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(54) **METHOD AND SYSTEM FOR ACTIVE NOISE CANCELLATION**

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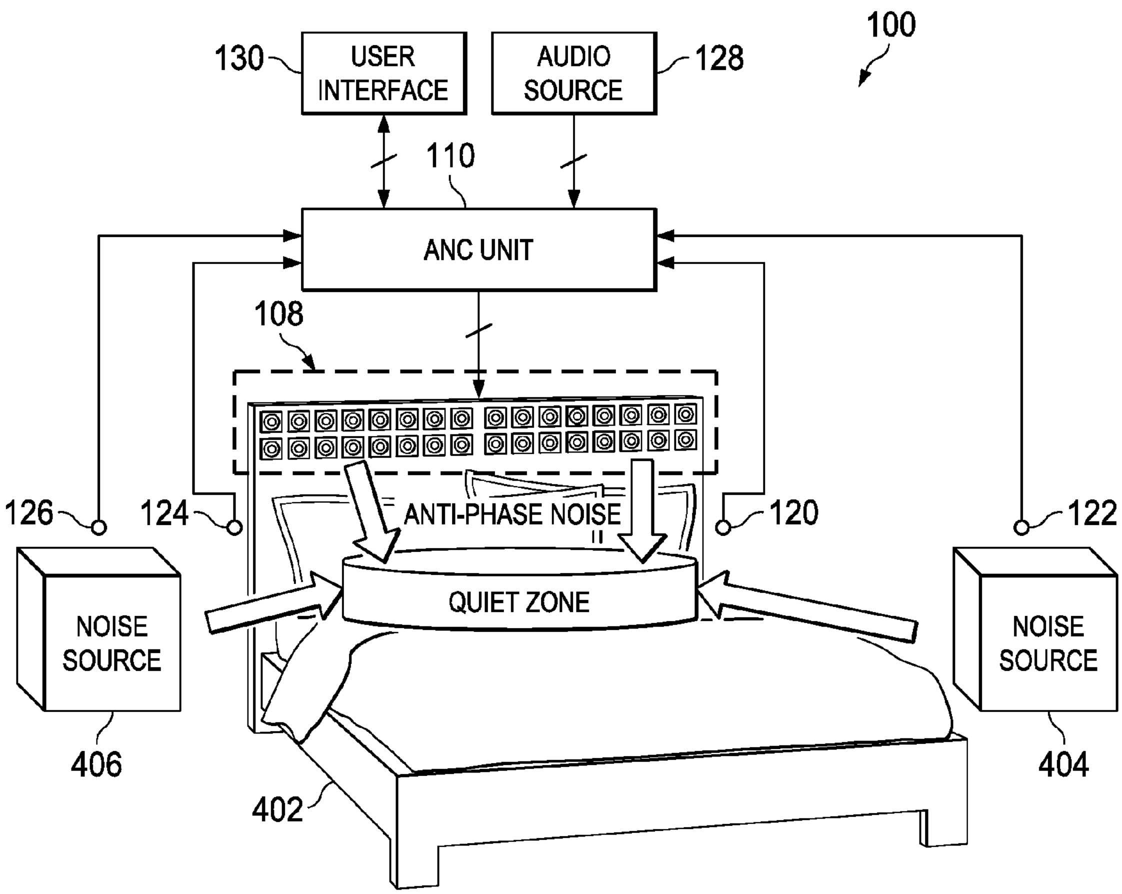
(57) **ABSTRACT**

From at least a first microphone, first microphone signals are received that represent first sound waves. From at least a second microphone, second microphone signals are received that represent second sound waves. In response to the first microphone signals, first noise in the first sound waves is estimated, and first cancellation signals are output for causing a speaker array to generate first additional sound waves via at least a first acoustic beam for cancelling at least some of the first noise. In response to the second microphone signals, second noise in the second sound waves is estimated, and second cancellation signals are output for causing the speaker array to generate second additional sound waves via at least a second acoustic beam for cancelling at least some of the second noise.



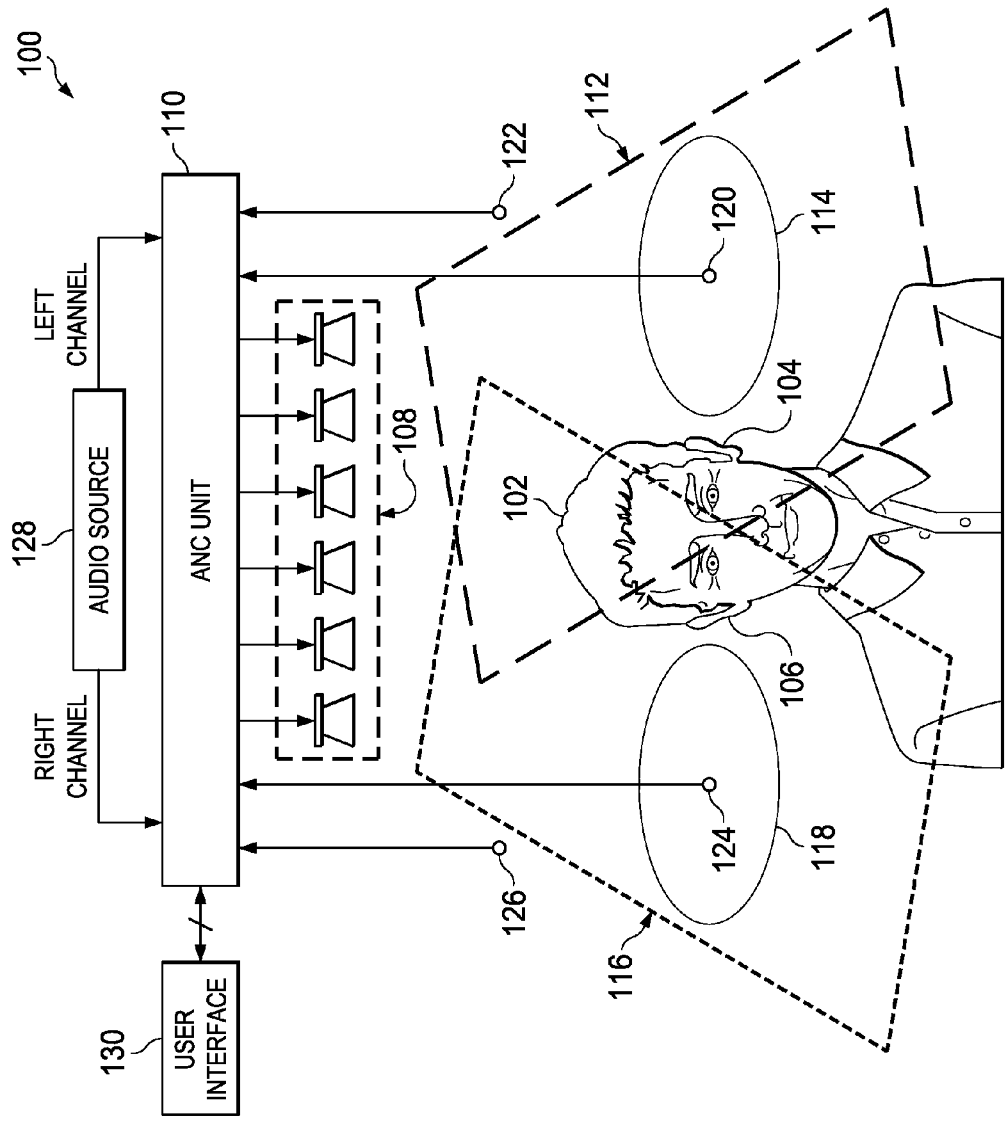

100
110
ANC UNIT
AUDIO SOURCE
128
LEFT CHANNEL
RIGHT CHANNEL
USER INTERFACE
130
108
122
120
112
114
104
102
106
124
118
126
116

FIG. 1

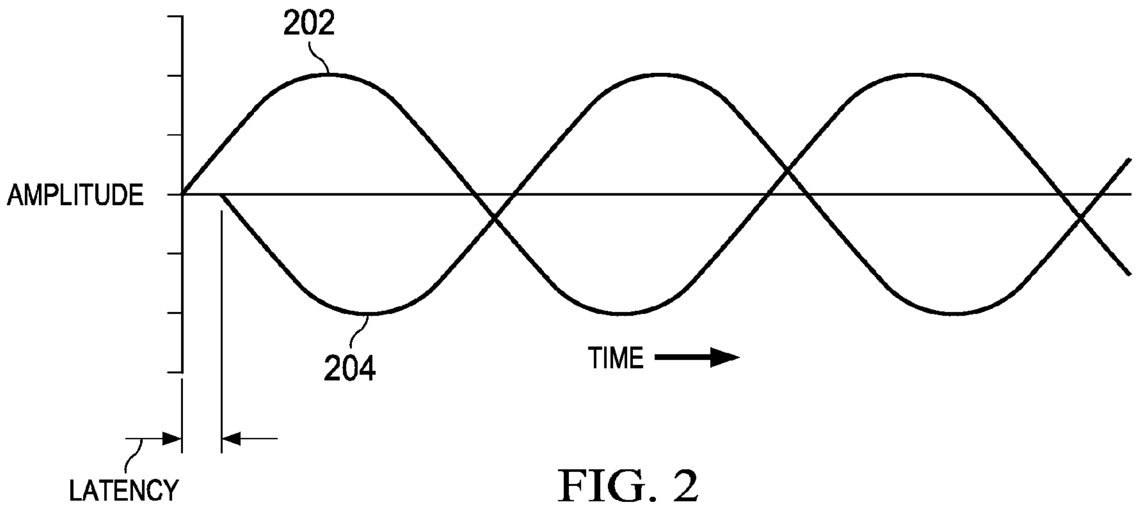

202
AMPLITUDE
204
TIME
LATENCY

FIG. 2

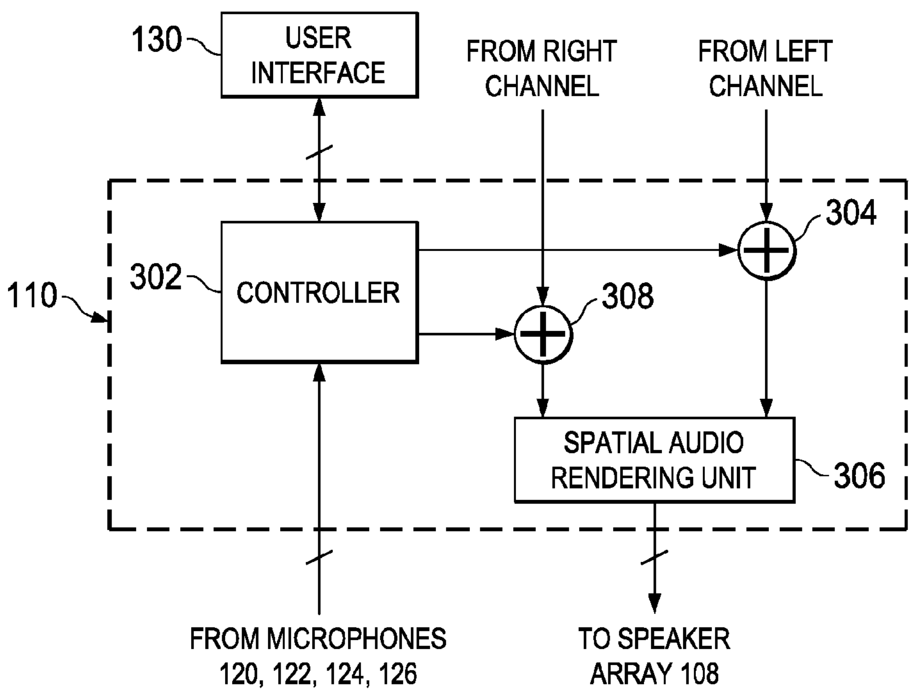

130
USER INTERFACE
FROM RIGHT CHANNEL
FROM LEFT CHANNEL
304
110
302
CONTROLLER
308
SPATIAL AUDIO RENDERING UNIT
306
FROM MICROPHONES 120, 122, 124, 126
TO SPEAKER ARRAY 108

FIG. 3

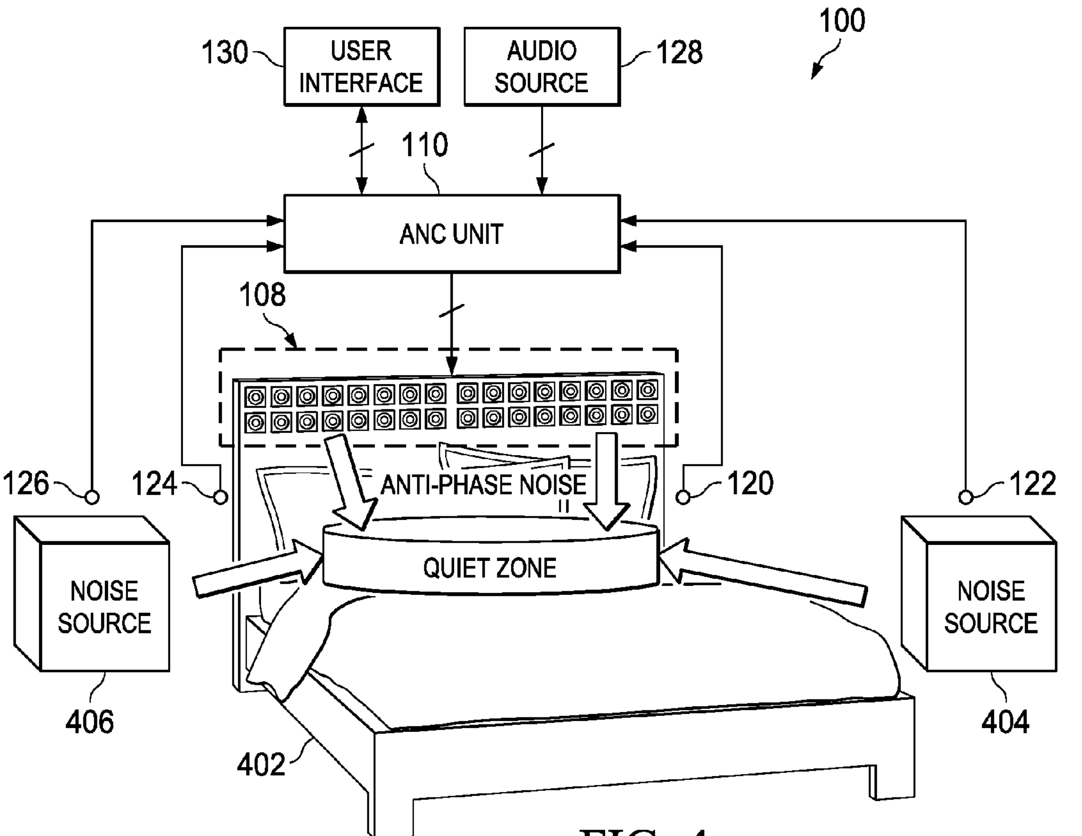

100
130
USER INTERFACE
AUDIO SOURCE
128
110
ANC UNIT
108
126
124
ANTI-PHASE NOISE
120
122
QUIET ZONE
NOISE SOURCE
NOISE SOURCE
406
404
402

FIG. 4

METHOD AND SYSTEM FOR ACTIVE NOISE CANCELLATION

BACKGROUND

[0001] The disclosures herein relate in general to audio signal processing, and in particular to a method and system for active noise cancellation.

[0002] A user may hear noise from a surrounding environment. A mechanical structure can attempt to physically buffer the user's ears against some of the noise, but the mechanical structure has limits. In addition to the mechanical structure, an active noise cancellation system can attempt to generate signals for cancelling at least some of the noise. Nevertheless, different techniques for active noise cancellation have respective shortcomings and trade-offs.

SUMMARY

[0003] From at least a first microphone, first microphone signals are received that represent first sound waves. From at least a second microphone, second microphone signals are received that represent second sound waves. In response to the first microphone signals, first noise in the first sound waves is estimated, and first cancellation signals are output for causing a speaker array to generate first additional sound waves via at least a first acoustic beam for cancelling at least some of the first noise. In response to the second microphone signals, second noise in the second sound waves is estimated, and second cancellation signals are output for causing the speaker array to generate second additional sound waves via at least a second acoustic beam for cancelling at least some of the second noise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. **1** is a block diagram of a system of the illustrative embodiments.

[0005] FIG. **2** is a graph of an example noise signal and an example noise cancellation signal.

[0006] FIG. **3** is a block diagram of an active noise cancellation unit of FIG. **1**.

[0007] FIG. **4** is a diagram of an example implementation of the system of FIG. **1**.

DETAILED DESCRIPTION

[0008] FIG. **1** is a block diagram of a system, indicated generally at **100**, of the illustrative embodiments. A human user **102** has a left ear **104** and a right ear **106** for hearing. The system **100** includes an array **108** of speakers for generating sound waves.

[0009] The array **108** is suitable for acoustic beam forming. Examples of acoustic beam forming are described in co-owned U.S. Patent Application Publication No. 2012/0093348, co-owned U.S. Patent Application Publication No. 2012/0121113, and co-owned U.S. Pat. No. 8,396,233, which are hereby fully incorporated herein by reference. Accordingly, in response to signals from an active noise cancellation ("ANC") unit **110**, the array **108** generates: (a) at least a first acoustic beam through a region **112**, so that at least first sound waves exist within an environment **114** (which is part of the region **112**) around the ear **104**; and (b) at least a second acoustic beam through a region **116**, so that at least second sound waves (distinct from the first sound waves) exist within an environment **118** (which is part of the region **116**) around the ear **106**.

[0010] In the example of FIG. **1**, an error microphone **120** is located within the environment **114**, and a reference microphone **122** is located outside the region **112**. The error microphone **120**: (a) converts, into signals, sound waves from the environment **114** (e.g., including sound waves of at least the first acoustic beam from the array **108**); and (b) outputs those signals. The reference microphone **122**: (a) converts, into signals, sound waves from outside the region **112** (e.g., ambient noise around the reference microphone **122**); and (b) outputs those signals.

[0011] Similarly, an error microphone **124** is located within the environment **118**, and a reference microphone **126** is located outside the region **116**. The error microphone **124**: (a) converts, into signals, sound waves from the environment **118** (e.g., including sound waves of at least the second acoustic beam from the array **108**); and (b) outputs those signals. The reference microphone **126**: (a) converts, into signals, sound waves from outside the region **116** (e.g., ambient noise around the reference microphone **126**); and (b) outputs those signals.

[0012] Accordingly, the signals from the error microphone **120** and the reference microphone **122** represent various sound waves ("first sounds"). The ANC unit **110**: (a) receives and processes the signals from the error microphone **120** and the reference microphone **122**; and (b) in response thereto, outputs signals for causing the array **108** to generate first additional sound waves (via at least the first acoustic beam) that cancel at least some noise in those first sounds.

[0013] Similarly, the signals from the error microphone **124** and the reference microphone **126** represent various sound waves ("second sounds"). The ANC unit **110**: (a) receives and processes the signals from the error microphone **124** and the reference microphone **126**; and (b) in response thereto, outputs signals for causing the array **108** to generate second additional sound waves (via at least the second acoustic beam) that cancel at least some noise in those second sounds.

[0014] In one example, the ANC unit **110** optionally: (a) receives audio signals from a left channel of an audio source **128** ("left audio"); and (b) combines the left audio into the first signals that the ANC unit **110** outputs to the array **108**. Accordingly, in this example: (a) the array **108** generates the first additional sound waves to also represent the left audio's information (e.g., music and/or speech), which is audible to the ear **104** via at least the first acoustic beam; and (b) the ANC unit **110** suitably accounts for the left audio in its further processing (e.g., estimating noise) of the signals from the error microphone **120** for cancelling at least some noise in those sound waves.

[0015] Similarly, the ANC unit **110** optionally: (a) receives audio signals from a right channel of the audio source **128** ("right audio"); and (b) combines the right audio into the second signals that the ANC unit **110** outputs to the array **108**. Accordingly, in this example: (a) the array **108** generates the second additional sound waves to also represent the right audio's information (e.g., music and/or speech), which is audible to the ear **106** via at least the second acoustic beam; and (b) the ANC unit **110** suitably accounts for the right audio in its further processing (e.g., estimating noise) of the signals from the error microphone **124** for cancelling at least some noise in those sound waves.

[0016] In one embodiment, a user interface **130** is a touchscreen, such as: (a) a liquid crystal display ("LCD") device; and (b) touch-sensitive circuitry of such LCD device, so that the touch-sensitive circuitry is integral with such LCD device. In such embodiment, the user **102** operates the touchscreen (e.g., virtual keys thereof, such as a virtual keyboard and/or virtual keypad) for: (a) viewing information (e.g., alphanumeric text information) from the ANC unit **110**; and (b) specifying information to the ANC unit **110**, which receives that user-specified information from the touchscreen and operates in response thereto. Accordingly, the user **102** operates the user interface **130** to control various operations of the ANC unit **110**.

[0017] Although FIG. **1** shows six (6) speakers in the array **108**, an exact number and positioning of those speakers is variable in the illustrative embodiments. Further, although FIG. **1** shows two (2) microphones **120** and **122** on a left side of the user **102**, an exact number and positioning of those microphones on the left side of the user **102** is variable in the illustrative embodiments. Similarly, although FIG. **1** shows two (**2**) microphones **124** and **126** on a right side of the user **102**, an exact number and positioning of those microphones on the right side of the user **102** is variable in the illustrative embodiments.

[0018] FIG. **2** is a graph of: (a) an example noise signal **202**, such as a signal from the error microphone **120** or the reference microphone **122**; and (b) an example noise cancellation signal **204**, such as a signal from the ANC unit **110** to the array **108** for at least the first acoustic beam. As shown in FIG. **2**, the signal **204** is substantially inverted from the signal **202**, so that a phase of the signal **204** is shifted (relative to a phase of the signal **202**) by ~180 degrees (e.g., 180 degrees plus a latency) across a bandwidth of the signals **202** and **204**. For example, the latency may result from a processing cycle of the ANC unit **110**. In this manner, the signal **204** is effective for cancelling at least some noise in a sound wave that is represented by the signal **202**.

[0019] FIG. **3** is a block diagram of the ANC unit **110**. As shown in FIG. **3**, the ANC unit **110** includes a controller **302** (e.g., a feed-forward controller and/or a feedback controller). The microphones **120**, **122**, **124** and **126** are connected to the controller **302**, which: (a) receives the signals that are output from those microphones in response to sound waves on the left and right sides of the user **102**; (b) in response to those signals, estimates noise in those sound waves; (c) generates first signals for cancelling at least some of the estimated noise in those sound waves on the left side of the user **102** ("first noise cancellation signals"); and (d) generates second signals for cancelling at least some of the estimated noise in those sound waves on the right side of the user **102** ("second noise cancellation signals").

[0020] A mixer **304**: (a) combines the first noise cancellation signals and the left audio (which the ANC unit **110** receives from the left channel of the audio source **128**); and (b) outputs those combined signals to a spatial audio rendering unit **306**. Similarly, a mixer **308**: (a) combines the second noise cancellation signals and the right audio (which the ANC unit **110** receives from the right channel of the audio source **128**); and (b) outputs those combined signals to the spatial audio rendering unit **306**. In response to those signals from the mixers **304** and **308**, the spatial audio rendering unit **306** causes the array **108** to generate the first and second acoustic beams through the regions **112** and **116**, respectively.

[0021] For clarity, although FIG. **3** shows the user interface **130** connected to only the controller **302**, the user interface **130** is further coupled to the spatial audio rendering unit **306**. The controller **302** and the spatial audio rendering unit **306** receive the user-specified information from the user interface **130** and operate in response thereto. Accordingly, the user **102** operates the user interface **130** to control various operations of the controller **302** and the spatial audio rendering unit **306**. For example, in response to the user-specified information: (a) the spatial audio rendering unit **306** causes the array **108** to generate the first and second acoustic beams in shapes and/or directions specified by the user **102**; and (b) the controller **302** identifies a number and positioning of microphones on the left and right sides of the user **102** (as specified by the user **102**), so that the controller **302** suitably performs its estimation of noise (and its generation of the first and second noise cancellation signals) in response to such number and positioning.

[0022] FIG. **4** is a diagram of an example implementation of the system **100**, in which the array **108** is integral with a headboard of a bed **402**. Although FIG. **4** is not drawn to scale, it shows one example positioning of the microphones **120**, **122**, **124** and **126** relative to the bed **402**, and relative to noise sources **404** and **406**. In response to the user-specified information from the user interface **130**, the ANC unit **110** causes the array **108** to generate the first and second acoustic beams in shapes and/or directions specified by the user **102**.

[0023] As discussed hereinabove in connection with FIG. **1**, the first and second acoustic beams include the first and second additional sound waves (collectively "anti-phase noise"), respectively. In this example, the anti-phase noise cancels at least some noise in a "quiet zone" near pillows of the bed **402**, as shown in FIG. **4**. Accordingly, if a head of the user **102** is located in the "quiet zone," then the system **100** enables the user **102** to rest (e.g., sleep) more easily with less noise around the ears **104** and **106**.

[0024] Although illustrative embodiments have been shown and described by way of example, a wide range of alternative embodiments is possible within the scope of the foregoing disclosure.

What is claimed is:

1. A method performed by at least one device for active noise cancellation, the method comprising:

from at least a first microphone, receiving first microphone signals that represent first sound waves;

from at least a second microphone, receiving second microphone signals that represent second sound waves;

in response to the first microphone signals, estimating first noise in the first sound waves, and outputting first cancellation signals for causing a speaker array to generate first additional sound waves via at least a first acoustic beam for cancelling at least some of the first noise; and

in response to the second microphone signals, estimating second noise in the second sound waves, and outputting second cancellation signals for causing the speaker array to generate second additional sound waves via at least a second acoustic beam for cancelling at least some of the second noise.

2. The method of claim **1**, wherein the first microphone is located within a first environment around a first ear, and wherein the second microphone is located within a second environment around a second ear, so that the first sound waves are from the first environment, and the second sound waves are from the second environment.

3. The method of claim **2**, wherein the first ear and the first microphone are located within a first region of the first acoustic beam, and wherein the second ear and the second microphone are located within a second region of the second acoustic beam.

4. The method of claim 1, wherein the first microphone is located outside a first region of the first acoustic beam, and wherein the second microphone is located outside a second region of the second acoustic beam.

5. The method of claim 1, wherein the first additional sound waves are distinct from the second additional sound waves.

6. The method of claim 1, and comprising:

receiving first audio signals from a first channel of an audio source;

receiving second audio signals from a second channel of the audio source;

combining the first audio signals into the first cancellation signals for causing the speaker array to generate the first additional sound waves via at least the first acoustic beam, so that the first additional sound waves also represent information of the first audio signals; and

combining the second audio signals into the second cancellation signals for causing the speaker array to generate the second additional sound waves via at least the second acoustic beam, so that the second additional sound waves also represent information of the second audio signals.

7. A method performed by at least one device for active noise cancellation, the method comprising:

from at least a first microphone located within a first environment around a first ear, receiving first microphone signals that represent first sound waves from the first environment;

from at least a second microphone located within a second environment around a second ear, receiving second microphone signals that represent second sound waves from the second environment;

from at least a third microphone located outside a first region of a first acoustic beam, receiving third microphone signals that represent third sound waves from outside the first region;

from at least a fourth microphone located outside a second region of a second acoustic beam, receiving fourth microphone signals that represent fourth sound waves from outside the second region;

in response to the first and third microphone signals, estimating first noise in the first and third sound waves, and outputting first cancellation signals for causing a speaker array to generate first additional sound waves via at least the first acoustic beam for cancelling at least some of the first noise, wherein the first ear and the first microphone are located within the first region of the first acoustic beam; and

in response to the second and fourth microphone signals, estimating second noise in the second and fourth sound waves, and outputting second cancellation signals for causing the speaker array to generate second additional sound waves via at least the second acoustic beam for cancelling at least some of the second noise, wherein the second ear and the second microphone are located within the second region of the second acoustic beam.

8. The method of claim 7, wherein the first additional sound waves are distinct from the second additional sound waves.

9. The method of claim 7, and comprising:

receiving first audio signals from a first channel of an audio source;

receiving second audio signals from a second channel of the audio source;

combining the first audio signals into the first cancellation signals for causing the speaker array to generate the first additional sound waves via at least the first acoustic beam, so that the first additional sound waves also represent information of the first audio signals; and

combining the second audio signals into the second cancellation signals for causing the speaker array to generate the second additional sound waves via at least the second acoustic beam, so that the second additional sound waves also represent information of the second audio signals.

10. The method of claim 7, wherein the speaker array is integral with a headboard of a bed.

11. A system for active noise cancellation, the system comprising:

at least one device for: from at least a first microphone, receiving first microphone signals that represent first sound waves; from at least a second microphone, receiving second microphone signals that represent second sound waves; in response to the first microphone signals, estimating first noise in the first sound waves, and outputting first cancellation signals for causing a speaker array to generate first additional sound waves via at least a first acoustic beam for cancelling at least some of the first noise; and, in response to the second microphone signals, estimating second noise in the second sound waves, and outputting second cancellation signals for causing the speaker array to generate second additional sound waves via at least a second acoustic beam for cancelling at least some of the second noise.

12. The system of claim 11, wherein the first microphone is located within a first environment around a first ear, and wherein the second microphone is located within a second environment around a second ear, so that the first sound waves are from the first environment, and the second sound waves are from the second environment.

13. The system of claim 12, wherein the first ear and the first microphone are located within a first region of the first acoustic beam, and wherein the second ear and the second microphone are located within a second region of the second acoustic beam.

14. The system of claim 11, wherein the first microphone is located outside a first region of the first acoustic beam, and wherein the second microphone is located outside a second region of the second acoustic beam.

15. The system of claim 11, wherein the first additional sound waves are distinct from the second additional sound waves.

16. The system of claim 11, wherein the at least one device is for: receiving first audio signals from a first channel of an audio source; receiving second audio signals from a second channel of the audio source; combining the first audio signals into the first cancellation signals for causing the speaker array to generate the first additional sound waves via at least the first acoustic beam, so that the first additional sound waves also represent information of the first audio signals; and combining the second audio signals into the second cancellation signals for causing the speaker array to generate the second additional sound waves via at least the second acoustic beam, so that the second additional sound waves also represent information of the second audio signals.

17. A system for active noise cancellation, the system comprising:

at least one device for: from at least a first microphone located within a first environment around a first ear, receiving first microphone signals that represent first sound waves from the first environment; from at least a second microphone located within a second environment around a second ear, receiving second microphone signals that represent second sound waves from the second environment; from at least a third microphone located outside a first region of a first acoustic beam, receiving third microphone signals that represent third sound waves from outside the first region; from at least a fourth microphone located outside a second region of a second acoustic beam, receiving fourth microphone signals that represent fourth sound waves from outside the second region; in response to the first and third microphone signals, estimating first noise in the first and third sound waves, and outputting first cancellation signals for causing a speaker array to generate first additional sound waves via at least the first acoustic beam for cancelling at least some of the first noise, wherein the first ear and the first microphone are located within the first region of the first acoustic beam; and, in response to the second and fourth microphone signals, estimating second noise in the second and fourth sound waves, and outputting second cancellation signals for causing the speaker array to generate second additional sound waves via at least the second acoustic beam for cancelling at least some of the second noise, wherein the second ear and the second microphone are located within the second region of the second acoustic beam.

18. The system of claim **17**, wherein the first additional sound waves are distinct from the second additional sound waves.

19. The system of claim **17**, wherein the at least one device is for: receiving first audio signals from a first channel of an audio source; receiving second audio signals from a second channel of the audio source; combining the first audio signals into the first cancellation signals for causing the speaker array to generate the first additional sound waves via at least the first acoustic beam, so that the first additional sound waves also represent information of the first audio signals; and combining the second audio signals into the second cancellation signals for causing the speaker array to generate the second additional sound waves via at least the second acoustic beam, so that the second additional sound waves also represent information of the second audio signals.

20. The system of claim **17**, wherein the speaker array is integral with a headboard of a bed.

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