US 20190021633A1

(19) **United States**

(12) **Patent Application Publication**

Wang et al.

(10) **Pub. No.: US 2019/0021633 A1**

(43) **Pub. Date: Jan. 24, 2019**

(54) **DETECTING RESPIRATORY RATES IN AUDIO USING AN ADAPTIVE LOW-PASS FILTER**

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(21) Appl. No.: **15/819,220**

(22) Filed: **Nov. 21, 2017**

Publication Classification

(51) **Int. Cl.**

A61B 5/08 (2006.01)

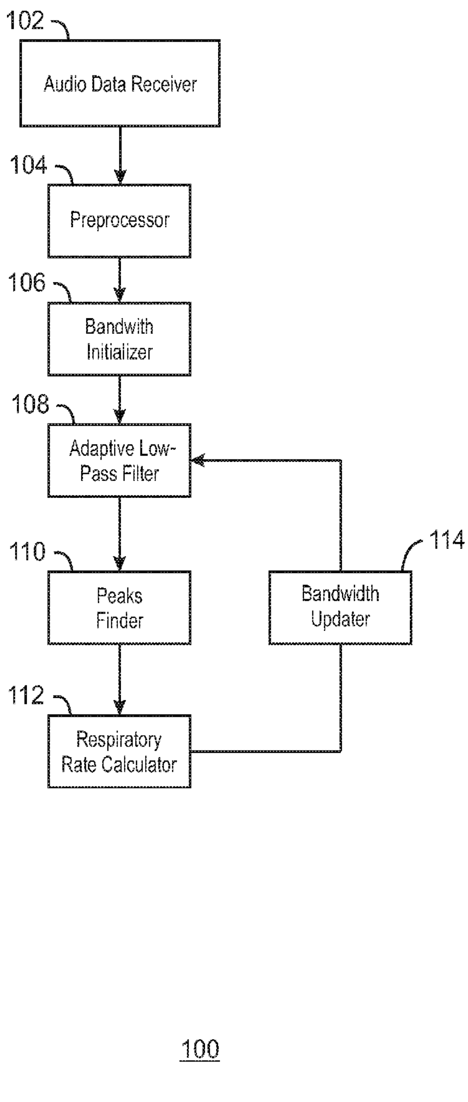
A61B 5/00 (2006.01)

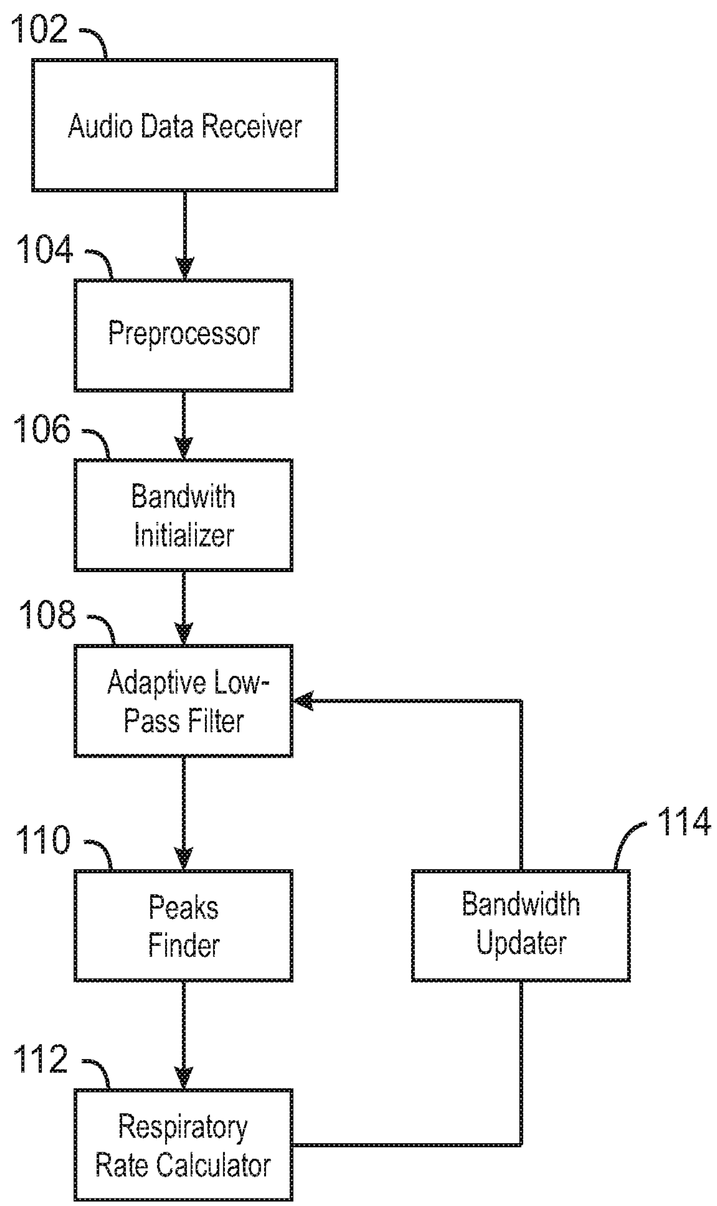
(52) **U.S. Cl.**

CPC ***A61B 5/0816*** (2013.01); *A61B 5/0871* (2013.01); ***A61B 5/725*** (2013.01)

(57) **ABSTRACT**

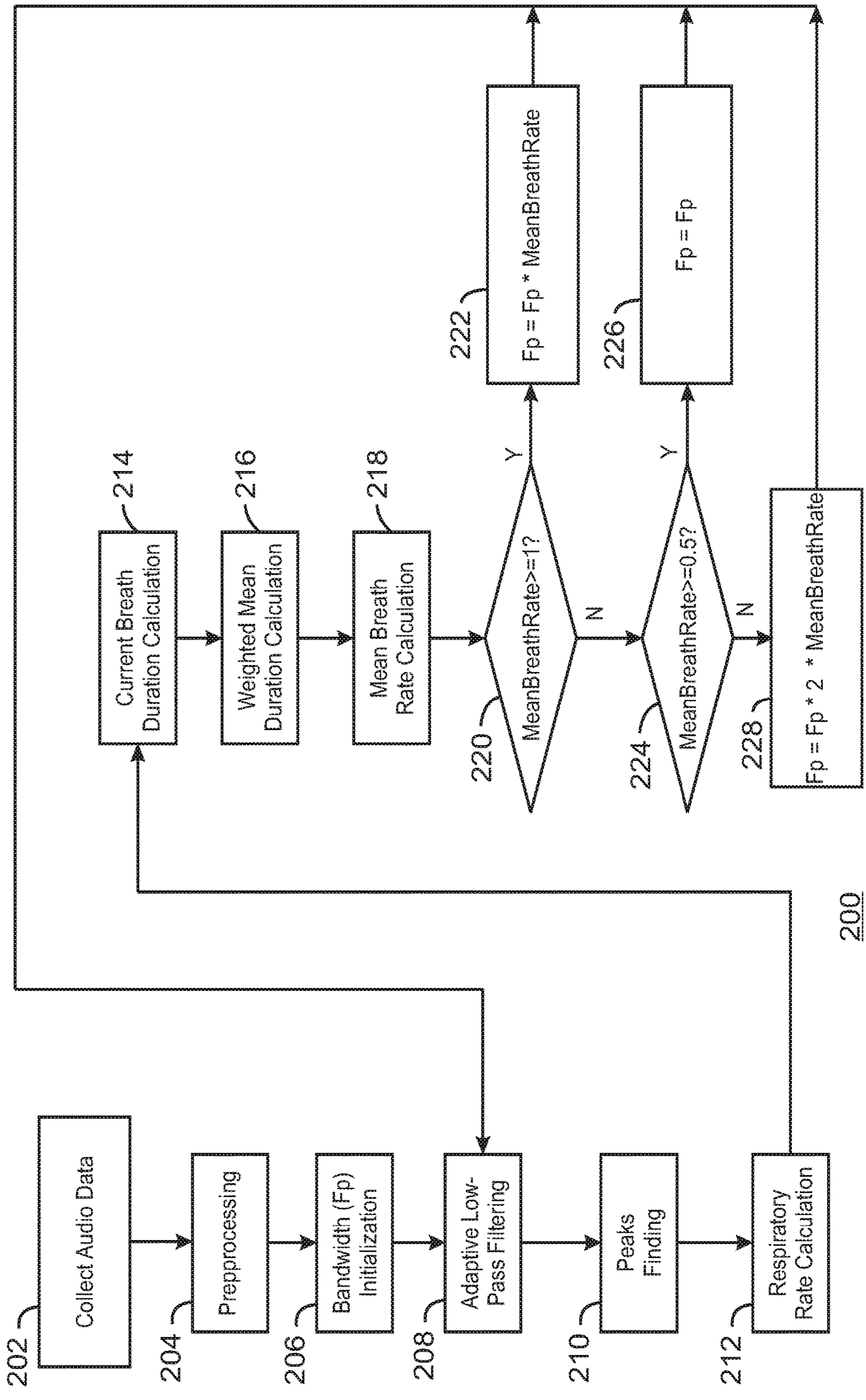
An example apparatus for detecting respiratory rates includes an audio receiver to receive audio including respiratory sounds. The apparatus also includes an adaptive low-pass filter to process the audio using an adaptive bandwidth based on a mean breath rate to generate an envelope. The apparatus further includes a peak detector to detect a plurality of peaks from the envelope. The apparatus includes a respiratory rate calculator to calculate a respiratory rate based on the detected plurality of peaks.




102
Audio Data Receiver
104
Preprocessor
106
Bandwith
Initializer
108
Adaptive Low-
Pass Filter
110
Peaks
Finder
112
Respiratory
Rate Calculator
114
Bandwidth
Updater

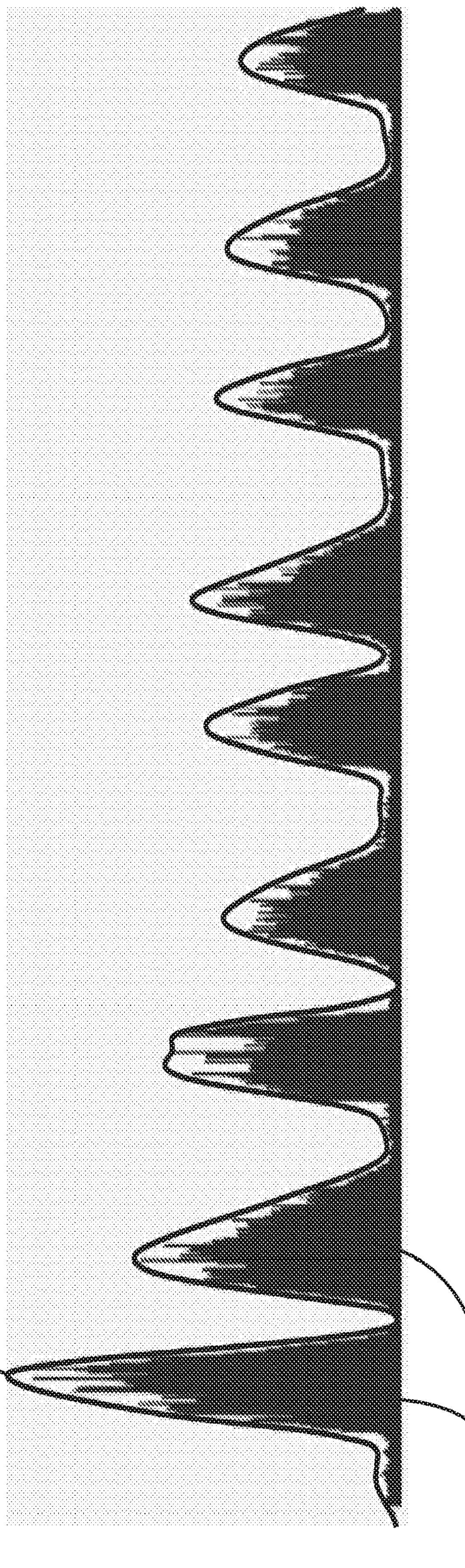
100

FIG. 1


202
Collect Audio Data
204
Prepprocessing
206
Bandwidth (Fp) Initialization
208
Adaptive Low-Pass Filtering
210
Peaks Finding
212
Respiratory Rate Calculation
214
Current Breath Duration Calculation
216
Weighted Mean Duration Calculation
218
Mean Breath Rate Calculation
220
MeanBreathRate>=1?
Y
N
222
Fp = Fp * MeanBreathRate
224
MeanBreathRate>=0.5?
Y
N
226
Fp = Fp
228
Fp = Fp * 2 * MeanBreathRate

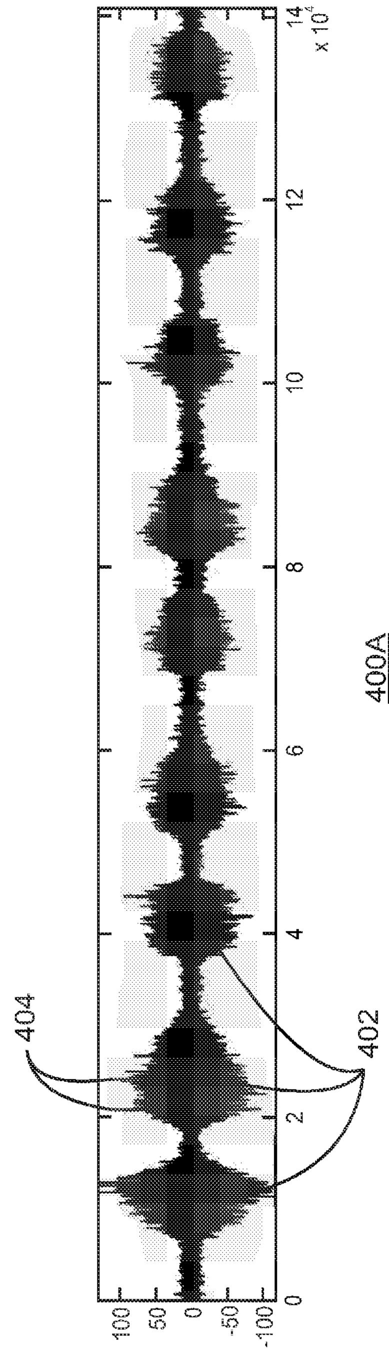
200

FIG. 2

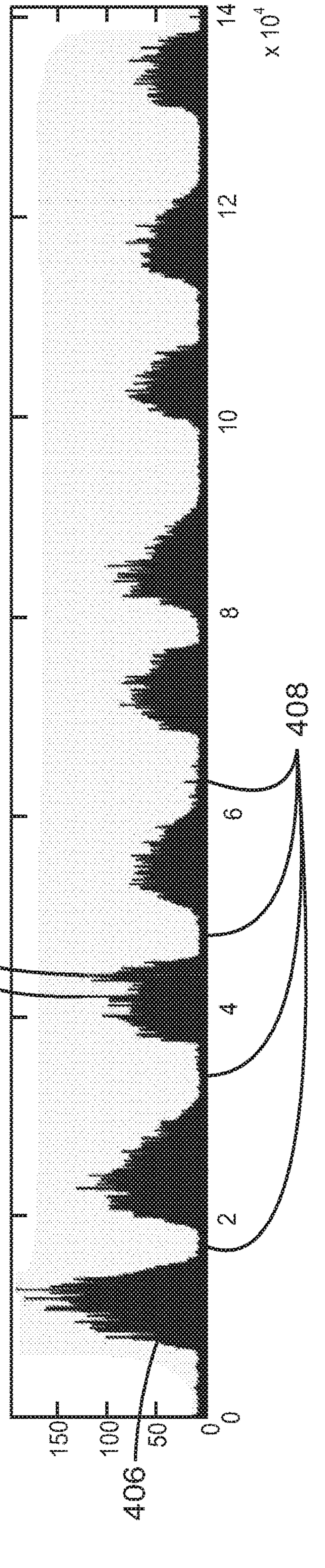


300
FIG. 3

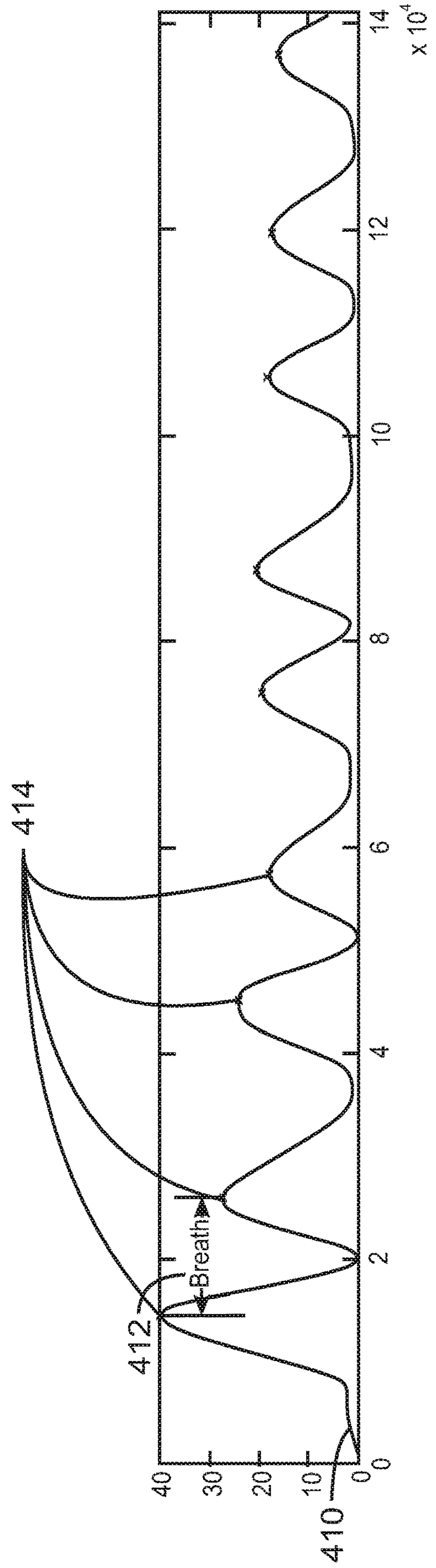
4/10



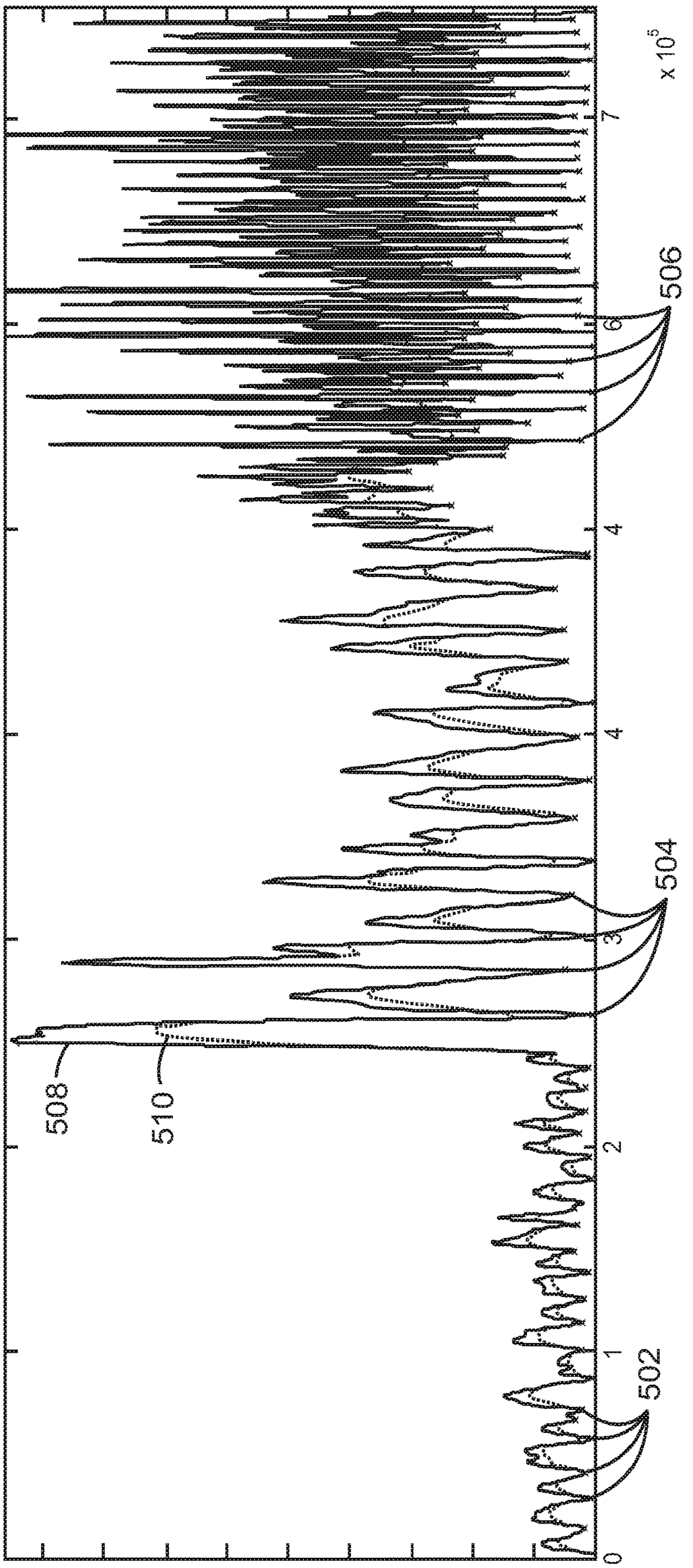
400A
FIG. 4A



400B
FIG. 4B

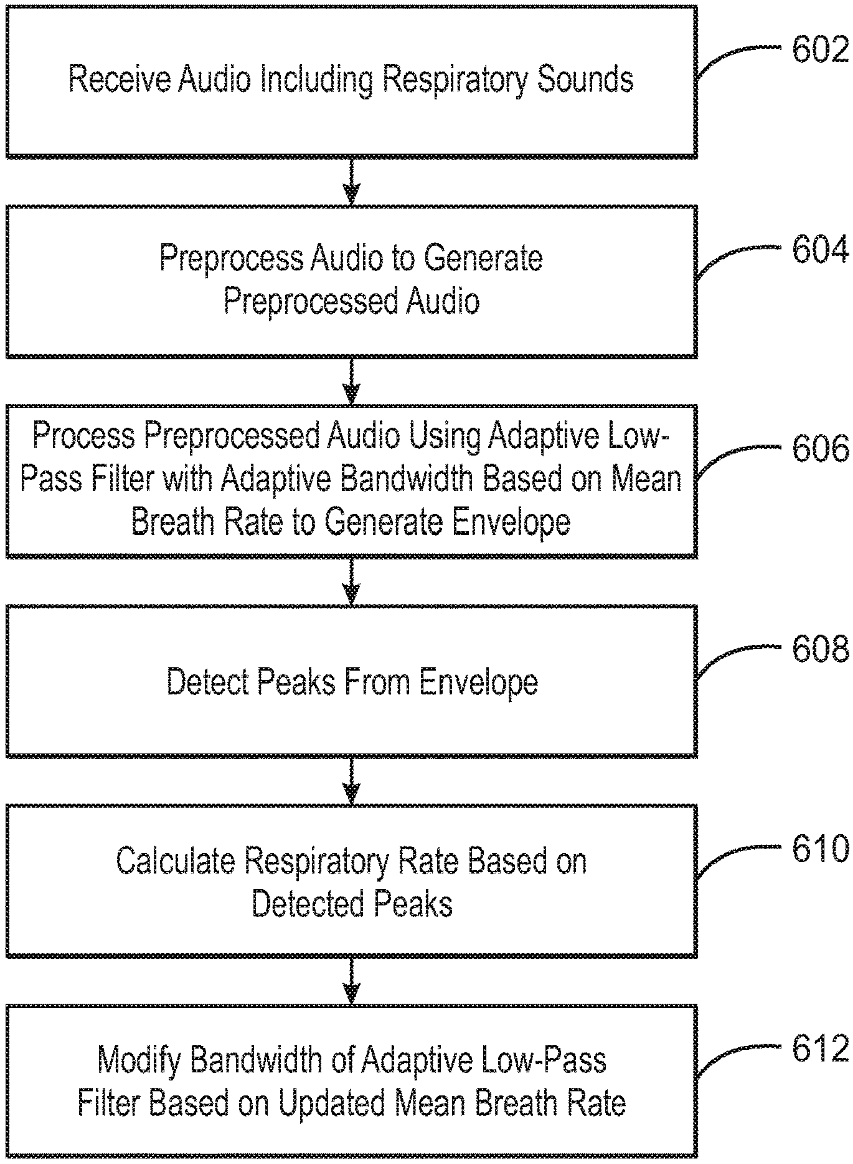


400C
FIG. 4C



500

FIG. 5


Receive Audio Including Respiratory Sounds
602
Preprocess Audio to Generate Preprocessed Audio
604
Process Preprocessed Audio Using Adaptive Low-Pass Filter with Adaptive Bandwidth Based on Mean Breath Rate to Generate Envelope
606
Detect Peaks From Envelope
608
Calculate Respiratory Rate Based on Detected Peaks
610
Modify Bandwidth of Adaptive Low-Pass Filter Based on Updated Mean Breath Rate
612

600
FIG. 6

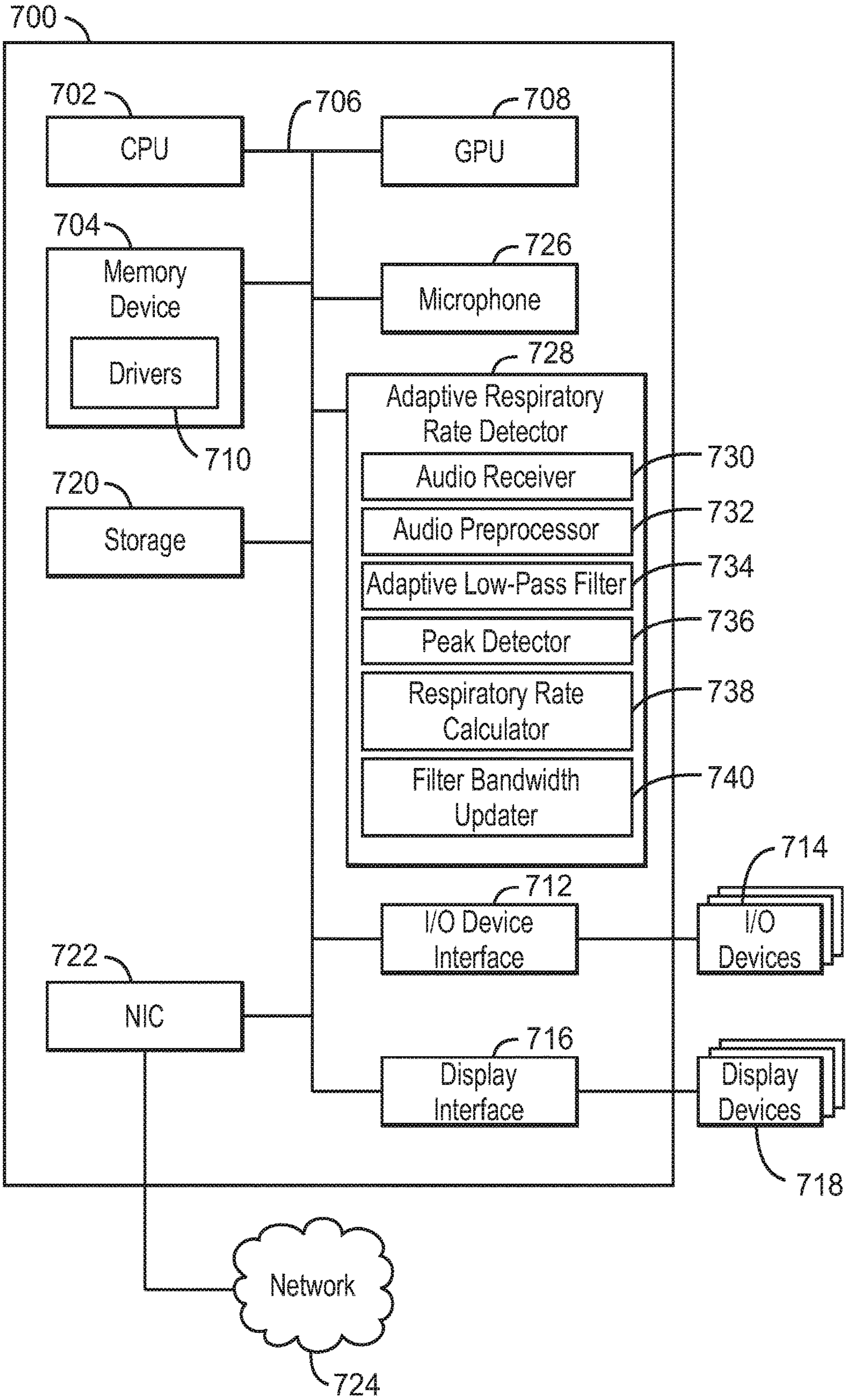

700
702
CPU
706
708
GPU
704
Memory Device
Drivers
710
726
Microphone
728
Adaptive Respiratory Rate Detector
Audio Receiver
730
Audio Preprocessor
732
Adaptive Low-Pass Filter
734
Peak Detector
736
Respiratory Rate Calculator
738
Filter Bandwidth Updater
740
720
Storage
714
712
I/O Device Interface
I/O Devices
722
NIC
716
Display Interface
Display Devices
718
Network
724

FIG. 7

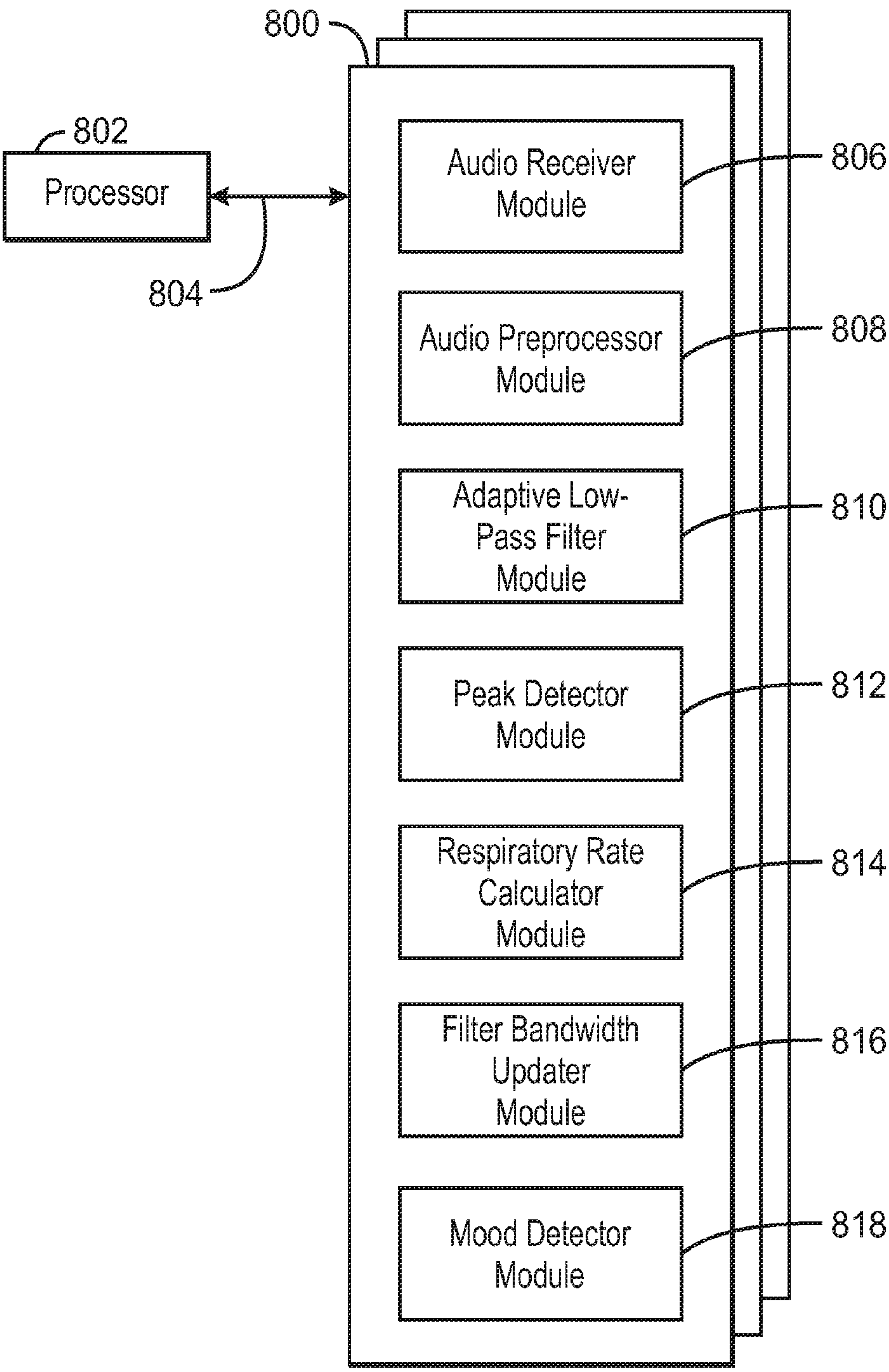

800
802
Processor
804
Audio Receiver Module
806
Audio Preprocessor Module
808
Adaptive Low-Pass Filter Module
810
Peak Detector Module
812
Respiratory Rate Calculator Module
814
Filter Bandwidth Updater Module
816
Mood Detector Module
818

FIG. 8

DETECTING RESPIRATORY RATES IN AUDIO USING AN ADAPTIVE LOW-PASS FILTER

BACKGROUND

[0001] Respiratory rate measuring instruments may be used to detect patterns of respiration. For example, such respiratory rate measuring instruments may use a flow-rate and pressure-relationship, a pressure and temperature change, infrared imaging techniques, or oxygen and carbon dioxide amount change analysis to detect changes in respiratory rate of a monitored individual.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. **1** is a block diagram illustrating an example system for detecting respiratory rates in audio signals using an adaptive low-pass filter;

[0003] FIG. **2** is a detailed flow chart illustrating an example process for detecting respiratory rates in audio signals using an adaptive low-pass filter;

[0004] FIG. **3** is a diagram illustrating an example preprocessed audio signal with a corresponding envelope;

[0005] FIG. **4**A is a diagram illustrating an example raw audio signal;

[0006] FIG. **4**B is a diagram illustrating an example preprocessed audio signal;

[0007] FIG. **4**C is a diagram illustrating an example envelope with a detected breath;

[0008] FIG. **5** is a diagram illustrating example set of detection results;

[0009] FIG. **6** is a flow chart illustrating a method for detecting respiratory rates in audio signals using an adaptive low-pass filter;

[0010] FIG. **7** is block diagram illustrating an example computing device that can detect respiratory rates in audio signals using an adaptive low-pass filter; and

[0011] FIG. **8** is a block diagram showing computer readable media that store code for detecting respiratory rates in audio signals using an adaptive low-pass filter.

[0012] The same numbers are used throughout the disclosure and the figures to reference like components and features. Numbers in the **100** series refer to features originally found in FIG. **1**; numbers in the **200** series refer to features originally found in FIG. **2**; and so on.

DESCRIPTION OF THE EMBODIMENTS

[0013] As discussed above, respiratory rate measuring instruments may use various techniques to detect patterns of respiration. For example, some instruments may use a flow-rate and pressure-relationship, a pressure and temperature change, infrared imaging techniques, oxygen and carbon dioxide amount change. However, such respiratory rate measuring instruments may be designed for use in a hospital. For example, the respiratory rate measuring instruments may be usually large in size, high in price, complex, or otherwise inconvenient to use at home. Moreover, such respiratory rate measuring instruments may also not be portable.

[0014] In some examples, audio of respiration may be captured and used to detect respiratory rates. For example, a low-pass filter may be used to generate a signal envelope in an audio signal containing respiratory sounds. As used herein, an envelope refers to smooth curve outlining extremes in an audio sample. However, setting the low-pass filter to a bandwidth that is too low or too high may result in inaccurate detections or failed detections. For example, if the bandwidth is too low, then the envelope may not be able to distinguish fast breathing and may cause potential detections to be missed. On the other hand, if the bandwidth is too high, there may be more spikes in the audio signal of slower breathing that may cause false detections. As used herein, a spike refers to a sudden steep increase followed by a sudden steep drop in amplitude of an audio signal. Audio of respiration may refer to the audio signals created as a result of respiration.

[0015] The present disclosure relates generally to techniques for detecting respiratory rates in audio. Specifically, the techniques described herein include an apparatus, method, and system for detecting respiratory rates in audio signals using an adaptive low-pass filter. For example, the adaptive low-pass filter may have an adaptive bandwidth that may be adaptive to a detected mean breath rate. An example apparatus includes an audio receiver to receive audio including respiratory sounds. The apparatus includes an adaptive low-pass filter to process the audio using a bandwidth based on a mean breath rate to generate an envelope. The apparatus further includes a peak detector to detect a plurality of peaks from the envelope. The apparatus also includes a respiratory rate calculator to calculate a respiratory rate based on the detected plurality of peaks. In some examples, the apparatus further includes an audio preprocessor to preprocess the audio to generate preprocessed audio, the preprocessed audio to be processed to generate the envelope. The apparatus can also further include a filter bandwidth updater to update a bandwidth of the adaptive low-pass filter based on an updated mean breath rate.

[0016] The techniques described herein thus enable a dynamic bandwidth that significantly improves the accuracy of respiratory detection in audio signals. For example, adapting the bandwidth of the low-pass filter to the audio signal may reduce false detections while preventing missed detections. Moreover, the detected patterns of respiration using the techniques described herein may be used to enable health and work benefits. In some examples, respiratory rates may be increased by stress or anxiety. For example, stress may cause changes in one's mind and body and this will be reflected in respiratory rate. By knowing more about personal breathing patterns, a user can discover stress factors, factors that engage the user, when normal stress of the user turns into anxiety or worry, and apply breathing management to help control stress levels. The techniques may thus provide a mobile solution of monitoring respiratory rates and thus stress levels in users.

[0017] FIG. **1** is a block diagram illustrating an example system for detecting respiratory rates in audio signals using an adaptive low-pass filter. The example system is referred to generally by the reference number **100** and can be implemented in the computing device **700** below in FIG. **7** using the method **600** of FIG. **6** below.

[0018] The example system **100** includes an audio data receiver **102**. For example, the audio data receiver may receive audio including respiratory sounds. The system **100** also includes a preprocessor **104** that is communicatively coupled to audio data receiver **102**. For example, the preprocessor **104** may preprocess audio to remove noise. The preprocessor **104** is communicatively coupled to a bandwidth initializer **106**. For example, the bandwidth initializer **106** may set an initial value for a bandwidth of an adaptive low-pass filter **108**. The adaptive low-pass filter **108** is communicatively coupled to the bandwidth initializer **106**. In some examples, the adaptive low-pass filter **108** can be used to generate envelopes from a received audio based on the bandwidth value. The system **100** also includes a peaks finder **110** that is communicatively coupled to the adaptive low-pass filter **108**. For example, the peaks finder **110** may be used to detect peaks in envelopes generated by the adaptive low-pass filter **108**. The system **100** further includes a respiratory rate calculator **112** that is communicatively coupled to the peaks finder **110** that can calculate a respiratory rate based on the detected peaks. The system also further includes a bandwidth updater **114** that is communicatively coupled to both the respiratory rate calculator **112** and the adaptive low-pass filter **108**.

[0019] As shown in FIG. **1**, the audio data receiver **102** may receive audio including respiratory sounds. For example, the respiratory sounds may be breathing captured by a microphone in a device (not shown). For example, the device may be a mobile device, such as a cellphone or a tablet. In some examples, the device can be a pair of smart glasses with an embedded microphone.

[0020] The preprocessor **104** can process the audio to make the audio more suitable for envelope generation and peak finding. For example, the preprocessor **104** can remove noise from the audio or reduce a DC offset of the audio. As used herein, a DC offset refers to a mean value of the waveform of the audio. For example, if the mean amplitude of an audio waveform is zero, then there is no DC offset. In some examples, the preprocessor **104** can also take an absolute value of the audio to generate a preprocessed audio, as described in greater detail below.

[0021] The bandwidth initializer **106** can set an initial bandwidth for the adaptive low-pass filter **108**. For example, given nine breaths and a breath duration of about 14,000 milliseconds, the average duration of a breath in FIG. **4**C may be about 14000/9=1555 milliseconds. A corresponding average breathing rate may be 0.65 Hz. In some examples, the initial bandwidth set by the bandwidth initializer may be based on an average breathing rate. For example, an initial bandwidth of the adaptive low-pass filter **108** may be approximately Fp=1.5 Hertz (Hz). In some examples, the initial value set by the bandwidth initializer **106** may be based on an activity of the user. For example, a set of preset initial values may be selected from based on the detected activity.

[0022] The adaptive low-pass filter **108** may then generate an envelope for the received audio. For example, the envelope may be generated based on the initial bandwidth value.

[0023] The peaks finder **110** can then detect peaks in the envelope. For example, one peak may be detected for each inhalation and exhalation sound in the audio.

[0024] The respiratory rate calculator **112** can then detect a respiratory rate based on the detected peaks. For example, the respiratory rate calculator **112** can detect a breath for every two detected peaks. In some examples, a duration of a breath may be the time between two consecutive peaks. As used herein, a breath refers to an inhalation or an exhalation, rather than a full breathing cycle that includes both an inhalation and an exhalation.

[0025] The bandwidth updater **114** can update the bandwidth of the adaptive low-pass filter **108**. For example, the bandwidth updater **114** can update the bandwidth of the adaptive low-pass filter **108** in real-time. In some examples, if the breathing rate of a user is much higher or lower than 0.65 Hz, or the breathing rate of a user moves up or down, then the bandwidth of the adaptive low-pass filter **108** may be updated.

[0026] The diagram of FIG. **1** is not intended to indicate that the example system **100** is to include all of the components shown in FIG. **1**. Rather, the example system **100** can be implemented using fewer or additional components not illustrated in FIG. **1** (e.g., additional preprocessors, filters, etc.).

[0027] FIG. **2** is a detailed flow chart illustrating an example process for detecting respiratory rates in audio signals using an adaptive low-pass filter. The example process is generally referred to by the reference number **200** and can be implemented in the system **100** above in FIG. **1** or using the processor **702** of the computing device **700** of FIG. **7** below.

[0028] At block **202**, a processor can collect audio data. For example, an audio sample may be captured by a microphone. The audio sample may include respiratory sounds corresponding to the breathing of a user.

[0029] At block **204**, the processor performs preprocessing on the audio data. For example, the preprocessing may be applied to the audio data in order to remove noise. In some examples, a difference may be calculated between two data in response to detecting that there is a DC offset in an audio. In some examples, the absolute value of the audio signal may be calculated. In some examples, a band stop filter may be applied to remove a certain frequency interference. For example, AC interference may be at 50 Hz or 60 Hz.

[0030] At block **206**, the processor performs a bandwidth initialization. For example, an initial value for the bandwidth to be used by an adaptive low-pass filter may be set. In some examples, the initial value set for the bandwidth may be based on an average breath rate. For example, the average duration of a breath in FIG. **4**C is about 14000/9=1555 ms, resulting in a breathing rate of about 0.65 Hz. Thus, in some examples, the bandwidth of the low pass filter may be set to an initial value of Fp=1.5 Hz in accordance with the Nyquist Theorem as discussed in greater detail below. In some examples, the initial value of the bandwidth of the adaptive low-pass filter may be set based on a detected activity of the user.

[0031] At block **208**, the processor causes an adaptive low-pass filtering. For example, an adaptive low-pass filter can apply the low-pass filtering on audio or preprocessed audio to generate an envelope corresponding to the audio. In some examples, the envelope may be based on different bandwidth values depending on a mean breath rate, as described in greater detail below.

[0032] At block **210**, the processor performs a peak finding algorithm. For example, one or more peaks may be detected in the envelope generated at block **208**. In some examples, the one or more peaks can be detected using one or more adaptive thresholds. For example, the thresholds can be based on peak amplitude and distance between detected peaks.

[0033] At block **212**, the processor performs a respiratory rate calculation. For example, the respiratory rate calculation may divide the total number of peaks over a period of time.

For example, the respiratory rate may measure the total number of breaths (inhalations or exhalations) in a given period of time.

[0034] At block **214**, the processor receives a current breath duration. For example, the current breath duration can have been calculated by the duration between the current and the previous peak.

[0035] At block **216**, the processor performs a weighted mean duration calculation. For example, the current weighted mean duration can be calculated by the weighted mean of the current duration and a previously calculated weighted mean.

[0036] At block **218**, the processor performs a mean breath rate calculation. For example, the mean breath rate can be calculated by 1 second divided by the weighted mean duration from block **216**.

[0037] At decision diamond **220**, the processor can determine whether mean breath rate is equal to or greater than the value one. If the mean breath rate is equal to or greater than the value one, then the process may continue at block **222**. If the mean breath rate is not equal to or greater than the value one, then the process may continue at decision diamond **224**.

[0038] At block **222**, the processor increases the bandwidth in response to detecting that the mean breath rate has increased. For example, the processor can calculate the new bandwidth based on the equation:

$$F_{Pnew}=F_{Pold}*\text{MeanBreathRate} \quad \text{Eq. 1}$$

where the MeanBreathRate is equal to or greater than one, F_{Pnew} is a newly calculated bandwidth for an adaptive low-pass filter, and F_{Pold} is a previously used bandwidth of the adaptive low-pass filter.

[0039] At decision diamond **224**, the processor can determine whether mean breath rate is equal to or greater than the value 0.5. For example, if the mean breath rate is equal to or greater than the value 0.5, then the process may continue at block **226**. If the mean breath rate is not equal to or greater than 0.5, then the process may continue at block **228**.

[0040] At block **226**, the processor sets the new bandwidth to the same value as the old bandwidth in response to detecting a breath rate between 0.5 and 1. In some examples, the processor may not update the bandwidth of the adaptive low-pass filter such that the adaptive low-pass filter continues to use the same bandwidth.

[0041] At block **228**, processor decreases the bandwidth in response to detecting a mean breathing rate less than 0.5. For example, the processor can decrease the bandwidth based on the equation:

$$F_{Pnew}=F_{Pold}*2*\text{MeanBreathRate} \quad \text{Eq. 2}$$

where the MeanBreathRate is less than 0.5.

[0042] Thus, as described above, when a user is breathing faster, the bandwidth may be increased such that the resulting envelope has more detail. On the other hand; when the user is breathing slower, the bandwidth may be reduced such that the envelope is not too spiky to avoid false detections of peaks. Using such an adaptive bandwidth for the adaptive low-pass filter, the accuracy of the detection of peaks and thus respiratory rate may be significantly improved.

[0043] This process flow diagram is not intended to indicate that the blocks of the example process **200** are to be executed in any particular order, or that all of the blocks are to be included in every case. Further, any number of additional blocks not shown may be included within the example process **200**, depending on the details of the specific implementation. For example, although three ranges for the mean bandwidth are use above, including >1, between 0.5 and 1, and <0.5, in some examples, the number of cases and the numbers (0.5, 1, 2 . . .) can be further fine-tuned. For example, the ranges can be divided into additional ranges, or $F_{Pnew}=F_{Pold}*1.05*\text{MeanBreathRate}$ in some examples, and $F_{Pnew}=F_{Pold}*1.12*\text{MeanBreathRate}$ in other examples.

[0044] FIG. **3** is a diagram illustrating an example preprocessed audio signal with a corresponding envelope. The example preprocessed audio signal is generally referred to by the reference number **300** and can be generated by in the computing device **700** below. For example, the preprocessed audio signal **300** can be generated using the preprocessor **104** of the system **100** of FIG. **1**, the audio preprocessor **732** of the computing device **700** of FIG. **7** below, or the audio preprocessor module **808** of the computer readable media **800** of FIG. **8** below.

[0045] FIG. **3** shows a set of preprocessed signals **302** that have been preprocessed as described above. For example, the preprocessed signals **302** may have been processed by a preprocessor to take an absolute value. In addition, the audio may have been processed to remove noise. As shown in FIG. **3**, an envelope **304** may have been generated by an adaptive low-pass filter as described above. In some examples, peak finding may be performed on the envelope as described above and below. For example, since the envelope may have only one local maximum associated with each of the breaths in the preprocessed signals **302**, peak finding may be performed more accurately on the generated envelope **304**.

[0046] The diagram of FIG. **3** is not intended to indicate that the example preprocessed audio signal **300** is to include all of the components shown in FIG. **3**. Rather, the example preprocessed audio signal **300** can be implemented using fewer or additional components not illustrated in FIG. **3** (e.g., additional preprocessing, preprocessed signals, etc.).

[0047] FIG. **4**A is a diagram illustrating an example raw audio signal. The example raw audio signal is generally referred to by the reference number **400**A and can be implemented in the computing device **700** below. For example, the raw audio signal **400**A can be received at the audio data receiver **102** of the system **100** of FIG. **1**, the audio receiver **730** of the computing device **700** of FIG. **7** below, or the audio receiver module **806** of the computer readable media **800** of FIG. **8** below.

[0048] FIG. **4**A shows a set of sounds **402**. As shown in FIG. **4**A, the sounds **402** may include multiple spikes **404** indicating louder portions of the sounds **402**. In some examples, the spikes **404** may be falsely detected as two separate respiratory sounds if a peak finding was performed directly on the raw audio signal **400**A. Therefore, in some examples, preprocessing and envelope generation may be performed on the raw audio **400**A, as described in FIGS. **4**B and **4**C below.

[0049] The diagram of FIG. **4**A is not intended to indicate that the example raw audio signal **400**A is to include all of the components shown in FIG. **4**A. Rather, the example raw audio signal **400**A can be implemented using fewer or additional components not illustrated in FIG. **4**A (e.g., additional waveforms, audio signals, etc.).

[0050] FIG. **4**B is a diagram illustrating an example preprocessed audio signal. The example preprocessed audio signal is generally referred to by the reference number **400**B and can be implemented in the computing device **700** below.

For example, the preprocessed audio signal **400**B can be generated by the preprocessor **104** of the system **100** of FIG. **1**, the audio preprocessor **732** of the computing device **700** of FIG. **7** below, or the audio preprocessor module **808** of the computer readable media **800** of FIG. **8** below.

[0051] The preprocessed audio signal **400**B of FIG. **4**B includes a set of preprocessed sounds **406** corresponding to sounds **402**. The preprocessed sounds **406** may be the absolute value of the sounds **402** of the raw audio signal **400**A. In addition, the preprocessed audio signal **400**B includes gaps **408** with reduced noise. For example, a difference may have been taken between two audio signals to remove noise from the preprocessed audio signal **400**B. As shown in FIG. **4**B, each of the sounds **404** may still include multiple peaks. Therefore, in some examples, an envelope may be generated as described in FIG. **4**C below.

[0052] The diagram of FIG. **4**B is not intended to indicate that the example preprocessed audio signal **400**B is to include all of the components shown in FIG. **4**B. Rather, the example preprocessed audio signal **400**B can be implemented using fewer or additional components not illustrated in FIG. **4**B (e.g., additional processing, sounds, etc.).

[0053] FIG. **4**C is a diagram illustrating an example envelope with a detected breath. The example detected respiratory rate is generally referred to by the reference number **400**C and can be detected using the system **100** above or the computing device **700** below. For example, the detected respiratory rate **400**C can be detected by the adaptive low-pass filter **108** of the system **100** of FIG. **1**, the adaptive low-pass filter **734** of the computing device **700** of FIG. **7** below, or the adaptive low-pass filter module **810** of the computer readable media **800** of FIG. **8** below.

[0054] FIG. **4**C includes an envelope **410**. For example, the envelope **410** may have been generated by an adaptive low-pass filter. In some examples, the adaptive low-pass filter may have a bandwidth that is based on a mean breath rate. For example, the mean breath rate can be a weighted mean breath rate.

[0056] The diagram of FIG. **4**C is not intended to indicate that the example detected respiratory rate **400**C is to include all of the components shown in FIG. **4**C. Rather, the example detected respiratory rate **400**C can be implemented using fewer or additional components not illustrated in FIG. **4**C (e.g., additional envelopes, peaks, detected breaths, etc.).

[0057] FIG. **5** is a diagram illustrating an example set of detection results. The example set of detection results is generally referred to by the reference number **500** and can be implemented in the computing device **700** below. For example, the set of detection results **500** can be generated using the system **100** of FIG. **1** above, the adaptive respiratory rate detector **728** of the computing device **700** of FIG. **7** below, or the computer readable media **800** of FIG. **8** below.

[0058] FIG. **5** shows a set of detection results **500** of an experiment. The results **500** include three types of breaths, including slow breaths **502**, normal breaths **504**, and rapid shallow breaths **506**. In the example of FIG. **5**, the accuracy of breath detections in the three types of breaths, including normal breaths **502**, deep breathes **504**, and shallow breaths **506**, are all above 90%. Six detections are missing from the rapid shallow breathing **506**, and all the missing detections are at the transition of the sudden change from slow deep breathing **504** to rapid shallow breathing **506**. In some examples, breaths can be detected using valley finding rather than peak finding. For example, a received signal can be reversed and the peaks may become valleys. In the example of FIG. **5**, the detected valleys in FIG. **5** are indicated using "x"s. In addition, FIG. **5** shows a preprocessed signals **508** as well as adaptive thresholds **510** used for valley finding. For example, the detection results **500** for adaptive bandwidth low-pass filter peak detection are shown in Table 1 below in the bottom row as compared to other static low-pass filters.

TABLE 1

Detection Results for Low-Pass Filters Using Different Bandwidths.

Band-width	Normal Breaths (0.65 Hz)			Deep Breaths (0.44 Hz)			Shallow Breaths (2.2 Hz)			Average
(Fp)	Missing	Wrong	Accuracy	Missing	Wrong	Accuracy	Missing	Wrong	Accuracy	Accuracy
1.2	1	0	95.00%	1	0	92.86%	70	0	0.00%	62.62%
2	1	0	95.00%	1	0	92.86%	69	0	1.43%	63.10%
3	1	1	90.00%	0	1	92.86%	34	0	51.43%	78.10%
4	0	4	80.00%	0	1	92.86%	23	0	67.14%	80.00%
6	0	9	55.00%	0	6	57.14%	0	0	100.00%	70.71%
8	0	15	25.00%	0	12	14.29%	0	0	100.00%	46.43%
Adaptive	1	1	90%	0	0	100%	4	0	94.3%	94.8%

[0055] As shown in FIG. **4**C, a breath **412** may be detected between two of a number of nine total detected peaks **414**. For example, each of the detected peaks **414** may be associated with one of the sounds **408** of example **400**B above. Thus, each of the waveforms may now be associated with one detected peak **414**. In some examples, a single breath **408** may then be detected for every two detected peaks **414**. Thus, a respiratory rate can be calculated based on the number of breathes **412** detected over any period of time. Since only one peak is associated with each sound, false detections of additional breaths may be avoided.

[0059] In some examples, an accuracy of the detection can be determined using the equation:

Accuracy=((Number of Breaths)−(Number of Wrong Detections)−(Number of Missing Detections))/(Number of Breaths) Eq. 3

[0060] For example, according to the Nyquist Theorem, the bandwidth Fp can be at least twice the breathing rate. In the example audio sample used for the detection results above with a sampling rate of 8 k/s, the normal breathing rate is about 0.65 Hz, the deep breathing rate is about 0.44

Hz, and the shallow rapid breathing rate is about 2.2 Hz. As shown in Table 1, the shallow rapid breathing detection is not working when Fp<4, and the normal and deep breathing detection is good when Fp=1.2 or 2. On the other hand, when the bandwidth Fp is too large, more details are showing in the envelope. The envelope may thus be very spiky, with many tiny peaks detectable in one breathing, leading to increased wrong detections. Thus, as shown in Table 1, when the bandwidth Fp>=6, both normal breathing and deep breathing detections are worse.

[0061] In some examples, by making the change from slow deep breathing **504** to rapid shallow breathing **506** gradual instead of sudden, there may be fewer missing detections in the detection results **500**. For example, the use of a mean breath rate may be used to gradually change a bandwidth of an adaptive low-pass filter. The improved envelope extraction may thus increase detection accuracy. For example, the adaptive bandwidth may gradually follow the change of breathing rate and prevent missed detections accordingly.

[0062] The diagram of FIG. **5** is not intended to indicate that the example set of detection results **500** is to include all of the components shown in FIG. **5**. Rather, the example set of detection results **500** can be implemented using fewer or additional components not illustrated in FIG. **5** (e.g., additional breathing rates, detections, etc.).

[0063] FIG. **6** is a flow chart illustrating a method for detecting respiratory rates in audio signals using an adaptive low-pass filter. The example method is generally referred to by the reference number **600** and can be implemented in the system **100** of FIG. **1** above, the processor **702** of the computing device **700** of FIG. **7** below, or the computer readable media **800** of FIG. **8** below.

[0064] At block **602**, a processor receives audio including a number of respiratory sounds. For example, the respiratory sounds may be sounds related to inhaling and exhaling of a user.

[0065] At block **604**, the processor preprocesses the audio to generate preprocessed audio. For example, the processor can preprocess the audio to reduce a DC offset of the audio. In some examples, the processor can take an absolute value of the audio to generate a preprocessed audio.

[0066] At block **606**, the processor processes the audio using an adaptive low-pass filter with an adaptive bandwidth based on a mean breath rate to generate an envelope. In some examples, the processor can set an initial value for the bandwidth of the adaptive low-pass filter based on an average breath rate. Additionally, in some examples, the processor can set the initial value for the bandwidth of the adaptive low-pass filter based on a detected activity of a user. For example, the detected activity may be running, walking, sitting, etc.

[0067] At block **608**, the processor detects a plurality of peaks from the envelope. For example, the processor can detect if one or more adaptive thresholds based on peak amplitude and distance between peaks are exceeded.

[0068] At block **610**, the processor calculates a respiratory rate based on the detected plurality of peaks. For example, the processor can detect a breath based on a number of detected peaks.

[0069] At block **612**, the processor modifies the bandwidth of the adaptive-low pass filter based on an updated mean breath rate. For example, the processor can increase the bandwidth of the adaptive-low pass filter in response to detecting an increase in the mean breath rate. In some examples, the processor can decrease the bandwidth of the adaptive-low pass filter in response to detecting a decrease in the mean breath rate.

[0070] This process flow diagram is not intended to indicate that the blocks of the example process **600** are to be executed in any particular order, or that all of the blocks are to be included in every case. Further, any number of additional blocks not shown may be included within the example process **600**, depending on the details of the specific implementation. For example, the processor can also detect a stress level based on the respiratory rate and sending a notification in response to detecting the stress level exceeds a threshold stress level. In some examples, the processor can detect a mood of a user based on the respiratory rate.

[0071] Referring now to FIG. **7**, a block diagram is shown illustrating an example computing device that can detect respiratory rates in audio signals using an adaptive low-pass filter. The computing device **700** may be, for example, a laptop computer, desktop computer, tablet computer, mobile device, or wearable device, among others. In some examples, the computing device **700** may be embedded into a pair of glasses. The computing device **700** may include a central processing unit (CPU) **702** that is configured to execute stored instructions, as well as a memory device **704** that stores instructions that are executable by the CPU **702**. The CPU **702** may be coupled to the memory device **704** by a bus **706**. Additionally, the CPU **702** can be a single core processor, a multi-core processor, a computing cluster, or any number of other configurations. Furthermore, the computing device **700** may include more than one CPU **702**. In some examples, the CPU **702** may be a system-on-chip (SoC) with a multi-core processor architecture. In some examples, the CPU **702** can be a specialized digital signal processor (DSP) used for image processing. The memory device **704** can include random access memory (RAM), read only memory (ROM), flash memory, or any other suitable memory systems. For example, the memory device **704** may include dynamic random access memory (DRAM).

[0072] The memory device **704** can include random access memory (RAM), read only memory (ROM), flash memory, or any other suitable memory systems. For example, the memory device **704** may include dynamic random access memory (DRAM).

[0073] The computing device **700** may also include a graphics processing unit (GPU) **708**. As shown, the CPU **702** may be coupled through the bus **706** to the GPU **708**. The GPU **708** may be configured to perform any number of graphics operations within the computing device **700**. For example, the GPU **708** may be configured to render or manipulate graphics images, graphics frames, videos, or the like, to be displayed to a user of the computing device **700**.

[0074] The memory device **704** can include random access memory (RAM), read only memory (ROM), flash memory, or any other suitable memory systems. For example, the memory device **704** may include dynamic random access memory (DRAM). The memory device **704** may include device drivers **710** that are configured to execute the instructions for detecting respiratory rates. The device drivers **710** may be software, an application program, application code, or the like.

[0075] The CPU **702** may also be connected through the bus **706** to an input/output (I/O) device interface **712** configured to connect the computing device **700** to one or more I/O devices **714**. The I/O devices **714** may include, for example, a keyboard and a pointing device, wherein the pointing device may include a touchpad or a touchscreen, among others. The I/O devices **714** may be built-in components of the computing device **700**, or may be devices that are externally connected to the computing device **700**. In some examples, the memory **704** may be communicatively coupled to I/O devices **714** through direct memory access (DMA).

[0076] The CPU **702** may also be linked through the bus **706** to a display interface **716** configured to connect the computing device **700** to a display device **718**. The display device **718** may include a display screen that is a built-in component of the computing device **700**. The display device **718** may also include a computer monitor, television, or projector, among others, that is internal to or externally connected to the computing device **700**.

[0077] The computing device **700** also includes a storage device **720**. The storage device **720** is a physical memory such as a hard drive, an optical drive, a thumbdrive, an array of drives, a solid-state drive, or any combinations thereof. The storage device **720** may also include remote storage drives.

[0078] The computing device **700** may also include a network interface controller (NIC) **722**. The NIC **722** may be configured to connect the computing device **700** through the bus **706** to a network **724**. The network **724** may be a wide area network (WAN), local area network (LAN), or the Internet, among others. In some examples, the device may communicate with other devices through a wireless technology. For example, the device may communicate with other devices via a wireless local area network connection. In some examples, the device may connect and communicate with other devices via Bluetooth® or similar technology.

[0079] The computing device **700** further includes a microphone **726**. For example, the microphone may include one or more transducers that can convert sound into electrical signals. For example, the microphone **726** may be located in a device such as glasses. As one example, the microphone **726** may be embedded into the nose bridge of a pair of glasses.

[0080] The computing device **700** further includes an adaptive respiratory rate detector **728**. For example, the adaptive respiratory rate detector **728** can be used to detect respiratory rates in audio signals. The adaptive respiratory rate detector **728** can include an audio receiver **730**, an audio preprocessor **732**, an adaptive low-pass filter **734**, a peak detector **736**, a respiratory rate calculator **738**, and a filter bandwidth updater **740**. In some examples, each of the components **730**-**740** of the adaptive respiratory rate detector **728** may be a microcontroller, embedded processor, or software module. The audio receiver **730** can receive audio including respiratory sounds. For example, the audio may be an audio signal corresponding to an audio sample of breathing of a user. The audio preprocessor **732** can reduce a DC offset of the audio to generate preprocessed audio, reduce or remove noise, generate an absolute value of audio signals, or any combination thereof. For example, the preprocessed audio can be processed to generate the envelope. In some examples, the audio preprocessor **732** can take an absolute value of the audio to generate a preprocessed audio. The adaptive low-pass filter **734** can process the audio using an adaptive bandwidth based on a detected mean breath rate to generate an envelope. For example, the mean breath rate may be a weighted mean breath rate, with more recent breaths having a higher weight, and older breaths having less weight. The adaptive bandwidth of the adaptive low-pass filter **734** may be adaptive to the mean breath rate. In some examples, an initial bandwidth used by the adaptive low-pass filter is based on an average breath rate. In some examples, an initial bandwidth used by the adaptive low-pass filter is estimated based on a detected activity of a user. For example, the initial bandwidth may be set based on whether the user is running, walking, sitting, etc. In some examples, the adaptive low-pass filter **734** can process preprocessed audio to generate the envelope. The peak detector **736** can detect a plurality of peaks from the envelope. For example, the peak detector **736** can detect peaks using one or more adaptive thresholds based on peak amplitude and distance between peaks. The respiratory rate calculator **738** can calculate a respiratory rate based on the detected plurality of peaks. For example, the respiratory rate calculator **738** can detect a breath rate based on a number of detected peaks. For example, the respiratory rate calculator **738** can detect a breath rate based on a number of detected peaks and the duration of the peaks. The filter bandwidth updater **740** can calculate a mean breath rate based on historical data and update the bandwidth based on the mean breath rate. For example, filter bandwidth updater **740** can calculate a weighted mean breath rate based on historical data. The filter bandwidth updater **740** can then update the bandwidth based on the weighted mean breath rate. For example, a weight of the weighted mean breath rate is based on a regularity of the breathing rate. In some examples, the filter bandwidth updater **740** can increase the bandwidth of the adaptive low-pass filter in response to detecting an increase in the mean breath rate. In some examples, the filter bandwidth updater **740** can decrease the bandwidth of the adaptive low-pass filter in response to detecting a decrease in the mean breath rate.

[0081] The block diagram of FIG. **7** is not intended to indicate that the computing device **700** is to include all of the components shown in FIG. **7**. Rather, the computing device **700** can include fewer or additional components not illustrated in FIG. **7**, such as additional buffers, additional processors, and the like. The computing device **700** may include any number of additional components not shown in FIG. **7**, depending on the details of the specific implementation. Furthermore, any of the functionalities of the audio receiver **730**, the audio preprocessor **732**, the adaptive low-pass filter **734**, the peak detector **736**, the respiratory rate calculator **738**, and the filter bandwidth updater **740**, may be partially, or entirely, implemented in hardware and/or in the processor **702**. For example, the functionality may be implemented with an application specific integrated circuit, in logic implemented in the processor **702**, or in any other device. In addition, any of the functionalities of the CPU **702** may be partially, or entirely, implemented in hardware and/or in a processor. For example, the functionality of the adaptive respiratory rate detector **728** may be implemented with an application specific integrated circuit, in logic implemented in a processor, in logic implemented in a specialized audio processing unit, or in any other device.

[0082] FIG. **8** is a block diagram showing computer readable media **800** that store code for detecting respiratory rates in audio signals using an adaptive low-pass filter. The computer readable media **800** may be accessed by a processor **802** over a computer bus **804**. Furthermore, the computer readable medium **800** may include code configured to direct the processor **802** to perform the methods described herein. In some embodiments, the computer readable media **800** may be non-transitory computer readable media. In some examples, the computer readable media **800** may be storage media.

[0083] The various software components discussed herein may be stored on one or more computer readable media **800**, as indicated in FIG. **8**. For example, an audio receiver module **806** may be configured to receive audio including respiratory sounds. An audio preprocessor module **808** may be configured to preprocess the audio to reduce a DC offset of the audio. In some examples, the audio preprocessor module **808** may be configured to take an absolute value of the audio to generate a preprocessed audio. An adaptive low-pass filter module **810** may be configured to process the audio using an adaptive low-pass filter with an adaptive bandwidth based on a mean breath rate to generate an envelope. A peak detector module **812** may be configured to detect a plurality of peaks from the envelope. For example, the peak detector module **812** may be configured to detect a peak in response to detecting that one or more adaptive thresholds based on peak amplitude and distance between peaks are exceeded in the audio. A respiratory rate module **814** may be configured to calculate a respiratory rate based on the detected plurality of peaks. For example, the respiratory rate module **814** may be configured to detect a breath based on a number of detected peaks. For example, a breath may be detected for every two detected peaks. A filter bandwidth updater module **816** may be configured to modify the bandwidth of the adaptive-low pass filter based on an updated mean breath rate. For example, the filter bandwidth updater module **816** may be configured to increase the bandwidth of the adaptive-low pass filter in response to detecting an increase in the mean breath rate. The filter bandwidth updater module **816** may be configured to decrease the bandwidth of the adaptive-low pass filter in response to detecting a decrease in the mean breath rate. In some examples, the filter bandwidth updater module **816** may be configured to set an initial value for the bandwidth of the adaptive low-pass filter based on an average breath rate or a detected activity of a user. A mood detector module **818** may be configured to detect a stress level based on the respiratory rate. In some examples, the mood detector module **818** may be configured to send a notification in response to detecting the stress level exceeds a threshold stress level. In some examples, the mood detector module **818** may be configured to detect a mood based on the respiratory rate. For example, the mood may be angry, excited, happy, depressed, etc.

[0084] The block diagram of FIG. **8** is not intended to indicate that the computer readable media **800** is to include all of the components shown in FIG. **8**. Further, the computer readable media **800** may include any number of additional components not shown in FIG. **8**, depending on the details of the specific implementation.

EXAMPLES

[0085] Example 1 is an apparatus for detecting respiratory rates. The apparatus includes an audio receiver to receive audio including respiratory sounds. The apparatus also includes an adaptive low-pass filter to process the audio using an adaptive bandwidth based on a mean breath rate to generate an envelope. The apparatus further includes a peak detector to detect a plurality of peaks from the envelope. The apparatus also further includes a respiratory rate calculator to calculate a respiratory rate based on the detected plurality of peaks.

[0086] Example 2 includes the apparatus of example 1, including or excluding optional features. In this example, the apparatus includes a bandwidth updater to calculate the mean breath rate based on historical data and update the bandwidth based on the mean breath rate.

[0087] Example 3 includes the apparatus of any one of examples 1 to 2, including or excluding optional features. In this example, the apparatus includes a bandwidth updater to calculate a weighted mean breath rate based on historical data and update the bandwidth based on the weighted mean breath rate, wherein a weight of the weighted mean breath rate is based on a regularity of the breathing rate.

[0088] Example 4 includes the apparatus of any one of examples 1 to 3, including or excluding optional features. In this example, the apparatus includes a bandwidth updater to increase the bandwidth of the adaptive low-pass filter in response to detecting an increase in the mean breath rate.

[0089] Example 5 includes the apparatus of any one of examples 1 to 4, including or excluding optional features. In this example, the apparatus includes a bandwidth updater to decrease the bandwidth of the adaptive low-pass filter in response to detecting a decrease in the mean breath rate.

[0090] Example 6 includes the apparatus of any one of examples 1 to 5, including or excluding optional features. In this example, the apparatus includes an audio preprocessor to reduce a DC offset of the audio to generate preprocessed audio, the preprocessed audio to be processed to generate the envelope.

[0091] Example 7 includes the apparatus of any one of examples 1 to 6, including or excluding optional features. In this example, the apparatus includes an audio preprocessor to take an absolute value of the audio to generate a preprocessed audio, the adaptive low-pass filter to process the preprocessed audio to generate the envelope.

[0092] Example 8 includes the apparatus of any one of examples 1 to 7, including or excluding optional features. In this example, the peak detector is to detect peaks using one or more adaptive thresholds based on peak amplitude and distance between peaks.

[0093] Example 9 includes the apparatus of any one of examples 1 to 8, including or excluding optional features. In this example, the mean breath rate includes a weighted mean breath rate.

[0094] Example 10 includes the apparatus of any one of examples 1 to 9, including or excluding optional features. In this example, an initial bandwidth used by the adaptive low-pass filter is estimated based on a detected activity of a user.

[0095] Example 11 is a method for detecting respiratory rates. The method includes receiving, via a processor, audio including respiratory sounds. The method also includes processing, via the processor, the audio using an adaptive low-pass filter with and adaptive bandwidth based on a mean breath rate to generate an envelope. The method also further includes detecting, via the processor, a plurality of peaks from the envelope. The method also includes calculating, via the processor, a respiratory rate based on the detected plurality of peaks.

[0096] Example 12 includes the method of example 11, including or excluding optional features. In this example, the method includes modifying, via the processor, the bandwidth of the adaptive-low pass filter based on an updated mean breath rate.

[0097] Example 13 includes the method of any one of examples 11 to 12, including or excluding optional features. In this example, the method includes increasing the bandwidth of the adaptive-low pass filter in response to detecting an increase in an updated mean breath rate or decreasing the bandwidth of the adaptive-low pass filter in response to detecting a decrease in an updated mean breath rate.

[0098] Example 14 includes the method of any one of examples 11 to 13, including or excluding optional features. In this example, detecting the peaks includes detecting that one or more adaptive thresholds based on peak amplitude and distance between peaks are exceeded.

[0099] Example 15 includes the method of any one of examples 11 to 14, including or excluding optional features. In this example, calculating the respiratory rate includes detecting a breath based on a number of detected peaks.

[0100] Example 16 includes the method of any one of examples 11 to 15, including or excluding optional features. In this example, the method includes preprocessing, via the processor, the audio to reduce a DC offset of the audio.

[0101] Example 17 includes the method of any one of examples 11 to 16, including or excluding optional features. In this example, the method includes preprocessing, via the processor, the audio by taking an absolute value of the audio to generate a preprocessed audio.

[0102] Example 18 includes the method of any one of examples 11 to 17, including or excluding optional features. In this example, the method includes setting an initial value for the bandwidth of the adaptive low-pass filter based on an average breath rate or a detected activity of a user.

[0103] Example 19 includes the method of any one of examples 11 to 18, including or excluding optional features. In this example, the method includes detecting a stress level based on the respiratory rate and sending a notification in response to detecting the stress level exceeds a threshold stress level.

[0104] Example 20 includes the method of any one of examples 11 to 19, including or excluding optional features. In this example, the method includes detecting a mood of a user based on the respiratory rate.

[0105] Example 21 is at least one computer readable medium for detecting respiratory rates having instructions stored therein that direct the processor to receive audio including respiratory sounds. The computer-readable medium also includes instructions that direct the processor to process the audio using an adaptive low-pass filter with an adaptive bandwidth based on a mean breath rate to generate an envelope. The computer-readable medium further includes instructions that direct the processor to detect a plurality of peaks from the envelope. The computer-readable medium also further includes instructions that direct the processor to calculate a respiratory rate based on the detected plurality of peaks.

[0106] Example 22 includes the computer-readable medium of example 21, including or excluding optional features. In this example, the computer-readable medium includes instructions to modify the bandwidth of the adaptive-low pass filter based on an updated mean breath rate.

[0107] Example 23 includes the computer-readable medium of any one of examples 21 to 22, including or excluding optional features. In this example, the computer-readable medium includes instructions to increase the bandwidth of the adaptive-low pass filter in response to detecting an increase in the detected breath rate or decrease the bandwidth of the adaptive-low pass filter in response to detecting a decrease in the detected breath rate.

[0108] Example 24 includes the computer-readable medium of any one of examples 21 to 23, including or excluding optional features. In this example, the computer-readable medium includes instructions to detect a peak in response to detecting that one or more adaptive thresholds based on peak amplitude and distance between peaks are exceeded in the audio.

[0109] Example 25 includes the computer-readable medium of any one of examples 21 to 24, including or excluding optional features. In this example, the computer-readable medium includes instructions to detect a breath based on a number of detected peaks.

[0110] Example 26 includes the computer-readable medium of any one of examples 21 to 25, including or excluding optional features. In this example, the computer-readable medium includes instructions to preprocess the audio to reduce a DC offset of the audio.

[0111] Example 27 includes the computer-readable medium of any one of examples 21 to 26, including or excluding optional features. In this example, the computer-readable medium includes instructions to preprocess the audio by taking an absolute value of the audio to generate a preprocessed audio.

[0112] Example 28 includes the computer-readable medium of any one of examples 21 to 27, including or excluding optional features. In this example, the computer-readable medium includes instructions to set an initial value for the bandwidth of the adaptive low-pass filter based on an average breath rate or a detected activity of a user.

[0113] Example 29 includes the computer-readable medium of any one of examples 21 to 28, including or excluding optional features. In this example, the computer-readable medium includes instructions to detect a stress level based on the respiratory rate and send a notification in response to detecting the stress level exceeds a threshold stress level.

[0114] Example 30 includes the computer-readable medium of any one of examples 21 to 29, including or excluding optional features. In this example, the computer-readable medium includes instructions to detect a mood of a user based on the respiratory rate.

[0115] Example 31 is a system for detecting respiratory rates. The system includes audio receiver to receive audio including respiratory sounds. The system also includes an adaptive low-pass filter to process the audio using an adaptive bandwidth based on a mean breath rate to generate an envelope. The system further includes a peak detector to detect a plurality of peaks from the envelope. The system also further includes a respiratory rate calculator to calculate a respiratory rate based on the detected plurality of peaks.

[0116] Example 32 includes the system of example 31, including or excluding optional features. In this example, the system includes a bandwidth updater to calculate the mean breath rate based on historical data and update the bandwidth based on the mean breath rate.

[0117] Example 33 includes the system of any one of examples 31 to 32, including or excluding optional features. In this example, the system includes a bandwidth updater to calculate a weighted mean breath rate based on historical data and update the bandwidth based on the weighted mean breath rate, wherein a weight of the weighted mean breath rate is based on a regularity of the breathing rate.

[0118] Example 34 includes the system of any one of examples 31 to 33, including or excluding optional features. In this example, the system includes a bandwidth updater to increase the bandwidth of the adaptive low-pass filter in response to detecting an increase in the mean breath rate.

[0119] Example 35 includes the system of any one of examples 31 to 34, including or excluding optional features. In this example, the system includes a bandwidth updater to decrease the bandwidth of the adaptive low-pass filter in response to detecting a decrease in the mean breath rate.

[0120] Example 36 includes the system of any one of examples 31 to 35, including or excluding optional features. In this example, the system includes an audio preprocessor to reduce a DC offset of the audio to generate preprocessed audio, the preprocessed audio to be processed to generate the envelope.

[0121] Example 37 includes the system of any one of examples 31 to 36, including or excluding optional features. In this example, the system includes an audio preprocessor to take an absolute value of the audio to generate a preprocessed audio, the adaptive low-pass filter to process the preprocessed audio to generate the envelope.

[0122] Example 38 includes the system of any one of examples 31 to 37, including or excluding optional features. In this example, the peak detector is to detect peaks using one or more adaptive thresholds based on peak amplitude and distance between peaks.

[0123] Example 39 includes the system of any one of examples 31 to 38, including or excluding optional features. In this example, the mean breath rate includes a weighted mean breath rate.

[0124] Example 40 includes the system of any one of examples 31 to 39, including or excluding optional features. In this example, an initial bandwidth used by the adaptive low-pass filter is estimated based on a detected activity of a user.

[0125] Example 41 is a system for detecting respiratory rates. The system includes means for receiving audio including respiratory sounds. The system also includes means for processing the audio using an adaptive bandwidth based on a mean breath rate to generate an envelope. The system further includes means for detecting a plurality of peaks from the envelope. The system also further includes means for calculating a respiratory rate based on the detected plurality of peaks.

[0126] Example 42 includes the system of example 41, including or excluding optional features. In this example, the system includes means for calculating the mean breath rate based on historical data and update the bandwidth based on the mean breath rate.

[0127] Example 43 includes the system of any one of examples 41 to 42, including or excluding optional features. In this example, the system includes means for calculating a weighted mean breath rate based on historical data and updating the bandwidth based on the weighted mean breath rate, wherein a weight of the weighted mean breath rate is based on a regularity of the breathing rate.

[0128] Example 44 includes the system of any one of examples 41 to 43, including or excluding optional features. In this example, the system includes means for increasing the bandwidth of the means for detecting the plurality of peaks in response to detecting an increase in the mean breath rate.

[0129] Example 45 includes the system of any one of examples 41 to 44, including or excluding optional features. In this example, the system includes means for decreasing the bandwidth of the means for detecting the plurality of peaks in response to detecting a decrease in the mean breath rate.

[0130] Example 46 includes the system of any one of examples 41 to 45, including or excluding optional features. In this example, the system includes means for reducing a DC offset of the audio to generate preprocessed audio, the preprocessed audio to be processed to generate the envelope.

[0131] Example 47 includes the system of any one of examples 41 to 46, including or excluding optional features. In this example, the system includes means for taking an absolute value of the audio to generate a preprocessed audio, the means for detecting the plurality of peaks to process the preprocessed audio to generate the envelope.

[0132] Example 48 includes the system of any one of examples 41 to 47, including or excluding optional features. In this example, the means for detecting a plurality of peaks is to detect peaks using one or more adaptive thresholds based on peak amplitude and distance between peaks.

[0133] Example 49 includes the system of any one of examples 41 to 48, including or excluding optional features. In this example, the mean breath rate includes a weighted mean breath rate.

[0134] Example 50 includes the system of any one of examples 41 to 49, including or excluding optional features. In this example, an initial bandwidth used by the means for detecting the plurality of peaks is estimated based on a detected activity of a user.

[0135] Not all components, features, structures, characteristics, etc. described and illustrated herein need be included in a particular aspect or aspects. If the specification states a component, feature, structure, or characteristic "may", "might", "can" or "could" be included, for example, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the element. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

[0136] It is to be noted that, although some aspects have been described in reference to particular implementations, other implementations are possible according to some aspects. Additionally, the arrangement and/or order of circuit elements or other features illustrated in the drawings and/or described herein need not be arranged in the particular way illustrated and described. Many other arrangements are possible according to some aspects.

[0137] In each system shown in a figure, the elements in some cases may each have a same reference number or a different reference number to suggest that the elements represented could be different and/or similar. However, an element may be flexible enough to have different implementations and work with some or all of the systems shown or described herein. The various elements shown in the figures may be the same or different. Which one is referred to as a first element and which is called a second element is arbitrary.

[0138] It is to be understood that specifics in the aforementioned examples may be used anywhere in one or more aspects. For instance, all optional features of the computing device described above may also be implemented with respect to either of the methods or the computer-readable medium described herein. Furthermore, although flow diagrams and/or state diagrams may have been used herein to describe aspects, the techniques are not limited to those diagrams or to corresponding descriptions herein. For example, flow need not move through each illustrated box or state or in exactly the same order as illustrated and described herein.

[0139] The present techniques are not restricted to the particular details listed herein. Indeed, those skilled in the art having the benefit of this disclosure will appreciate that many other variations from the foregoing description and drawings may be made within the scope of the present techniques. Accordingly, it is the following claims including any amendments thereto that define the scope of the present techniques.

What is claimed is:

1. An apparatus for detecting respiratory rates, comprising:
- an audio receiver to receive audio comprising respiratory sounds;
- an adaptive low-pass filter to process the audio using an adaptive bandwidth based on a mean breath rate to generate an envelope;
- a peak detector to detect a plurality of peaks from the envelope; and
- a respiratory rate calculator to calculate a respiratory rate based on the detected plurality of peaks.

2. The apparatus of claim **1**, comprising a bandwidth updater to calculate the mean breath rate based on historical data and update the bandwidth based on the mean breath rate.

3. The apparatus of claim **1**, comprising a bandwidth updater to calculate a weighted mean breath rate based on historical data and update the bandwidth based on the weighted mean breath rate, wherein a weight of the weighted mean breath rate is based on a regularity of the breathing rate.

4. The apparatus of claim **1**, comprising a bandwidth updater to increase the bandwidth of the adaptive low-pass filter in response to detecting an increase in the mean breath rate.

5. The apparatus of claim **1**, comprising a bandwidth updater to decrease the bandwidth of the adaptive low-pass filter in response to detecting a decrease in the mean breath rate.

6. The apparatus of claim **1**, comprising an audio preprocessor to reduce a DC offset of the audio to generate preprocessed audio, the preprocessed audio to be processed to generate the envelope.

7. The apparatus of claim **1**, comprising an audio preprocessor to take an absolute value of the audio to generate a preprocessed audio, the adaptive low-pass filter to process the preprocessed audio to generate the envelope.

8. The apparatus of claim **1**, wherein the peak detector is to detect peaks using one or more adaptive thresholds based on peak amplitude and distance between peaks.

9. The apparatus of claim **1**, wherein the mean breath rate comprises a weighted mean breath rate.

10. The apparatus of claim **1**, wherein an initial bandwidth used by the adaptive low-pass filter is estimated based on a detected activity of a user.

11. A method for detecting respiratory rates, comprising:
- receiving, via a processor, audio comprising respiratory sounds;
- processing, via the processor, the audio using an adaptive low-pass filter with and adaptive bandwidth based on a mean breath rate to generate an envelope;
- detecting, via the processor, a plurality of peaks from the envelope; and
- calculating, via the processor, a respiratory rate based on the detected plurality of peaks.

12. The method of claim **11**, comprising modifying, via the processor, the bandwidth of the adaptive-low pass filter based on an updated mean breath rate.

13. The method of claim **12**, comprising increasing the bandwidth of the adaptive-low pass filter in response to detecting an increase in the updated mean breath rate or decreasing the bandwidth of the adaptive-low pass filter in response to detecting a decrease in the updated mean breath rate.

14. The method of claim **11**, wherein detecting the peaks comprises detecting that one or more adaptive thresholds based on peak amplitude and distance between peaks are exceeded.

15. The method of claim **11**, wherein calculating the respiratory rate comprises detecting a breath based on a number of detected peaks.

16. The method of claim **11**, comprising preprocessing, via the processor, the audio to reduce a DC offset of the audio.

17. The method of claim **11**, comprising preprocessing, via the processor, the audio by taking an absolute value of the audio to generate a preprocessed audio.

18. The method of claim **11**, comprising setting an initial value for the bandwidth of the adaptive low-pass filter based on an average breath rate or a detected activity of a user.

19. The method of claim **11**, comprising detecting a stress level based on the respiratory rate and sending a notification in response to detecting the stress level exceeds a threshold stress level.

20. The method of claim **11**, comprising detecting a mood of a user based on the respiratory rate.

21. At least one computer readable medium for detecting respiratory rates having instructions stored therein that, in response to being executed on a computing device, cause the computing device to:
- receive audio comprising respiratory sounds;
- process the audio using a low-pass filter with an adaptive bandwidth based on a mean breath rate to generate an envelope;
- detect a plurality of peaks from the envelope; and
- calculate a respiratory rate based on the detected plurality of peaks.

22. The at least one computer readable medium of claim **21**, comprising instructions to modify the bandwidth of the adaptive-low pass filter based on an updated mean breath rate.

23. The at least one computer readable medium of claim **22**, comprising instructions to increase the bandwidth of the adaptive-low pass filter in response to detecting an increase in the updated mean breath rate or decrease the bandwidth of the adaptive-low pass filter in response to detecting a decrease in the updated mean breath rate.

24. The at least one computer readable medium of claim **23**, comprising instructions to detect a peak in response to detecting that one or more adaptive thresholds based on peak amplitude and distance between peaks are exceeded in the audio.

25. The at least one computer readable medium of claim **24**, comprising instructions to detect a breath based on a number of detected peaks.

* * * * *

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专利名称(译)	使用自适应低通滤波器检测音频中的呼吸率		
公开(公告)号	[US20190021633A1](US20190021633A1)	公开(公告)日	2019-01-24
申请号	US15/819220	申请日	2017-11-21
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发明人	WANG, LING CENGIJA, KAROLINA ROSEN, MICHAEL R. ANWAR, NAGHMA NGUYEN, THAO-VY		
IPC分类号	A61B5/08 A61B5/00		
CPC分类号	A61B5/0816 A61B5/725 A61B5/0871 A61B5/7242		
外部链接	Espacenet USPTO		

摘要(译)

用于检测呼吸率的示例装置包括用于接收包括呼吸声音的音频的音频接收器。该装置还包括自适应低通滤波器，用于基于平均呼吸速率使用自适应带宽处理音频以生成包络。该装置还包括峰值检测器，用于检测来自包络的多个峰值。该装置包括呼吸率计算器，用于基于检测到的多个峰值计算呼吸率。