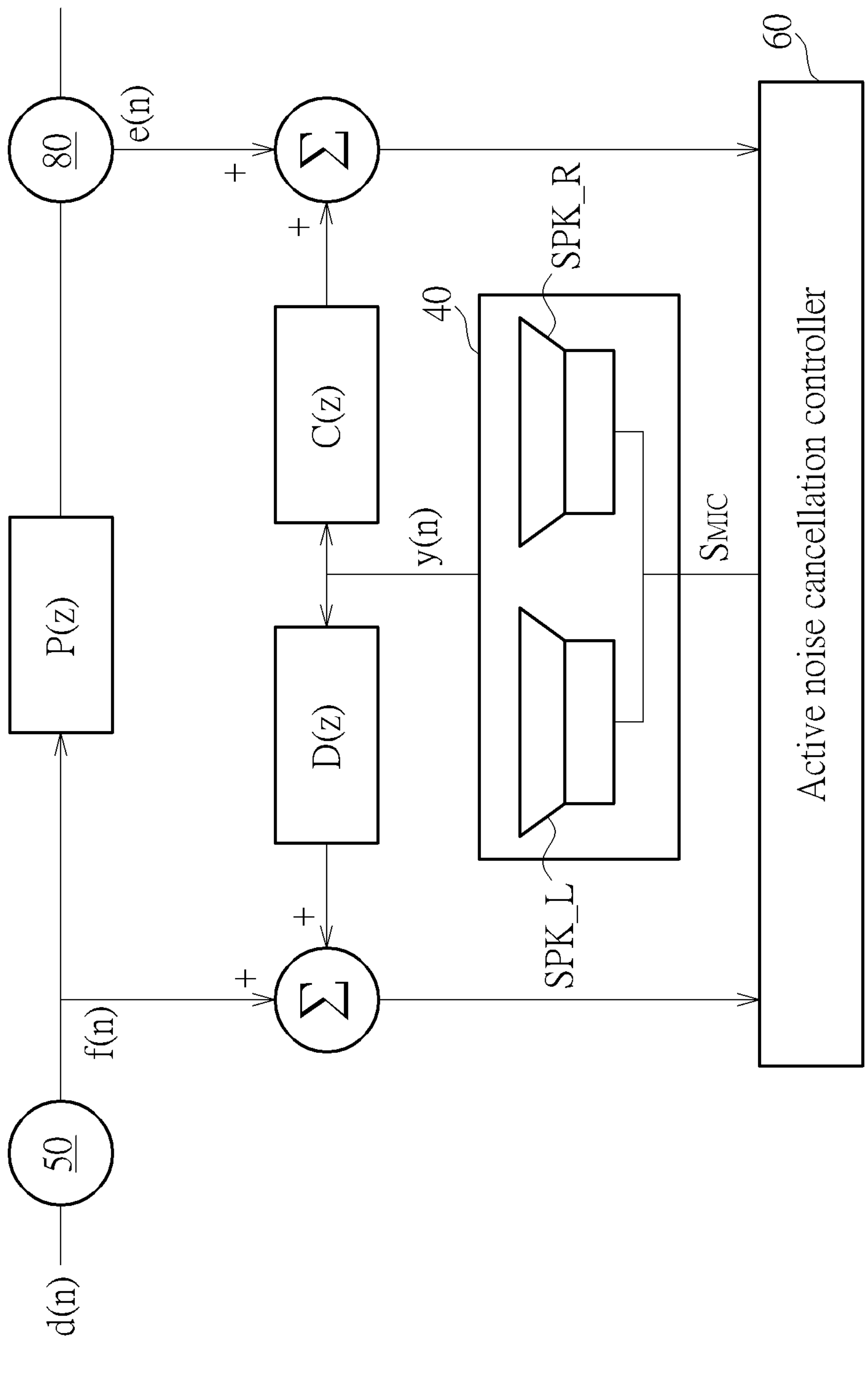

d(n)
50
f(n)
P(z)
80
e(n)
+
+
Σ
C(z)
y(n)
D(z)
+
+
Σ
40
SPK_R
SPK_L
S_{MIC}
60
Active noise cancellation controller

FIG. 5

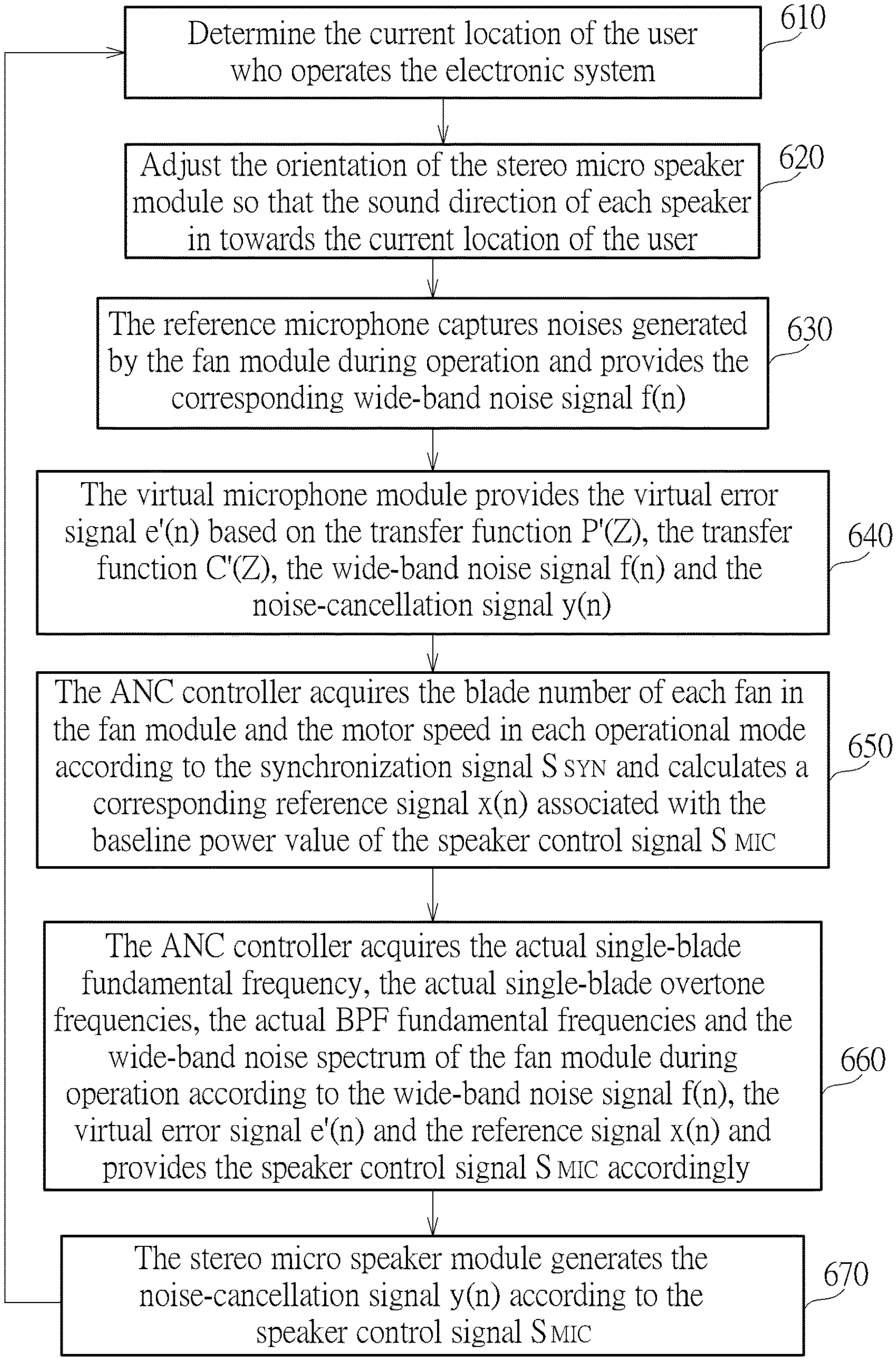

Determine the current location of the user who operates the electronic system
610
Adjust the orientation of the stereo micro speaker module so that the sound direction of each speaker in towards the current location of the user
620
The reference microphone captures noises generated by the fan module during operation and provides the corresponding wide-band noise signal f(n)
630
The virtual microphone module provides the virtual error signal e'(n) based on the transfer function P'(Z), the transfer function C'(Z), the wide-band noise signal f(n) and the noise-cancellation signal y(n)
640
The ANC controller acquires the blade number of each fan in the fan module and the motor speed in each operational mode according to the synchronization signal S SYN and calculates a corresponding reference signal x(n) associated with the baseline power value of the speaker control signal S MIC
650
The ANC controller acquires the actual single-blade fundamental frequency, the actual single-blade overtone frequencies, the actual BPF fundamental frequencies and the wide-band noise spectrum of the fan module during operation according to the wide-band noise signal f(n), the virtual error signal e'(n) and the reference signal x(n) and provides the speaker control signal S MIC accordingly
660
The stereo micro speaker module generates the noise-cancellation signal y(n) according to the speaker control signal S MIC
670

FIG. 6

ELECTRONIC SYSTEM HAVING HEAT DISSIPATION AND FEED-FORWARD ACTIVE NOISE CONTROL FUNCTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is related to an electronic system having heat dissipation and feed-forward active noise control function and a related method, and more particularly, to an electronic system having heat dissipation and feed-forward active wide-band noise control function based on virtual error signal and beam-forming technique and a related method.

2. Description of the Prior Art

Computer systems have been widely used in modern society. Computer components depend on the passage of electric current to process information. The current flow through the resistive elements of the computer components is accompanied by heat dissipation. The essence of thermal design is the safe removal of this internally generated heat which may jeopardize the components safety and reliability. An electronic system normally adopts a fan capable of accelerating the exchange of air for heat dissipation purpose.

The rotational speed and the static pressure of a fan determine the volume of air which the fan delivers per minute or per hour. The noise generated during the operation of the fan is roughly proportional to the fan speed to the power of 5. More efficient heat dissipation can be achieved under a faster fan speed, but with the main drawback of generating more noises. The trend of adopting more powerful central processing units (CPUs) and device miniaturization increase the amount of heat produced per unit area of the components. Therefore, there is a need of addressing the issues of heat dissipation and noise reduction at the same time.

SUMMARY OF THE INVENTION

The present invention provides an electronic system with heat dissipation and feed-forward active noise control function. The electronic system includes a fan module, an embedded controller, a reference microphone, a stereo micro speaker module, a beam-forming control module and an active noise cancellation controller. The fan module is configured to operate according to a fan control signal for providing heat dissipation. The embedded controller is configured to provide the fan control signal. The reference microphone is configured to detect a wide-band noise generated during an operation of the electronic system and provide a corresponding wide-band noise signal. The stereo micro speaker module includes at least a first speaker and a second speaker, and is configured to generate a noise-cancellation signal according to the speaker control signal. The beam-forming control module is configured to provide a beam-forming control signal for controlling an orientation of the stereo micro speaker module so that a sound direction of the first speaker and a sound direction of the second speaker are towards a specific location. The active noise cancellation controller is configured to provide a virtual error signal according to a first transfer function, a second transfer function and the wide-band noise signal; and provide the speaker control signal according to a synchronization signal, the wide-band noise signal and the virtual error signal. the synchronization signal includes information associated with a structure and an operational setting of the fan module. The first transfer function is a transfer function between the reference microphone and a physical error microphone when the stereo micro speaker is not in operation. The second transfer function is a transfer function between the stereo micro speaker module and the physical error microphone when the fan module is not in operation. The noise-cancellation signal includes a plurality of noise-compensation signals for canceling noises generated during the operation of the electronic system.

The present invention also provides a method of providing heat dissipation and feed-forward active noise control function in an electronic system. The method includes operating a fan module in the electronic system according to a fan control signal for providing heat dissipation; providing the fan control signal using an embedded controller in the electronic system; detecting a wide-band noise generated during an operation of the electronic system and providing a corresponding wide-band noise signal using a reference microphone in the electronic system; generating a noise-cancellation signal according to the speaker control signal using at least a first speaker and a second speaker of a stereo micro speaker module in the electronic system; providing a beam-forming control signal for controlling an orientation of the stereo micro speaker module using a beam-forming control module in the electronic system so that a sound direction of the first speaker and a sound direction of the second speaker are towards a specific location; providing a virtual error signal according to a first transfer function, a second transfer function and the wide-band noise signal using an active noise cancellation controller in the electronic system; and providing the speaker control signal according to a synchronization signal, the wide-band noise signal and the virtual error signal using the active noise cancellation controller. The synchronization signal includes information associated with a structure and an operational setting of the fan module. The first transfer function is a transfer function between the reference microphone and a physical error microphone when the stereo speaker is not in operation. The second transfer function is a transfer function between the stereo micro speaker module and the physical error microphone when the fan module is not in operation. The noise-cancellation signal includes a plurality of noise-compensation signals for canceling noises generated during the operation of the electronic system.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional diagram illustrating an electronic system having heat dissipation and feed-forward active noise control function when operating in an off-line mode according to an embodiment of the present invention.

FIG. **2** is a functional diagram illustrating an electronic system having heat dissipation and feed-forward active noise control function when operating in an on-line mode according to an embodiment of the present invention.

FIG. **3** is a diagram illustrating an implementation of an active noise cancellation controller in an electronic system according to an embodiment of the present invention.

FIG. **4** is a flowchart illustrating the operation of an electronic system having heat dissipation and feed-forward active noise control function in the off-line mode according to an embodiment of the present invention.

FIG. **5** is a diagram illustrating the transfer functions between a stereo micro speaker module, a reference microphone and a physical error microphone during signal transmission when an electronic system having heat dissipation and feed-forward active noise control function operates in the off-line mode according to an embodiment of the present invention.

FIG. **6** is a flowchart illustrating the operation of an electronic system having heat dissipation and feed-forward active noise control function in the on-line mode according to an embodiment of the present invention.

DETAILED DESCRIPTION

FIG. **1** is a functional diagram illustrating an electronic system **100** having heat dissipation and feed-forward active noise control function when operating in an off-line mode according to an embodiment of the present invention. FIG. **2** is a functional diagram illustrating the electronic system **100** having heat dissipation and feed-forward active noise control function when operating in an on-line mode according to an embodiment of the present invention.

The electronic system **100** includes a processor **10**, a fan module **20**, an embedded controller (EC) **30**, a stereo micro speaker module **40**, a reference microphone **50**, an active noise cancellation (ANC) controller **60** and a beam-forming control module **90**, wherein the ANC controller **60** includes a virtual microphone module **70**. The stereo micro speaker module **40** includes at least a left-channel speaker SPK_L and a right-channel speaker SPK_R.

In the present invention, the electronic system **100** may operate in the off-line mode and in the on-line mode. As depicted in FIG. **1**, when the electronic system **100** operates in the off-line mode, the beam-forming control module **90** is configured to provide a beam-forming control signal S_{BF} according to a location signal **S1**, and the stereo micro speaker module **40** is configured to adjust the orientation (sound direction) of the left-channel speaker SPK_L and the right-channel speaker SPK_R according to the beam-forming control signal S_{BF}. Also, the ANC controller **60** is configured to operate further according to an error signal e(n) provided by a physical error microphone **80** so as to acquire a transfer function D'(Z) between the stereo micro speaker module **40** and the reference microphone **50** at a specific fan speed, a transfer function C'(Z) between the stereo micro speaker module **40** and the physical error microphone **80** and a transfer function P'(Z) between the reference microphone **50** and the physical error microphone **80**.

As depicted in FIG. **2**, when the electronic system **100** operates in the on-line mode, the beam-forming control module **90** is configured to provide the beam-forming control signal S_{BF} according to a location signal **S2**, and the stereo micro speaker module **40** is configured to adjust the orientation (sound direction) of the left-channel speaker SPK_L and the right-channel speaker SPK_R according to the beam-forming control signal S_{BF}. Also, the virtual microphone module **70** of the ANC controller **60** is configured to acquire a virtual error signal e'(n) based on the transfer function P'(Z) and the transfer function C'(Z), and the ANC controller **60** is configured to provide a speaker control signal S_{MIC} based on the virtual error signal e'(n), a synchronization signal S_{SYN} and a wide-band noise signal f(n) associated with a noise-cancellation signal y(n) for driving the stereo micro speaker module **40**. This way, the noise-cancellation signal y(n) generated by the stereo micro speaker module **40** may cancel the virtual error signal e'(n), thereby providing feed-forward active noise control function. The detailed operation of the electronic system **100** in the off-line mode and in the on-line mode will be described in subsequent paragraphs.

The processor **10** may be a central processing unit (CPU) or a graphic processing unit (GPU). As the key engine of executing commands and procedures for running the operating system, the processor **10** is the main source of generating waste heat in the electronic system **100**.

The fan module **20** may have different structures depending on its type. Basically speaking, the fan blades are driven by a motor into rotation for drawing cool air into the housing and pushing out warm air for heat dissipation purpose. In the present invention, the fan module **20** is configured to operate according to a fan control signal S_{FG} provided by the embedded controller **30**. A larger value of the fan control signal S_{FG} results in a faster rotational speed of the motor in the fan module **20**. More efficient heat dissipation can be achieved by increasing the rotational speed of the motor in the fan module **20**, but with the main drawback of raising the noise level. During the operation of the electronic system **100**, the fan module **20** is the main source of generating noises. In an embodiment, the fan control signal S_{FG} may be a pulse width modulation (PWM) square wave which can be used to adjust the motor speed of the fan module **20** by varying its duty cycle. In an embodiment, the fan module **20** may include one or multiple axial fans or centrifugal fans. However, the number, the type and the driving method of the fans in the fan module **20** do not limit the scope of the present invention.

The embedded controller **30** may store the EC code of each task and timing constraints of the boot process. In the turned-off state of the electronic system **100**, the embedded controller **30** continues to operate for awaiting the wake-up message from the user. In the turned-on state of the electronic system **100**, the embedded controller **30** is configured to control the standby/hibernate mode, the keyboard controller, the charge indicator and the motor speed of the fan module **20**. The embedded controller **30** normally includes a thermal sensor (not shown in FIGS. **1** and **2**) for monitoring the operational temperature of the processor **10**, thereby outputting the fan control signal S_{FG} accordingly. When the operational temperature of the processor **10** raises, the duty cycle of the fan control signal S_{FG} is increased accordingly for accelerating the motor speed of the fan module **20**; when the operational temperature of the processor **10** drops, the duty cycle of the fan control signal S_{FG} is decreased accordingly for reducing the motor speed of the fan module **20**.

Each of the left-channel speaker SPK_L and the right-channel speaker SPK_R in the stereo micro speaker module **40** is an electronic component capable of converting electronic signals into audio signals and normally includes diaphragms and a control circuit made of electromagnets and coils. The stereo micro speaker module **40** is configured to adjust its orientation according to the beam-forming control signal S_{BF} so that the sound directions of the left-channel speaker SPK_L and the right-channel speaker SPK_R are both towards a specific location. Meanwhile, the stereo micro speaker module **40** is configured to provide the noise-cancellation signal y(n) according to the speaker control signal S_{MIC} provided by the ANC controller **60**. When the current of the speaker control signal S_{MIC} flows through the coils in the stereo micro speaker module **40**, the coils vibrate in the same frequency of the current. The diaphragms attached to the coils also start to vibrate, thereby causing disturbance in surrounding air for producing sound. Since the stereo micro speaker module **40** is used to provide sound effect when a user operates the electronic system **100**, it may be disposed on the front-side of the electronic system **100** facing the user.

The reference microphone **50** may be disposed near the fan blades of the fan module **20** for measuring noises generated by the fan module **20** during operation and for transmitting the corresponding wide-band noise signal f(n) to the ANC controller **60**, wherein the wide-band noise signal f(n) includes the wide-band noise spectrum of the turbulence noises generated by the fan module **20** during operation. In an embodiment, the reference microphone **50** may be a micro electro mechanical system (MEMS) microphone characterized in high heat tolerance, high anti-vibration and high RF immunity. However, the type of the reference microphone **50** does not limit the scope of the present invention.

FIG. **3** is a diagram illustrating an implementation of the ANC controller **60** in the electronic system. **100** according to an embodiment of the present invention. The ANC controller **60** includes a frequency calculator **62**, a signal generator **64**, a digital filter **66**, a speaker driving circuit **68**, a first path compensation transfer function module **71**, a second path compensation transfer function module **72**, an adaptive filter **76**, and the virtual microphone module **70**.

When the electronic system **100** operates in the off-line mode, the ANC controller **60** is configured to receive the synchronization signal S_{SYN}, receive the wide-band noise signal f(n) associated with the noise-cancellation signal y(n) from the reference microphone **50**, and receive the error signal e(n) from the physical error microphone **80** so as to acquire the transfer function C'(Z) between the stereo micro speaker module **40** and the physical error microphone **80**, the transfer function D'(Z) between the stereo micro speaker module **40** and the reference microphone **50**, and the transfer function P'(Z) between the reference microphone **50** and the physical error microphone **80**. The synchronization signal S_{SYN} includes the information associated with the structure of the fan module **20** (such as the number of blades in each fan) and the operational setting (such as the motor speed in different operational modes). In the embodiments depicted in FIGS. **1** and **2**, the synchronization signal S_{SYN} may be provided by the embedded controller **30**. In another embodiment of the present invention, the synchronization signal S_{SYN} may be provided by the processor **10** or another device.

When the electronic system **100** operates in the on-line mode, the ANC controller **60** is configured to receive the synchronization signal S_{SYN} and receive the wide-band noise signal f(n) associated with the noise-cancellation signal y(n) from the reference microphone **50**, Meanwhile the virtual microphone module **70** is configured to provide the virtual error signal e'(n) based on the transfer functions C'(Z) and P'(Z) acquired in the off-line mode. Based on the synchronization signal S_{SYN}, the wide-band noise signal f(n), the virtual error signal e'(n) and the transfer functions C'(Z) and D'(Z), the ANC controller **60** may calculate the actual wide-band noises among the noises generated by the fan module **20** when operating at a predetermined fan speed, thereby providing the speaker control signal S_{MIC} accordingly for driving the stereo micro speaker module **40**. This way, the noise signal d(n) may be effectively canceled by the noise-cancellation signal y(n) provided by the stereo micro speaker module **40**, with the expectation to keep the virtual error signal e'(n) at zero. In the embodiments depicted in FIGS. **1** and **2**, the synchronization signal S_{SYN} may be provided by the embedded controller **30**. In another embodiment of the present invention, the synchronization signal S_{SYN} may be provided by the processor **10** or another device.

FIG. **4** is a flowchart illustrating the operation of the electronic system **100** having heat dissipation and feed-forward active noise control function in the off-line mode according to an embodiment of the present invention. The flowchart in FIG. **4** includes the following steps:

Step **410**: dispose the physical error microphone **80** at a specific location.

Step **420**: adjust the orientation of the stereo micro speaker module **40** so that the sound direction of each speaker is towards the specific location.

Step **430**: measure the transfer function P'(Z) between the reference microphone **50** and the physical error microphone **80** when the stereo micro speaker module **40** is not in operation.

Step **440**: measure the transfer function D'(Z) between the stereo micro speaker module **40** and the reference microphone **50** and the transfer function C'(Z) between the stereo micro speaker module **40** and the physical error microphone **80** when the fan module **20** is not in operation.

FIG. **5** is a diagram illustrating the transfer functions between the stereo micro speaker module **40**, the reference microphone **50** and the physical error microphone **80** during signal transmission when the electronic system **100** having heat dissipation and feed-forward active noise control function operates in the off-line mode according to an embodiment of the present invention. In FIG. **5**, d(n) represents the noise signal generated during the operation of the electronic system **100** in the off-line mode, f(n) represents the wide-band noise signal measured by the reference microphone **50**, e(n) represents the error signal outputted by the physical error microphone **80**, y(n) represents the noise-cancellation signal provided by the stereo micro speaker module **40**, S_{MIC} represents the speaker control signal outputted by the ANC controller **60**, P(Z) represents the transfer function between the reference microphone **50** and the physical error microphone **80**, D(Z) represents the transfer function between the stereo micro speaker module **40** and the reference microphone **50**, and C(Z) represents the transfer function between the stereo micro speaker module **40** and the physical error microphone **80**. Since the fan module **20** generates different wind pressure when operating at different fan speeds, the transfer functions between the stereo micro speaker module **40**, the reference microphone **50** and the physical error microphone **80** also vary accordingly. Therefore, the transfer functions associated with each fan speed may be acquired in the off-line mode.

In step **410**, the physical error microphone **80** is disposed at the specific location which may be an estimated location of the user who operates the electronic system **100**. For example, when the electronic system **100** is a laptop computer, the head of the user is normally located in front of the screen with a certain distance apart. Therefore, the physical error microphone **80** may be disposed at the estimated location of the user's head, such as 30-45 cm in front of the screen of the electronic system **100**, but not limited thereto. The physical error microphone **80** is configured to capture the overall noises of the electronic system **100** in the off-line mode and output the corresponding error signal e(n) to the ANC controller **60**. More specifically, the error signal e(n) outputted by the physical error microphone **80** is the difference between the noise signal d(n) and the noise-cancellation signal y(n), and a smaller value of the error signal e(n) indicates better noise cancellation.

In step 420, the beam-forming control module 90 is configured to provide the beam-forming signal S_{BF} according to the location signal S1 so that the sound direction of each speaker may be directed towards the specific location. The location signal S1 is associated with the estimated location of the user, and may be provided by the processor 10, the embedded controller 30 or another device, but not limited thereto.

In step 430, the adaptive filter 73 is configured to measure the transfer function P'(Z) between the reference microphone 50 and the physical error microphone 80 when the stereo micro speaker module 40 is not in operation. More specifically, in step 430, the ANC controller 60 is configured to output the microphone control signal S_{MIC} for deactivating the stereo micro speaker module 40 (y(n)=0). Under such circumstance, the adaptive filter 76 is configured to adjust the parameter W(Z) of the digital filter 66 according to the wide-band noise signal f(n) measured by the reference microphone 50 and the error signal e(n) outputted by the physical error microphone 80. After performing the above-mentioned adaptive signal processing for a predetermined period of time, the parameter W(Z) of the digital filter 66 converges to a predetermined stable status, and the current parameter W(Z) of the digital filter 66 in the predetermined stable status may be used as the transfer function P'(Z) between the reference microphone 50 and the physical error microphone 80.

In step 440, the transfer function D'(Z) between the stereo micro speaker module 40 and the reference microphone 50 and the transfer function C'(Z) between the stereo micro speaker module 40 and the physical error microphone 80 are measured in a windless environment. More specifically, in step 440, the embedded controller 30 is configured to output the fan control signal S_{FG} for deactivating the fan module 20, and the ANC controller 60 is configured to output the microphone control signal S_{MIC} for controlling the stereo micro speaker module 40 to provide the noise-cancellation signal y(n). In the off-line mode, the noise-cancellation signal y(n) is used as white noise for test purpose, and the ANC controller 60 is configured to adjust the parameter W(Z) of the digital filter 66 according to the noise-cancellation signal y(n) provided by the stereo micro speaker module 40 and the error signal e(n) outputted by the physical error microphone 80. After performing the above-mentioned adaptive signal processing for a predetermined period of time, the parameter W(Z) of the digital filter 66 converges to a predetermined stable status, and the current parameter W(Z) of the digital filter 66 in the predetermined stable status may be used as the transfer function D'(Z) between the stereo micro speaker module 40 and the reference microphone 50 in the windless environment. Similarly, the adaptive filter 76 is configured to adjust the parameter W(Z) of the digital filter 66 according to the noise-cancellation signal y(n) provided by the stereo micro speaker module 40 and the error signal e(n) outputted by the physical error microphone 80. After performing the above-mentioned adaptive signal processing for a predetermined period of time, the parameter W(Z) of the digital filter 66 converges to a predetermined stable status, and the current parameter W(Z) of the digital filter 66 in the predetermined stable status may be used as the transfer function C'(Z) between the stereo micro speaker module 40 and the physical error microphone 80 in the windless environment.

FIG. 6 is a flowchart illustrating the operation of the electronic system 100 having heat dissipation and feed-forward active noise control function in the on-line mode according to an embodiment of the present invention. The flowchart in FIG. 6 includes the following steps:

Step 610: determine the current location of the user who operates the electronic system 100.

Step 620: adjust the orientation of the stereo micro speaker module 40 so that the sound direction of each speaker in towards the current location of the user

Step 630: the reference microphone 50 captures noises generated by the fan module 20 during operation and provides the corresponding wide-band noise signal f(n).

Step 640: the virtual microphone module 70 provides the virtual error signal e'(n) based on the transfer function P'(Z), the transfer function C'(Z), the wide-band noise signal f(n) and the noise-cancellation signal y(n).

Step 650: the ANC controller 60 acquires the blade number of each fan in the fan module 20 and the motor speed in each operational mode according to the synchronization signal S_{SYN} and calculates a corresponding reference signal x(n) associated with the baseline power value of the speaker control signal S_{MIC}.

Step 660: the ANC controller 60 acquires the actual single-blade fundamental frequency, the actual single-blade overtone frequencies, the actual blade passing frequency (BPF) fundamental frequencies and the wide-band noise spectrum of the fan module 20 during operation according to the wide-band noise signal f(n), the virtual error signal e'(n) and the reference signal x(n) and provides the speaker control signal S_{MIC} accordingly.

Step 670: the stereo micro speaker module 40 generates the noise-cancellation signal y(n) according to the speaker control signal S_{MIC}; execute step 610.

In step 610, the current location of the user when operating the electronic system 100 is determined. In an embodiment, the current location of the user may be defined by the electronic system 100. For example, the current location of the user may be located in front of the screen of the electronic system 100 with a predetermined distance apart, wherein the value of the predetermined distance may vary according to the type of the electronic system 100. In another embodiment, the electronic system 100 may further include an image identification unit for detecting the actual location of the user on a real-time basis.

In step 620, the beam-forming control module 90 is configured to provide the beam-forming signal S_{BF} according to the location signal S2 so that the sound direction of each speaker may be directed towards the current location of the user. In an embodiment, the location signal S2 is associated with the estimated location of the user defined by the electronic system 100, and may be provided by the processor 10, the embedded controller 30, or another device. In another embodiment, the location signal S2 is associated with the actual location of the user when operating the electronic system. 100, and may be provided by the image identification unit in the electronic system 100.

The noise source during the operation of the fan module 20 originates from the air flow caused by the rotation of the motor. The narrow-band component of the noises may be thickness noises or BPF noises. Thickness noises are the result of the sound wave pulse created by the repetitive rotary motion of the air being displaced by the blade surface. BPF noises are caused by structural vibration (axial force and surface force) of the fan module 20. Since BPF and related harmonic waves are associated with the turbulent flow fluctuations as each fan blade passes a specific reference point, the periodic pressure wave at the tip of each fan blade generates a specific narrow-band noise. Also, acoustic waves are generated when the instabilities in the laminar boundary layer on the suction side of the fan blade interact with the trailing edge of the blade. These acoustic waves radiate from the trailing edge and form a feedback loop with the source of the instabilities, resulting in vortex shedding which generates wide-band noises.

In step **630**, the reference microphone **50** is configured to capture noises generated by the fan module **20** when the electronic system **100** operates in the on-line mode and provide the corresponding wide-band noise signal f(n).

In step **640**, the virtual microphone module **70** is configured to provide the virtual error signal e'(n) based on the transfer function P'(Z), the transfer function C'(Z), the wide-band noise signal f(n) and the noise-cancellation signal y(n), wherein e'(n)=P'(Z)*f(n)+C'(Z)*y(n). As previously stated, P'(Z) is the transfer function between the reference microphone **50** and the physical error microphone **80** at a specific fan speed, C'(Z) is the transfer function between the stereo micro speaker module **40** and the physical error microphone **80** in the windless environment, and D'(Z) is the transfer function between the stereo micro speaker module **40** and the reference microphone **50** in the windless environment. In the present invention, the virtual microphone module **70** may be implemented by software or firmware, but is not limited thereto.

In step **650**, the frequency calculator **62** of the ANC controller **60** is configured to acquire the motor speed, the single-blade frequencies and the blade number of the fan module **20** according to the synchronization signal S_{SYN}, wherein the value of BPF is the multiple of the motor speed and the blade number of the fan module **20**. Assuming that each fan in the fan module **20** has 37 blades, the following Table 1 illustrates the data calculated by the frequency calculator **62**, but does not limit the scope of present invention. The motor speed is shown in rpm, and the frequency is shown in Hertz.

TABLE 1

Motor speed	Fundamental frequency	1^{st}	2^{nd} overtone	3^{th}	Blade number	BPF	BPF × 2	BPF × 3
500	8.3	16.6	24.9	33.2	37	307.1	614.2	921.3
1000	16.6	33.2	49.8	66.4	37	614.2	1228.4	1842.6
1500	25	50	75	100	37	925	1850	2775
2000	33.3	66.6	99.9	133.2	37	1232.1	2464.2	3696.3
2500	41.7	83.4	125.1	166.8	37	1542.9	3085.8	4628.7
3000	50	100	150	200	37	1850	3700	5550
3500	58.3	116.6	174.9	233.2	37	2157.1	4314.2	6471.3
4000	66.7	133.4	200.1	266.8	37	2467.9	4935.8	7403.7
4500	75	150	225	300	37	2775	5550	8325
5000	83.3	166.6	249.9	333.2	37	3082.1	6164.2	9246.3
5500	91.6	183.2	274.8	366.4	37	3389.2	6778.4	10167.6
5700	95	190	285	380	37	3515	7030	10545

Next, the signal generator **64** in the ANC controller **60** is configured to generate the reference signal x(n) according to the data calculated by the frequency calculator **62**, wherein the reference signal x(n) includes the information associated with the estimated overtones, the estimated BPF, and the sound pressure (dBSPL) at different fan speeds for determining the baseline power value of the speaker control signal S_{MIC}. The power value of the speaker control signal S_{MIC} may be adjusted by varying the parameter W(Z) of the digital filter **66**.

In step **660**, the ANC controller **60** is configured to acquire the actual single-blade fundamental frequency, the actual single-blade overtone frequencies, the actual BPF fundamental frequencies and the wide-band noise spectrum of the fan module **20** during operation according to the wide-band noise signal f(n), the virtual error signal e'(n) and the reference signal x(n), thereby providing the speaker control signal S_{MIC} accordingly for controlling the stereo micro speaker module **40** to provide the noise-cancellation signal y(n). More specifically, the noise-cancellation signal y(n) includes a plurality of noise-compensation signals which are reverse signals respectively associated with the actual single-blade fundamental frequency, the actual single-blade overtone frequency, the actual BPF fundamental frequency, the actual BPF overtone frequency and the wide-band noise spectrum.

In step **670**, the ANC controller **60** is configured to adjust the characteristics of the speaker control signal S_{MIC} according to the transfer function D'(Z) between the stereo micro speaker module **40** and the reference microphone **50** and the transfer function C'(Z) between the stereo micro speaker module **40** and the physical error microphone **80**. More specifically, the first path compensation transfer function module **71** is configured to process the noise-cancellation signal y(n) according to the transfer function D'(Z) between the stereo micro speaker module **40** and the reference microphone **50** which is associated with the current fan speed and acquired in the off-line mode and output the processed noise-cancellation signal y'(n) to the signal generator **64**. The signal generator **64** is configured to acquire the reference x(n) by subtracting the processed noise-cancellation signal y'(n) from the wide-band noise signal f(n) and output the reference x(n) to the digital filter **66** and the second path compensation transfer function module **72**. Next, the second path compensation transfer function module **72** is configured to calibrate the reference signal x(n) according to the transfer function C'(Z) between the stereo micro speaker module **40** and the physical error microphone **80** which is associated with the current fan speed and acquired in the off-line mode and output the calibrated reference signal x'(n) to the adaptive filter **76**.

The adaptive filter **76** is configured to process the calibrated reference signal x'(n) and the virtual error signal e'(n) based on a specific algorithm, thereby adjusting the parameter W(Z) of the digital filter **66**. More specifically, the calibrated reference signal x'(n) includes the information associated with motor speed, the estimated single-blade fundamental frequency, the estimated BPF and the estimated wind pressure of the fan module **20**. The adaptive filter **76** is configured acquire the information related to narrow-band noises (such as the actual single-blade fundamental frequency, the actual overtones and the actual BPF of the fan module **20**) according to the error signal e(n) for adjusting the parameter W(Z) of the digital filter **66**. This way, when the digital filter **66** drives the speaker driving circuit **68** for outputting the speaker control signal S_{MIC}, the noise-cancellation signal y(n) can reflect the actual operational status of the fan module **20**, the wind pressure at the current fan speed, and the current noise cancellation level. More specifically, the noise-cancellation signal y(n) includes a plurality of noise-compensation signals which are reverse signals respectively associated with the actual single-blade fundamental frequency, the actual single-blade overtone frequency, the actual BPF fundamental frequency, the actual BPF overtone frequency, the wide-band noise spectrum and the actual wind pressure. After signal transmission, the noise-cancellation signal y(n) provided by the stereo micro speaker module **40** may effectively cancel the noise signal d(n), with the expectation to keep the virtual error signal e'(n) at zero.

In an embodiment, the adaptive filter **76** may process the calibrated reference signal x'(n) and the virtual error signal e'(n) based on least mean square (LMS) algorithm. However, the algorithm adopted by the adaptive filter **76** does not limit the scope of the present invention.

In conclusion, in the electronic system **100** with heat dissipation and feed-forward active noise control function of the present invention, the beam-forming control module **90** is configured to adjust the orientation of the stereo micro speaker module **40** in the off-line mode so that the sound direction of each speaker may be directed towards a first specific location (such as the estimated location of the user when operating the electronic system **100**). Under such circumstance, the transfer function P'(Z) between the reference microphone **50** and the physical error microphone **80**, the transfer function D(Z) between the stereo micro speaker module **40** and the reference microphone **50** and the transfer function C(Z) between the stereo micro speaker module **40** and the physical error microphone **80** at each fan speed may be acquired in the off-line mode. Next in the on-line mode, the beam-forming control module **90** is configured to adjust the orientation of the stereo micro speaker module so that the sound direction of each speaker may be directed towards a second specific location (such as the estimated location or the actual location of the user when operating the electronic system **100**). Under such circumstance, the reference microphone **50** is configured to measure noises generated by the fan module **20** during operation and provide the corresponding wide-band noise signal f(n), and the virtual microphone module **70** is configured to capture noises during the operation of the electronic system **100** and provide the corresponding virtual error signal e'(n) according to the transfer function P'(Z) between the reference microphone **50** and the physical error microphone **80** at a specific fan speed, the transfer function C'(Z) between the stereo micro speaker module **40** and the physical error microphone **80** in the windless environment, the wide-band noise signal f(n) and the noise-cancellation signal y(n). According to the synchronization signal S_{SYN}, the wide-band noise signal f(n), the virtual error signal e'(n), and the transfer functions C'(Z) and D'(Z) acquired in the off-line mode, the ANC controller **60** is configured to acquire the information related to the wide-band noises among the noises generated by the fan module **20** when operating at a predetermined fan speed, thereby providing the speaker control signal S_{MIC} accordingly for driving the stereo micro speaker module **40**. This way, the noise signal d(n) may be effectively canceled by the noise-cancellation signal y(n) provided by the stereo micro speaker module **40**. The virtual microphone module **70** can simulate the operation of the physical error microphone **80** by operating based on the transfer functions P'(Z) and C'(Z).

Since the beam-forming control module **70** can adjust the orientation of the stereo micro speaker module **40** on a real-time basis so that the noise-cancellation signal y(n) may be directed towards the location of the user who operates the electronic system **100**. Therefore, the present electronic system **100** does not need to include a physical error microphone or an extra speaker module disposed along the fan path for providing feed-forward active noise control function.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. An electronic system with heat dissipation and feed-forward active noise control function, comprising:
- a fan module configured to operate according to a fan control signal for providing heat dissipation;
- an embedded controller configured to provide the fan control signal;
- a reference microphone configured to detect a wide-band noise generated during an operation of the electronic system and provide a corresponding wide-band noise signal;
- a stereo micro speaker module comprising at least a first speaker and a second speaker, and configured to generate a noise-cancellation signal according to the speaker control signal;
- a beam-forming control module configured to provide a beam-forming control signal for controlling an orientation of the stereo micro speaker module so that a sound direction of the first speaker and a sound direction of the second speaker are towards a specific location; and
- an active noise cancellation controller configured to:
  - provide a virtual error signal according to a first transfer function, a second transfer function and the wide-band noise signal; and
  - provide the speaker control signal according to a synchronization signal, the wide-band noise signal and the virtual error signal, wherein:
    - the synchronization signal includes information associated with a structure and an operational setting of the fan module;
    - the first transfer function is a transfer function between the reference microphone and a physical error microphone when the stereo micro speaker is not in operation;
    - the second transfer function is a transfer function between the stereo micro speaker module and the physical error microphone when the fan module is not in operation; and
    - the noise-cancellation signal includes a plurality of noise-compensation signals for canceling noises generated during the operation of the electronic system.

2. The electronic system of claim **1**, further comprising:
- an image identification unit configured to detect an actual location of a user who operates the electronic system, wherein the beam-forming control module is further configured to provide the beam-forming control signal based on the actual location of the user.

3. The electronic system of claim **1**, wherein:
- the active noise cancellation controller is further configured to:

measure the first transfer function between the reference microphone and the physical error microphone when the stereo micro speaker module is not in operation;

measure the second transfer function between the stereo micro speaker module and the physical error microphone when the fan module is not in operation;

measure a third transfer function between the stereo micro speaker module and the reference microphone when the fan module is not in operation; and

acquire the virtual error signal based on the first transfer function and the second transfer function, wherein a value of the virtual error signal is equal to a sum of a multiple of the first transfer function and the wide-band noise signal and a multiple of the second transfer function and the noise-cancellation signal; and

the specific location is an estimated location of the user when operating the electronic system during a period when the first transfer function, the second transfer function, and the third transfer function are measured.

4. The electronic system of claim **3**, wherein the active noise cancellation controller comprises:

a virtual microphone module configured to provide the virtual error signal according to the first transfer function and the second transfer function;

a frequency calculator configured to acquire an estimated single-blade fundamental frequency, an estimated single-blade overtone frequency, and an estimated blade passing frequency (BPF) fundamental frequency of the fan module according to the synchronization signal;

a signal generator configured to generate a reference signal according to the estimated single-blade fundamental frequency, the estimated single-blade overtone frequency, and the estimated BPF fundamental frequency; and

a digital filter configured to process the reference signal for determining a baseline power value of the speaker control signal.

5. The electronic system of claim **4**, wherein the active noise cancellation controller further comprises:

an adaptive filter configured to adjust a parameter of the digital filter based on the second transfer function, the third transfer function and the virtual error signal for adaptively adjusting a power value of the speaker control signal.

6. The electronic system of claim **5**, wherein the adaptive filter is further configured to process the reference signal, the wide-band noise signal and the virtual error signal based on a least mean square (LMS) algorithm.

7. The electronic system of claim **5**, wherein the active noise cancellation controller further comprises:

a first path compensation transfer function module coupled to the stereo micro speaker module for receiving the noise-cancellation signal, processing the noise-cancellation signal according to the third transfer function and outputting the processed noise-cancellation noise signal to the signal generator; and

a second path compensation transfer function module coupled to the signal generator for receiving the reference signal, processing the reference signal according to the second transfer function and outputting the processed reference signal to the adaptive filter.

8. The electronic system of claim **7**, wherein the signal generator is further configured to provide the reference signal by subtracting the processed noise-cancellation signal from the wide-band noise signal.

9. The electronic system of claim **1**, wherein the active noise cancellation controller is further configured to:

acquire an actual single-blade fundamental frequency, an actual single-blade overtone frequency, an actual BPF fundamental frequency, an actual BPF overtone frequency and an actual wide-band noise spectrum of the fan module according to the synchronization signal, the wide-band noise signal and the virtual error signal when the fan module operates at a predetermined fan speed; and

provide the speaker control signal according to the actual single-blade fundamental frequency, the actual single-blade overtone frequency, the actual BPF fundamental frequency, the actual BPF overtone frequency and the actual wide-band noise spectrum of the fan module.

10. The electronic system of claim **9**, wherein the plurality of noise-compensation signals are reverse signals respectively associated with the actual single-blade fundamental frequency, the actual single-blade overtone frequency, the actual BPF fundamental frequency, the actual BPF overtone frequency and the actual wide-band noise spectrum.

11. A method of providing heat dissipation and feed-forward active noise control function in an electronic system, comprising:

operating a fan module in the electronic system according to a fan control signal for providing heat dissipation;

providing the fan control signal using an embedded controller in the electronic system;

detecting a wide-band noise generated during an operation of the electronic system and providing a corresponding wide-band noise signal using a reference microphone in the electronic system;

generating a noise-cancellation signal according to the speaker control signal using at least a first speaker and a second speaker of a stereo micro speaker module in the electronic system;

providing a beam-forming control signal for controlling an orientation of the stereo micro speaker module using a beam-forming control module in the electronic system so that a sound direction of the first speaker and a sound direction of the second speaker are towards a specific location;

providing a virtual error signal according to a first transfer function, a second transfer function and the wide-band noise signal using an active noise cancellation controller in the electronic system; and

providing the speaker control signal according to a synchronization signal, the wide-band noise signal and the virtual error signal using the active noise cancellation controller, wherein:

the synchronization signal includes information associated with a structure and an operational setting of the fan module;

the first transfer function is a transfer function between the reference microphone and a physical error microphone when the stereo speaker is not in operation;

the second transfer function is a transfer function between the stereo micro speaker module and the physical error microphone when the fan module is not in operation; and

the noise-cancellation signal includes a plurality of noise-compensation signals for canceling noises generated during the operation of the electronic system.

12. The method of claim **11**, further comprising:

detecting an actual location of a user who operates the electronic system using an image identification unit in the electronic system; and

providing the beam-forming control signal based on the actual location of the user using the beam-forming control module.

13. The method of claim **11**, further comprising:

measuring the first transfer function between the reference microphone and the physical error microphone when the stereo micro speaker module is not in operation using the active noise cancellation controller;

measuring the second transfer function between the stereo micro speaker module and the physical error microphone when the fan module is not in operation using the active noise cancellation controller;

measuring a third transfer function between the stereo micro speaker module and the reference microphone when the fan module is not in operation using the active noise cancellation controller; and

acquiring the virtual error signal based on the first transfer function and the second transfer function, wherein:

a value of the virtual error signal is equal to a sum of a multiple of the first transfer function and the wide-band noise signal and a multiple of the second transfer function and the noise-cancellation signal; and

the specific location is an estimated location of the user when operating the electronic system during a period when the first transfer function, the second transfer function, and the third transfer function are measured.

14. The method of claim **11**, further comprising:

providing the virtual error signal according to the first transfer function and the second transfer function using a virtual microphone module in the active noise cancellation controller;

acquiring an estimated single-blade fundamental frequency, an estimated single-blade overtone frequency, and an estimated blade passing frequency (BPF) fundamental frequency of the fan module according to the synchronization signal using a frequency calculator in the active noise cancellation controller;

generating a reference signal according to the estimated single-blade fundamental frequency, the estimated single-blade overtone frequency, and the estimated BPF fundamental frequency using a signal generator in the active noise cancellation controller; and

processing the reference signal for determining a baseline power value of the speaker control signal using a digital filter in the active noise cancellation controller.

15. The method of claim **14**, further comprising:

adjusting a parameter of the digital filter based on the second transfer function, the third transfer function and the virtual error signal for adaptively adjusting a power value of the speaker control signal using an adaptive filter in the ANC controller.

16. The method of claim **15**, further comprising:

processing the reference signal, the wide-band noise signal and the virtual error signal using the adaptive filter based on a least mean square (LMS) algorithm.

17. The method of claim **15**, further comprising:

receiving the noise-cancellation signal, processing the noise-cancellation signal according to the third transfer function and outputting the processed noise-cancellation noise signal to the signal generator using a first path compensation transfer function module in the electronic system; and

receiving the reference signal, processing the reference signal according to the second transfer function and outputting the processed reference signal to the adaptive filter using a second path compensation transfer function in the electronic system.

18. The method of claim **17**, further comprising:

providing the reference signal by subtracting the processed noise-cancellation signal from the wide-band noise signal using the signal generator.

19. The method of claim **11**, further comprising:

acquiring an actual single-blade fundamental frequency, an actual single-blade overtone frequency, an actual BPF fundamental frequency, an actual BPF overtone frequency and an actual wide-band noise spectrum of the fan module according to the synchronization signal, the wide-band noise signal and the virtual error signal using the active noise cancellation controller when the fan module operates at the predetermined fan speed; and

providing the speaker control signal according to the actual single-blade fundamental frequency, the actual single-blade overtone frequency, the actual BPF fundamental frequency, the actual BPF overtone frequency and the actual wide-band noise spectrum of the fan module using the active noise cancellation controller.

20. The method of claim **19**, wherein the plurality of noise-compensation signals are reverse signals respectively associated with the actual single-blade fundamental frequency, the actual single-blade overtone frequency, the actual BPF fundamental frequency, the actual BPF overtone frequency and the actual wide-band noise spectrum.

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