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(54) **PHYSIOLOGICAL ACOUSTIC MONITORING SYSTEM**

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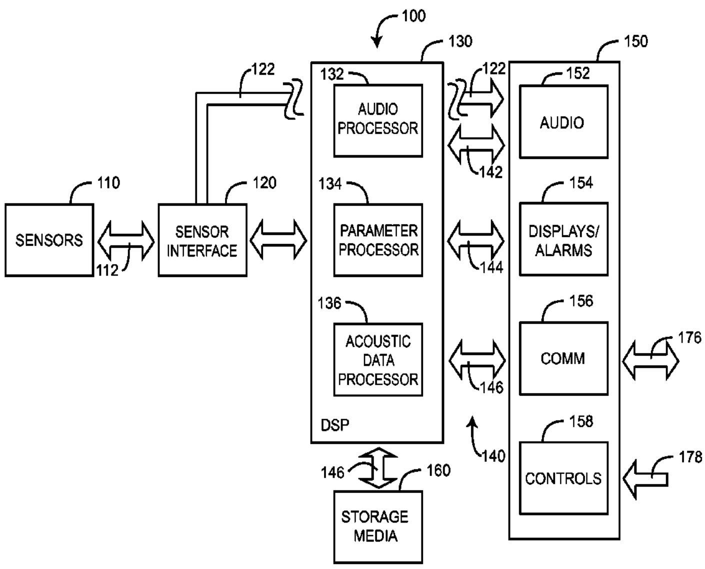
(57) **ABSTRACT**

A physiological acoustic monitoring system receives physiological data from an acoustic sensor, down-samples the data to generate raw audio of breathing sounds and compresses the raw audio. The acoustic monitoring system has an acoustic sensor signal responsive to tracheal sounds in a person. An A/D converter is responsive to the sensor signal so as to generate breathing sound data. A decimation filter and mixer down-samples the breathing sound data to raw audio data. A coder/compressor generates compressed audio data from the raw audio data. A decoder/decompressor decodes and decompresses the compressed audio data into decompressed audio data. The decompressed audio data is utilized to generate respiration-related parameters in real-time. The compressed audio data is stored and retrieved so as to generate respiration-related parameters in non-real-time. The real-time and non-real-time parameters are compared to verify matching results across multiple monitors.

20 Claims, 11 Drawing Sheets



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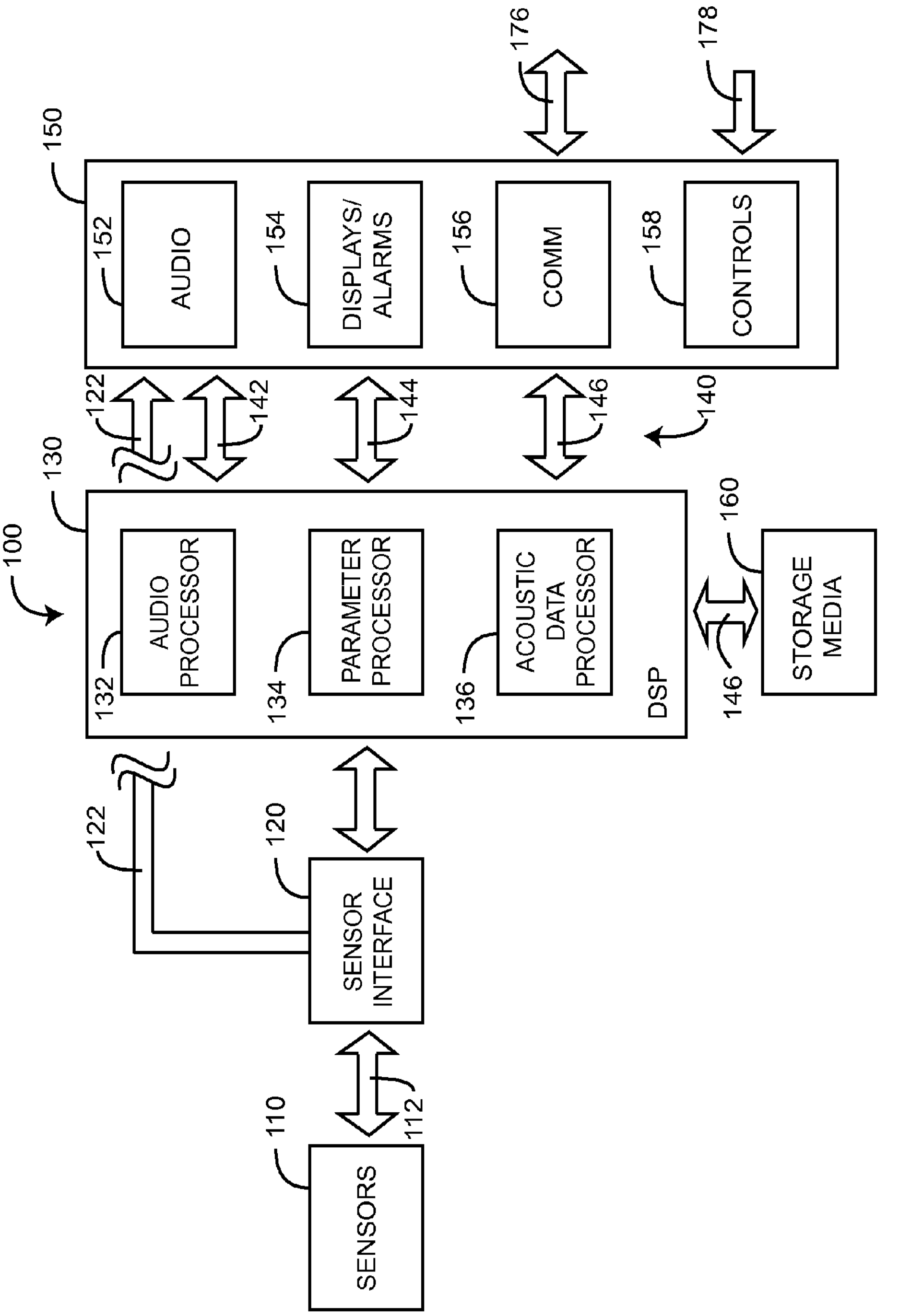


100
SENSORS
110
112
SENSOR INTERFACE
120
122
AUDIO PROCESSOR
132
PARAMETER PROCESSOR
134
ACOUSTIC DATA PROCESSOR
136
DSP
130
STORAGE MEDIA
160
146
122
142
144
146
140
AUDIO
152
DISPLAYS/ ALARMS
154
COMM
156
CONTROLS
158
150
176
178

FIG. 1

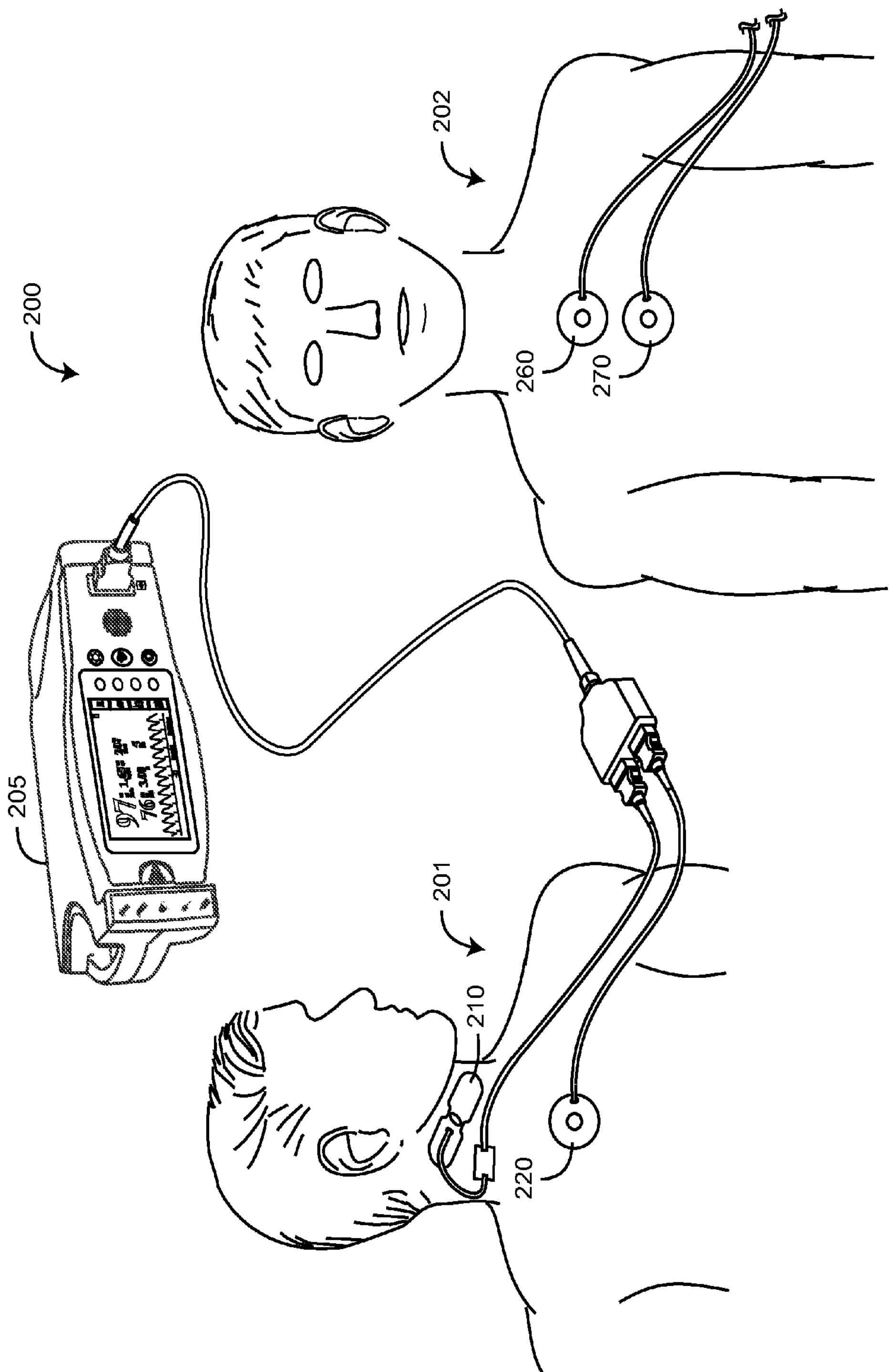


FIG. 2A

FIG. 2B

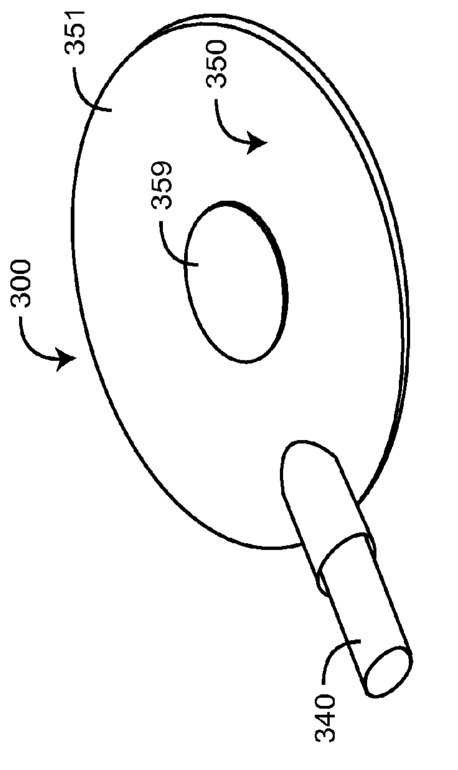


FIG. 3A

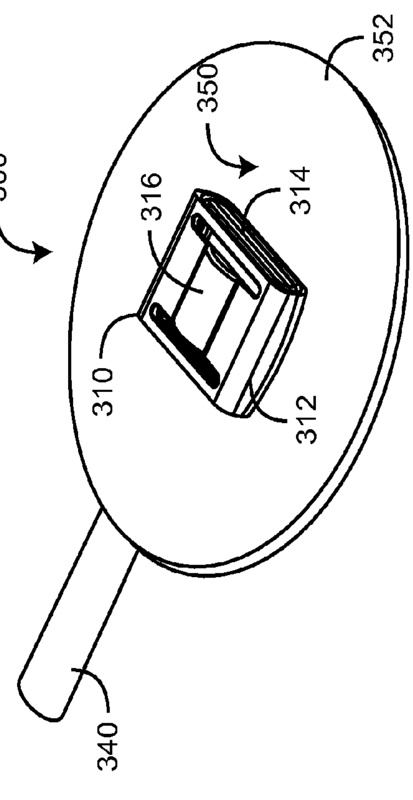
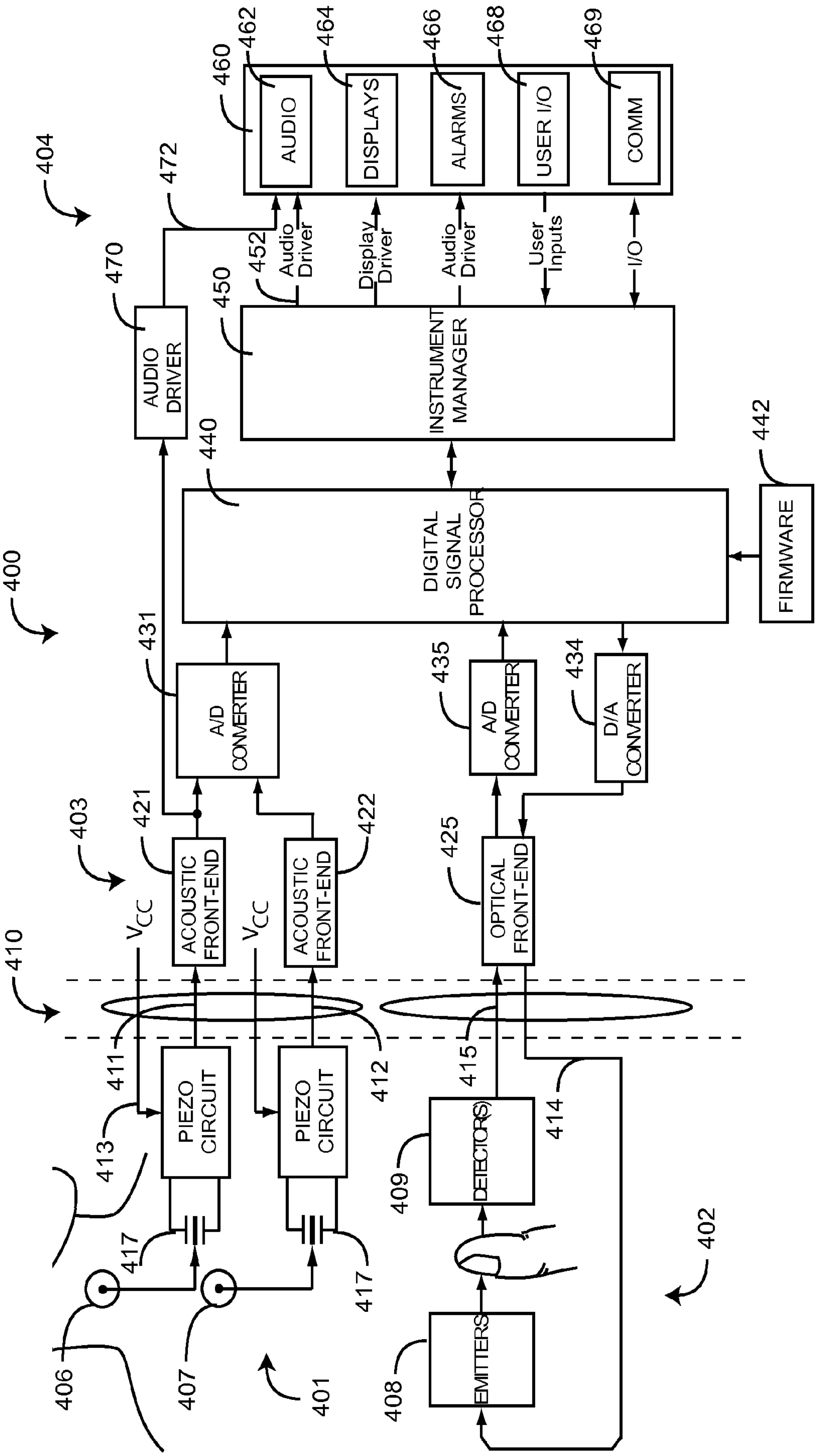


FIG. 3B



AUDIO
DISPLAYS
ALARMS
USER I/O
COMM
Audio Driver
Display Driver
Audio Driver
User Inputs
I/O
AUDIO DRIVER
INSTRUMENT MANAGER
DIGITAL SIGNAL PROCESSOR
FIRMWARE
A/D CONVERTER
A/D CONVERTER
D/A CONVERTER
ACOUSTIC FRONT-END
ACOUSTIC FRONT-END
OPTICAL FRONT-END
V_{CC}
V_{CC}
PIEZO CIRCUIT
PIEZO CIRCUIT
DETECTOR(S)
EMITTERS
400
401
402
403
404
406
407
408
409
410
411
412
413
414
415
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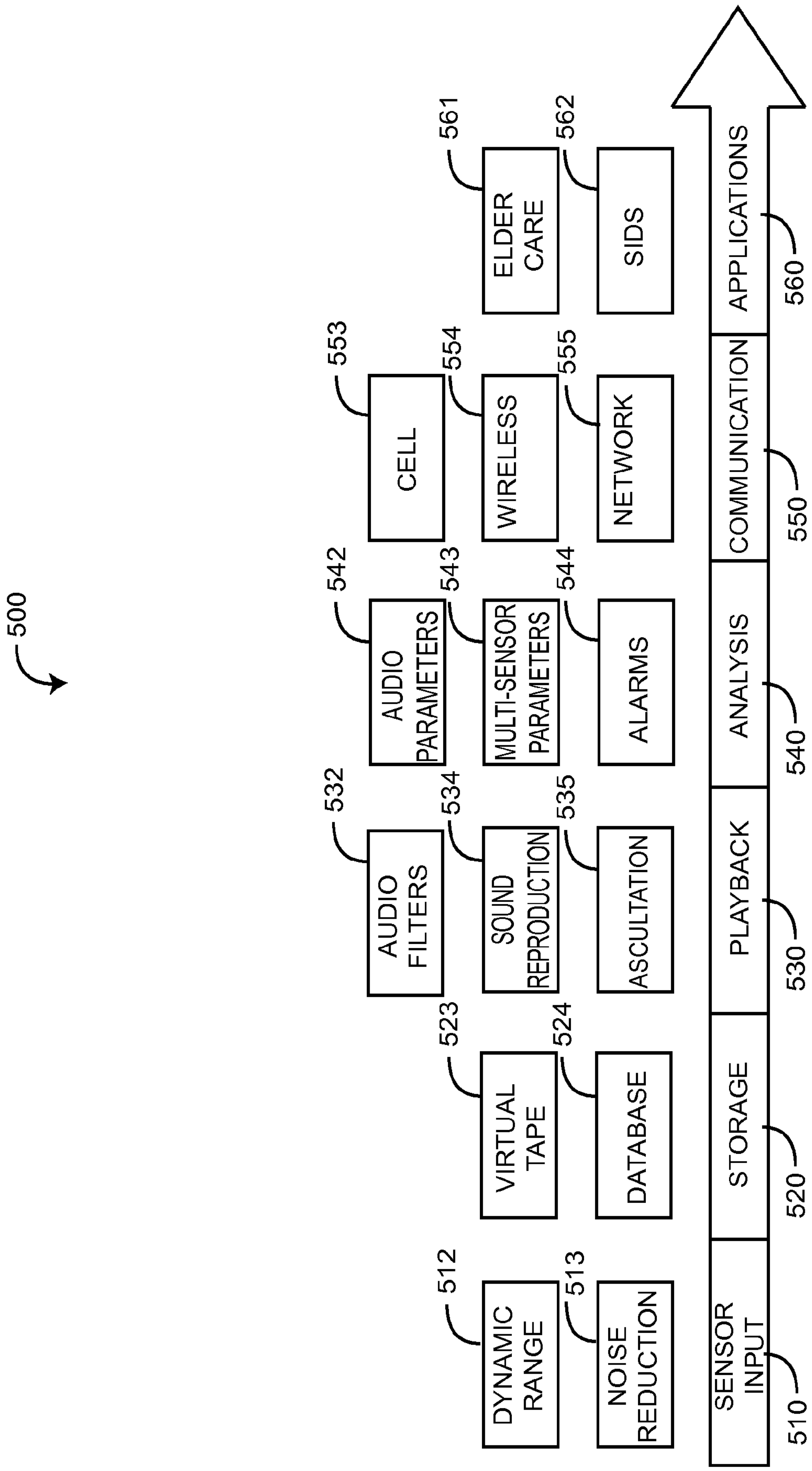
470
472

FIG. 4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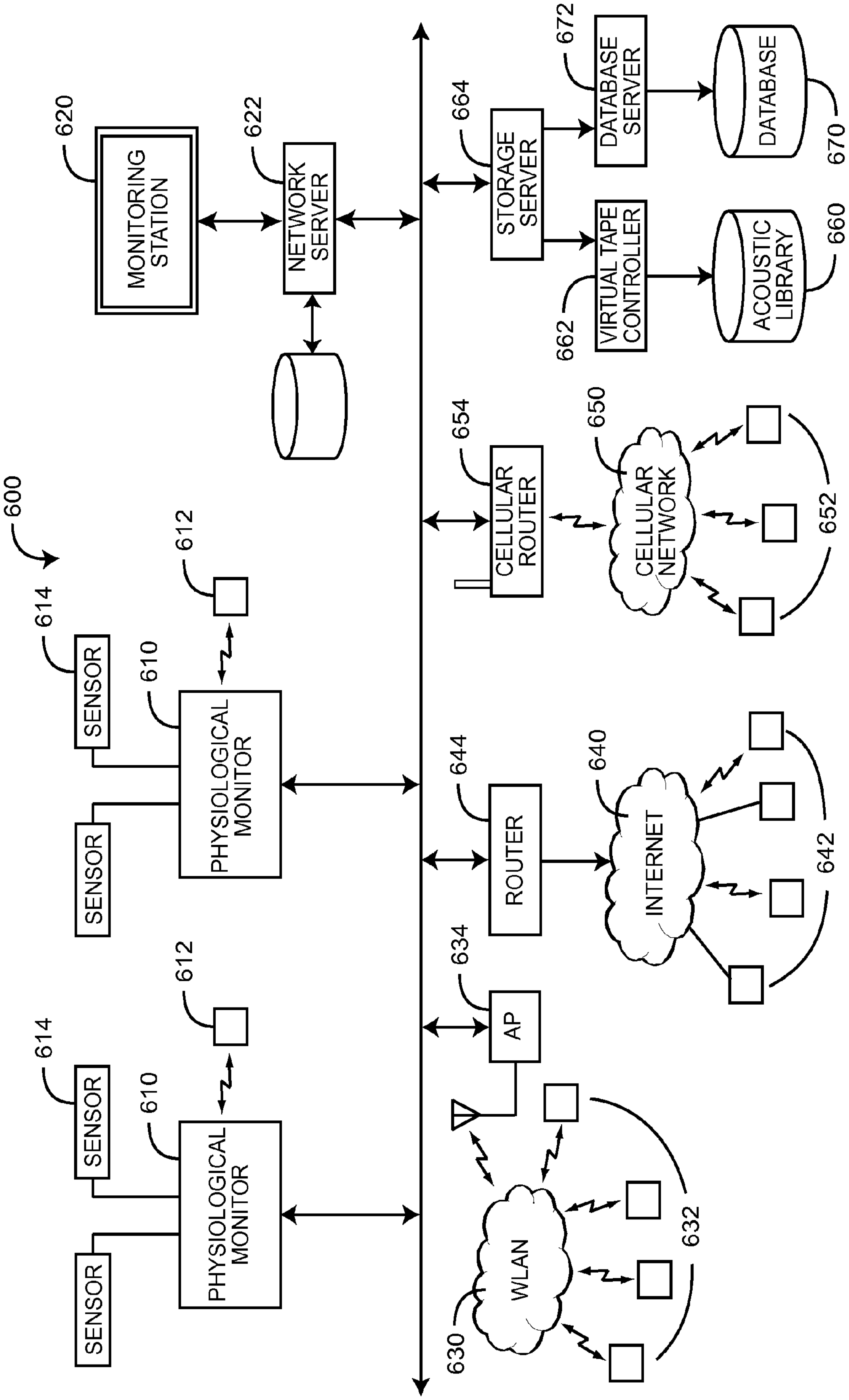
SENSOR INPUT
510
STORAGE
520
PLAYBACK
530
ANALYSIS
540
COMMUNICATION
550
APPLICATIONS
560
DYNAMIC RANGE
512
NOISE REDUCTION
513
VIRTUAL TAPE
523
DATABASE
524
AUDIO FILTERS
532
SOUND REPRODUCTION
534
ASCULTATION
535
AUDIO PARAMETERS
542
MULTI-SENSOR PARAMETERS
543
ALARMS
544
CELL
553
WIRELESS
554
NETWORK
555
ELDER CARE
561
SIDS
562

FIG. 5



600
PHYSIOLOGICAL MONITOR
610
SENSOR
614
SENSOR
612
PHYSIOLOGICAL MONITOR
610
SENSOR
614
SENSOR
612
MONITORING STATION
620
NETWORK SERVER
622
AP
634
WLAN
630
632
ROUTER
644
INTERNET
640
642
CELLULAR ROUTER
654
CELLULAR NETWORK
650
652
STORAGE SERVER
664
VIRTUAL TAPE CONTROLLER
662
DATABASE SERVER
672
ACOUSTIC LIBRARY
660
DATABASE
670

FIG. 6

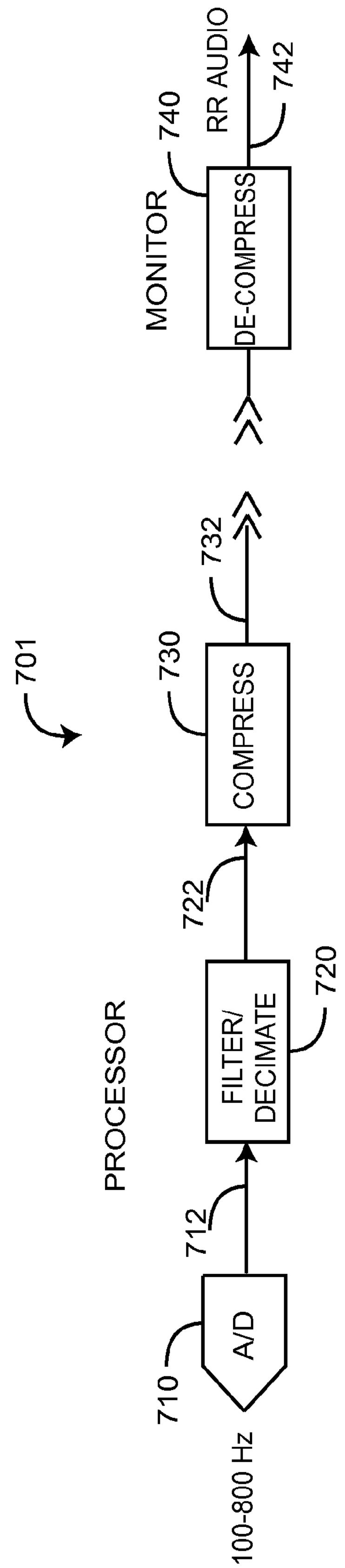

701
PROCESSOR
MONITOR
100-800 Hz
710
A/D
712
720
FILTER/ DECIMATE
722
730
COMPRESS
732
740
DE-COMPRESS
742
RR AUDIO

FIG. 7A

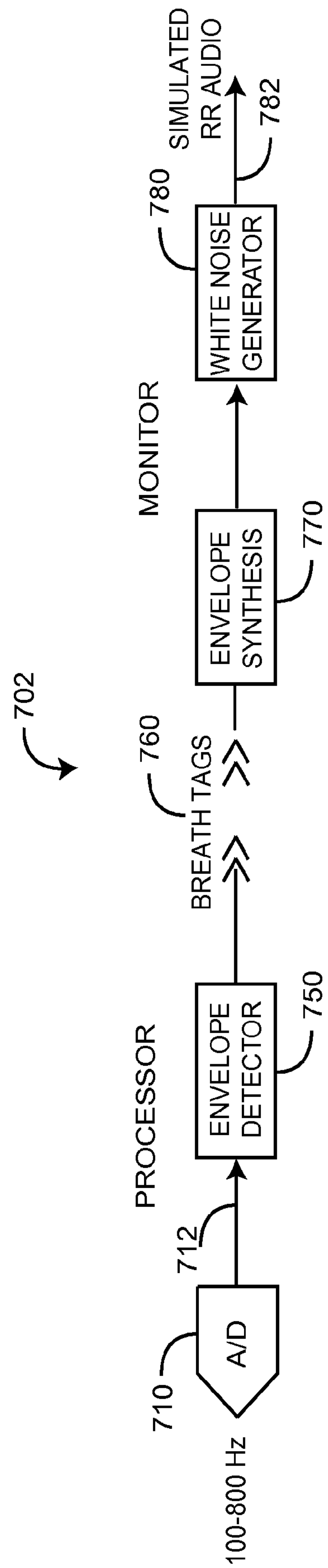

702
PROCESSOR
MONITOR
100-800 Hz
710
A/D
712
750
ENVELOPE DETECTOR
760
BREATH TAGS
770
ENVELOPE SYNTHESIS
780
WHITE NOISE GENERATOR
782
SIMULATED RR AUDIO

FIG. 7B

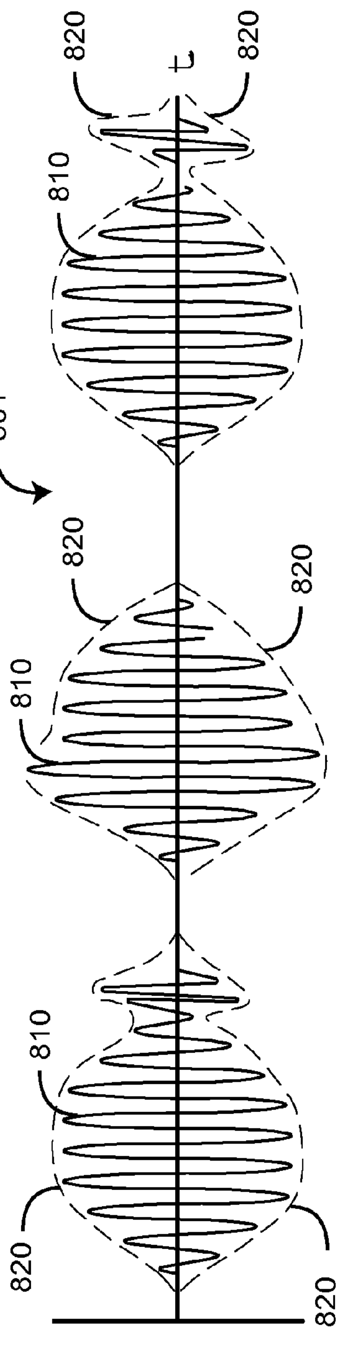


FIG. 8A

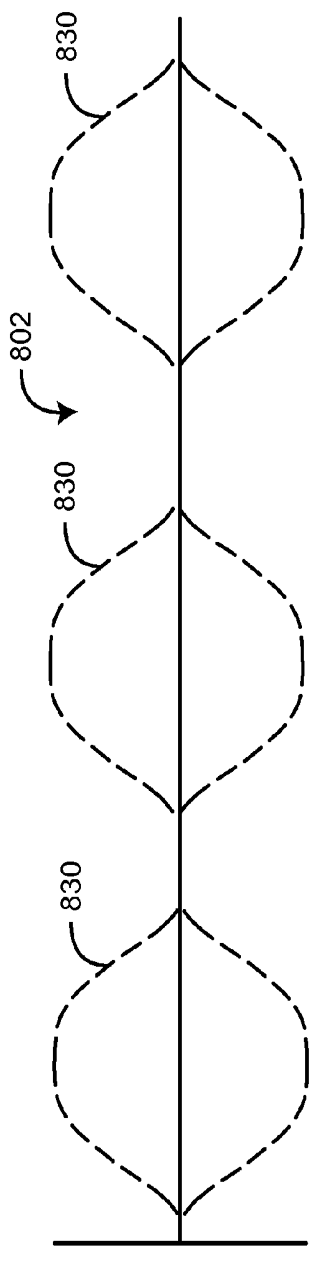


FIG. 8B

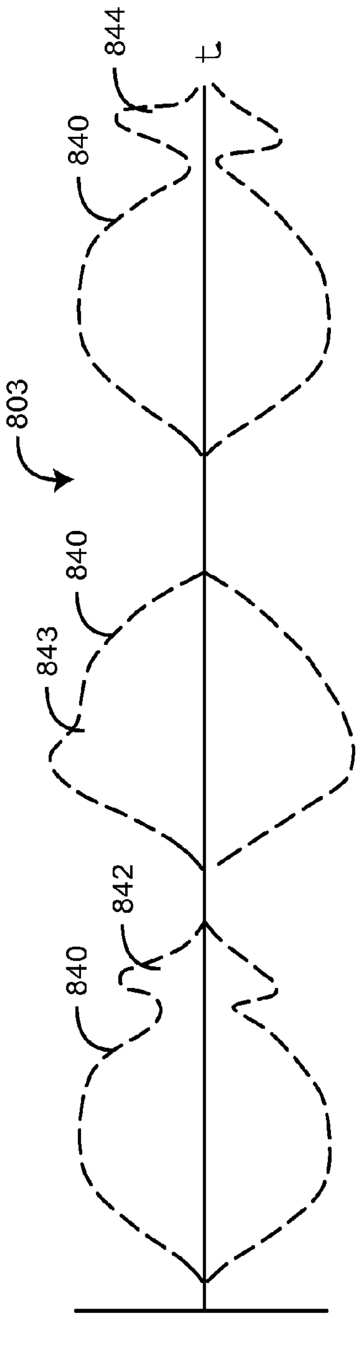


FIG. 8C

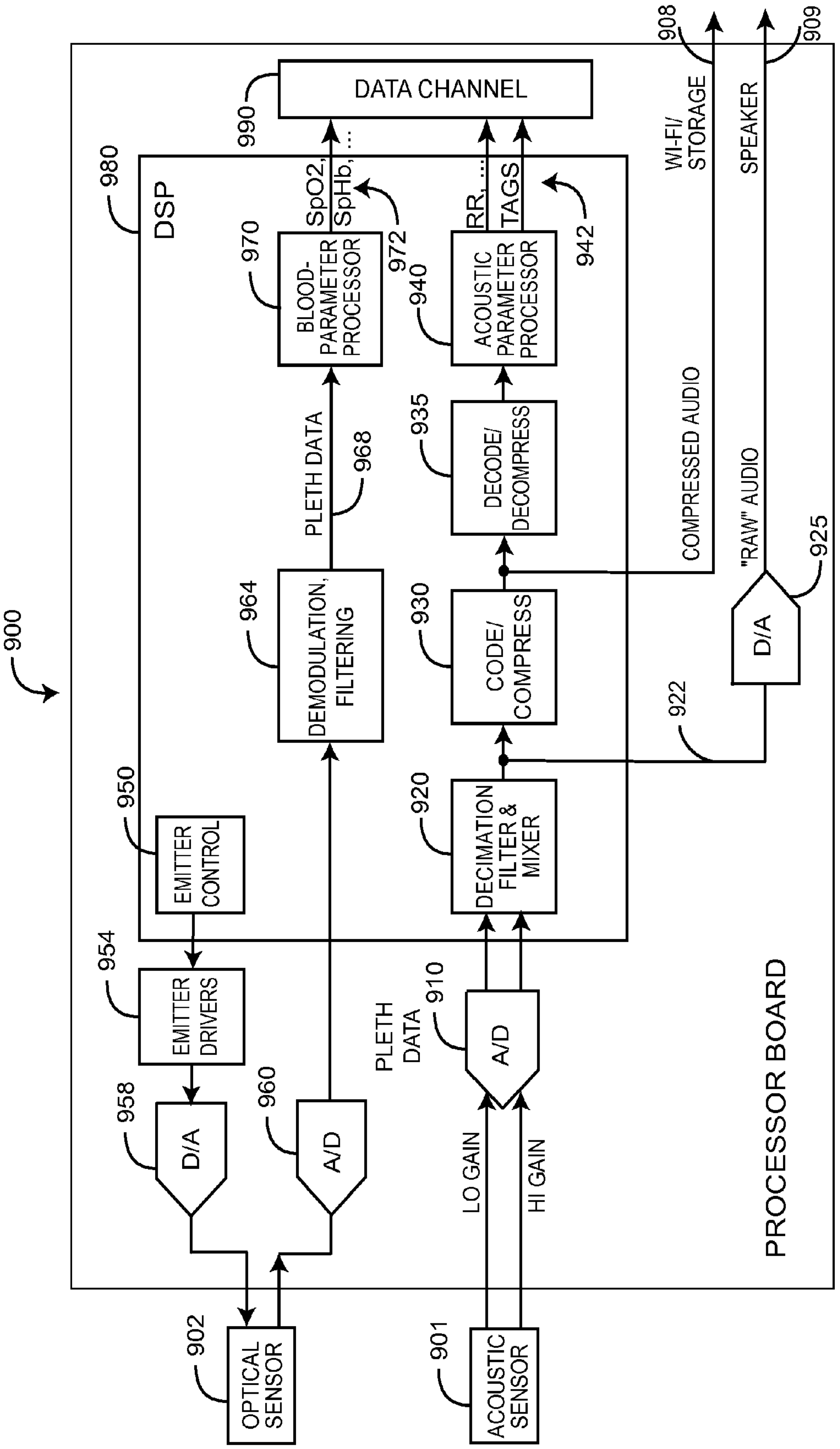

900
PROCESSOR BOARD
980
DSP
990
DATA CHANNEL
908
WI-FI/
STORAGE
909
SPEAKER
970
BLOOD-
PARAMETER
PROCESSOR
SpO2,
SpHb, ...
972
940
ACOUSTIC
PARAMETER
PROCESSOR
RR, ...
TAGS
942
964
DEMODULATION,
FILTERING
PLETH DATA
968
935
DECODE/
DECOMPRESS
COMPRESSED AUDIO
930
CODE/
COMPRESS
"RAW" AUDIO
925
D/A
922
950
EMITTER
CONTROL
920
DECIMATION
FILTER &
MIXER
954
EMITTER
DRIVERS
910
PLETH
DATA
A/D
958
D/A
960
A/D
LO GAIN
HI GAIN
902
OPTICAL
SENSOR
901
ACOUSTIC
SENSOR

FIG. 9

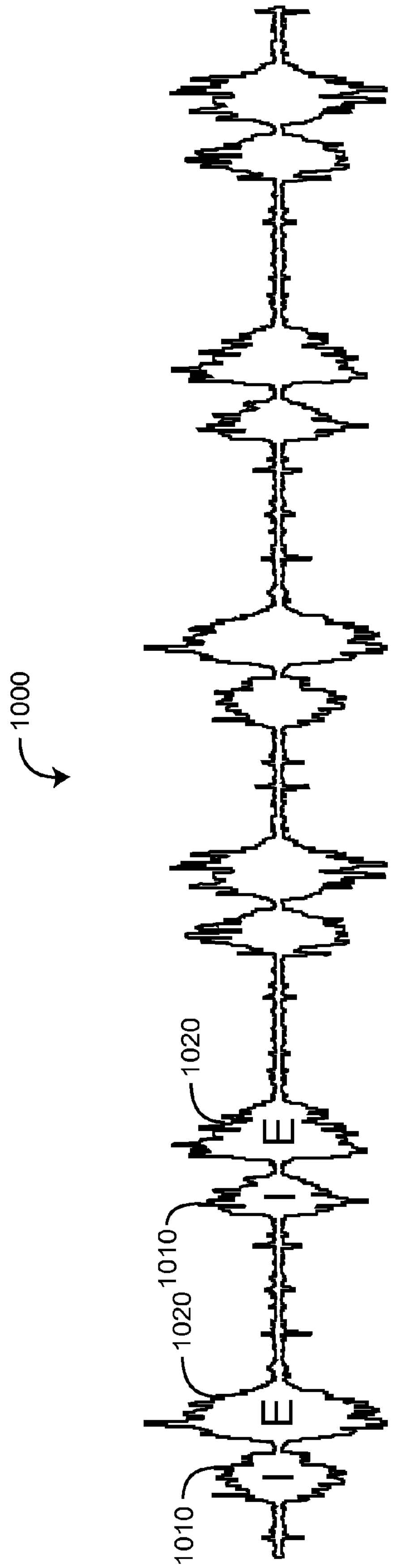


FIG. 10A

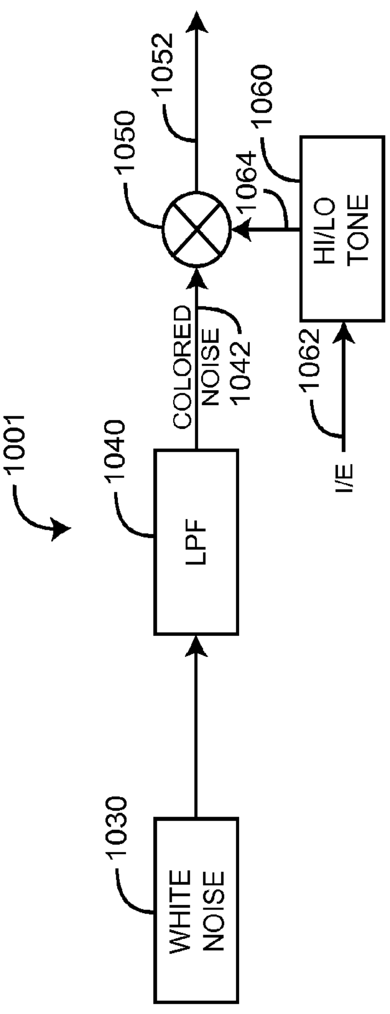
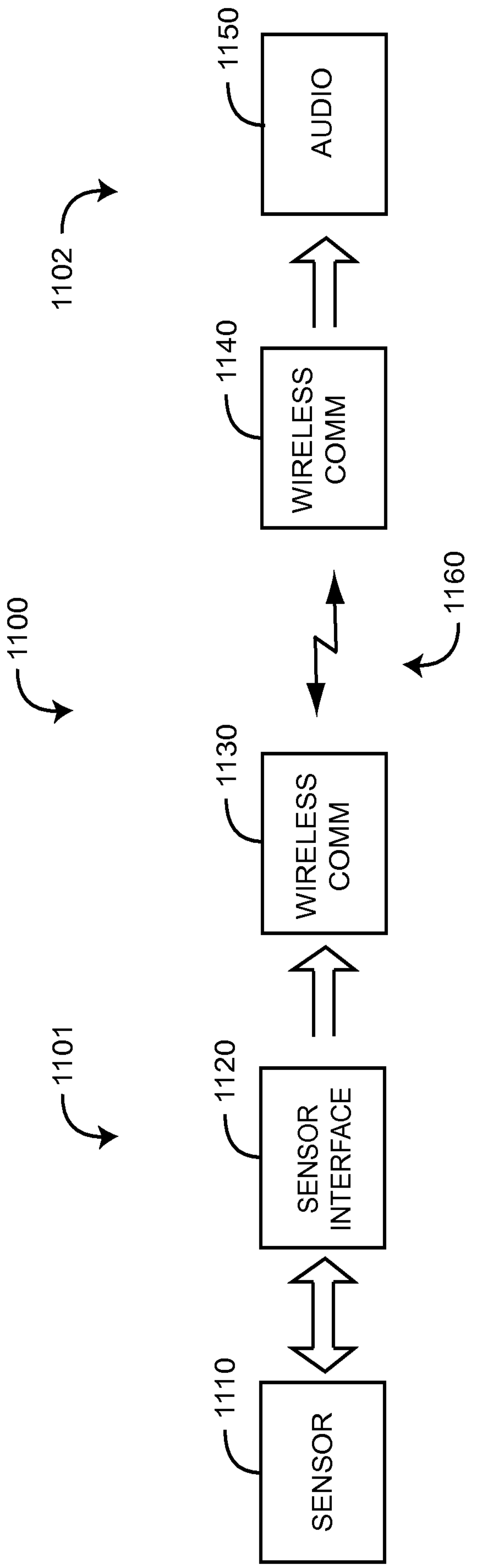


FIG. 10B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1101
1102
1110
SENSOR
1120
SENSOR INTERFACE
1130
WIRELESS COMM
1160
1140
WIRELESS COMM
1150
AUDIO

FIG. 11

PHYSIOLOGICAL ACOUSTIC MONITORING SYSTEM

This application claims the benefit of priority under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 61/547,007, titled Physiological Acoustic Monitoring System, filed Oct. 13, 2011 and is a continuation-in-part of U.S. patent application Ser. No. 12/905,036 titled Physiological Acoustic Monitoring System, which claims the benefit of priority under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 61/252,099, filed Oct. 15, 2009, and U.S. Provisional Patent Application No. 61/391,098, filed Oct. 8, 2010, the disclosures of which are hereby incorporated in their entirety by reference herein. Additionally, this application relates to the following U.S. patent applications, the disclosures of which are incorporated in their entirety by reference herein:

App. No.	Filing Date	Title
60/893,853	Mar. 8, 2007	MULTI-PARAMETER PHYSIOLOGICAL MONITOR
60/893,850	Mar. 8, 2007	BACKWARD COMPATIBLE PHYSIOLOGICAL SENSOR WITH INFORMATION ELEMENT
60/893,858	Mar. 8, 2007	MULTI-PARAMETER SENSOR FOR PHYSIOLOGICAL MONITORING
60/893,856	Mar. 8, 2007	PHYSIOLOGICAL MONITOR WITH FAST GAIN ADJUST DATA ACQUISITION
12/044,883	Mar. 8, 2008	SYSTEMS AND METHODS FOR DETERMINING A PHYSIOLOGICAL CONDITION USING AN ACOUSTIC MONITOR
61/252,083	Oct. 15, 2009	DISPLAYING PHYSIOLOGICAL INFORMATION
12/904,823	Oct. 14, 2010	BIDIRECTIONAL PHYSIOLOGICAL INFORMATION DISPLAY
61/141,584	Dec. 30, 2008	ACOUSTIC SENSOR ASSEMBLY
61/252,076	Oct. 15, 2009	ACOUSTIC SENSOR ASSEMBLY
12/643,939	Dec. 21, 2009	ACOUSTIC SENSOR ASSEMBLY
61/313,645	Mar. 12, 2010	ACOUSTIC RESPIRATORY MONITORING SENSOR HAVING MULTIPLE SENSING ELEMENTS
12/904,890	Oct. 14, 2010	ACOUSTIC RESPIRATORY MONITORING SENSOR HAVING MULTIPLE SENSING ELEMENTS
12/904,931	Oct. 14, 2010	ACOUSTIC RESPIRATORY MONITORING SENSOR HAVING MULTIPLE SENSING ELEMENTS
12/904,938	Oct. 14, 2010	ACOUSTIC RESPIRATORY MONITORING SENSOR HAVING MULTIPLE SENSING ELEMENTS
##/######	Oct. 14, 2010	ACOUSTIC PATIENT SENSOR
##/######	Oct. 14, 2010	ACOUSTIC RESPIRATORY MONITORING SYSTEMS AND METHODS
61/252,062	Oct. 15, 2009	PULSE OXIMETRY SYSTEM WITH LOW NOISE CABLE HUB
61/265,730	Dec. 1, 2009	PULSE OXIMETRY SYSTEM WITH ACOUSTIC SENSOR
##/######	Oct. 14, 2010	PULSE OXIMETRY SYSTEM WITH LOW NOISE CABLE HUB
##/######	Oct. 14, 2010	PHYSIOLOGICAL ACOUSTIC MONITORING SYSTEM
61/331,087	May 4, 2010	ACOUSTIC RESPIRATION DISPLAY

Many of the embodiments described herein are compatible with embodiments described in the above related applications. Moreover, some or all of the features described herein can be used or otherwise combined with many of the features described in the applications listed above.

BACKGROUND OF THE INVENTION

The "piezoelectric effect" is the appearance of an electric potential and current across certain faces of a crystal when it is subjected to mechanical stresses. Due to their capacity to convert mechanical deformation into an electric voltage, piezoelectric crystals have been broadly used in devices such as transducers, strain gauges and microphones. However, before the crystals can be used in many of these applications they must be rendered into a form which suits the requirements of the application. In many applications, especially those involving the conversion of acoustic waves into a corresponding electric signal, piezoelectric membranes have been used.

Piezoelectric membranes are typically manufactured from polyvinylidene fluoride plastic film. The film is endowed with piezoelectric properties by stretching the plastic while it is placed under a high-poling voltage. By stretching the film, the film is polarized and the molecular structure of the plastic aligned. A thin layer of conductive metal (typically nickel-copper) is deposited on each side of the film to form electrode coatings to which connectors can be attached.

Piezoelectric membranes have a number of attributes that make them interesting for use in sound detection, including: a wide frequency range of between 0.001 Hz to 1 GHz; a low acoustical impedance close to water and human tissue; a high dielectric strength; a good mechanical strength; and piezoelectric membranes are moisture resistant and inert to many chemicals.

Due in large part to the above attributes, piezoelectric membranes are particularly suited for the capture of acoustic waves and the conversion thereof into electric signals and, accordingly, have found application in the detection of body sounds. However, there is still a need for a reliable acoustic sensor, particularly one suited for measuring bodily sounds in noisy environments.

SUMMARY OF THE INVENTION

An aspect of a physiological acoustic monitoring system receives physiological data from an acoustic sensor, down-samples the data to generate raw audio of breathing sounds and compresses the raw audio. The acoustic monitoring system has an acoustic sensor signal responsive to tracheal sounds in a person. An A/D converter is responsive to the sensor signal so as to generate breathing sound data. A decimation filter and mixer down-samples the breathing sound data to raw audio data. A coder/compressor generates compressed audio data from the raw audio data. A decoder/decompressor decodes and decompresses the compressed audio data into decompressed audio data. The decompressed audio data is utilized to generate respiration-related parameters in real-time. The compressed audio data is stored and retrieved so as to generate respiration-related parameters in non-real-time. The real-time and non-real-time parameters are compared to verify matching results across multiple monitors.

Another aspect of a physiological acoustic monitoring system inputs an acoustic sensor signal responsive to tracheal sounds of a person and generates breath tags and a respiration rate. The breath tags represent the acoustic envelope of the tracheal sound, and the respiration rate represents the inverse period of the acoustic envelope. The breath tags and respiration rate have a sufficiently low bandwidth to share a data channel with other physiological parameters. In an embodiment, the acoustic monitor has an acoustic sensor input and an A/D converter that digitizes the sensor input and outputs a digitized sensor signal. A decimation filter and mixer reduces the data rate of the digitized sensor signal and outputs a digitized raw audio. An acoustic parameter processor generates a respiration rate and breath tags in response to the digitized raw audio.

In various embodiments, the acoustic monitoring system has a coder/compressor that compresses the digitized raw audio to generate compressed audio data, which is stored and retrieved so as to generate respiration-related parameters in non-real-time. A decoder/decompressor decompresses the compressed audio data for the acoustic parameter processor. A D/A converter inputs the digitized raw audio and generates a raw audio analog signal for local playback and listening to the acoustic sensor signal. The compressed audio is transmitted to a remote location as a troubleshooting aid at a remote monitor.

A further aspect of a physiological acoustic monitoring system inputs a sensor signal responsive to respiratory sounds of a living being, digitizes the sensor signal so as to generate acoustic data, extracts an envelope from the acoustic data, defines an idealized envelope from the extracted envelope, describes the idealized envelope as breath tags and transmits the breath tags over a data channel. In various embodiments, the breath tags are received from the data channel, a reconstructed envelope is synthesized in response to the breath tags and reconstructed acoustic data is generated by filling the envelope with an artificial waveform. In an embodiment, the artificial waveform is white noise.

An additional aspect of a physiological acoustic monitoring system detects a physiological feature in the extracted envelope and includes the physiological feature in the breath tags. The reconstructed envelope is modified with the detected physiological feature, which may be wheezing or coughing, as examples. The respiratory sounds are approximately reproduced by playing the reconstructed acoustic data on an audio transducer.

Yet another aspect of a physiological acoustic monitoring system is a sensor signal responsive to respiratory sounds of a living being. An A/D converter digitizes the sensor signal into acoustic data. A parameter generator extracts a respiratory sound envelope from the acoustic data so as to generate a breath tag, which is transmitted over a data channel as a representation of the respiratory sounds. In various embodiments, a remote monitoring station receives the breath tag and a corresponding respiration rate. The monitoring station synthesizes an envelope from the breath tag and the respiration rate and fills the envelope with an artificial waveform so as to generate reconstituted respiratory sounds. In an embodiment, the artificial waveform is white noise.

In various other embodiments, a decimation filter and mixer down-samples the acoustic data to raw audio data, a D/A converter converts the raw audio data to a raw audio signal and a speaker that plays the raw audio signal. The parameter generator detects a physiological feature in the extracted envelope and includes the physiological feature in the breath tag. The remote monitor modifies the reconstructed envelope with the detected physiological feature. An audio transducer approximately reproduces the reconstructed acoustic data as compared to the raw audio signal. A compressor generates compressed audio data, which is stored and retrieved so as to generate respiration-related parameters in non-real-time.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a general block diagram of a physiological acoustic monitoring system;

FIGS. **2**A-B are illustrations of dual channel acoustic sensors;

FIG. **2**A illustrates a neck sensor for physiological measurements and a chest sensor for monaural body sound monitoring;

FIG. **2**B illustrates a dual acoustic sensor for stereo body sound monitoring;

FIGS. **3**A-B are top and bottom perspective views of a body sound sensor;

FIG. **4** is a general schematic diagram of acoustic and optical sensors and sensor drive elements and a corresponding digital signal processor and I/O drive elements;

FIG. **5** is a matrix diagram of processor modules and corresponding functionality;

FIG. **6** is a network diagram for a physiological acoustic monitoring system;

FIGS. **7**A-B are block diagrams of respiration sound generator embodiments;

FIGS. **8**A-C are graphs illustrating breath tag generator embodiments;

FIG. **9** is a block diagram illustrating a physiological parameter processor embodiment for generating acoustic and optical sensor parameters, breath tags and compressed and raw audio outputs;

FIGS. **10**A-B are a waveform and a block diagram illustrating a respiration beep generator embodiment; and

FIG. **11** is a block diagram of a physiological acoustic monitoring system for wireless monitoring applications.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** generally illustrates a physiological acoustic monitoring system **100** embodiment having one or more sensors **110** in communications with one or more processors **130** via a sensor interface **120**. The processors **130** both initiate and respond to input/output **150**, including audio output **152**, displays and alarms **154**, communications **156** and controls **158**. In an embodiment, the processors **130** are implemented in firmware executing on one or more digital signal processors (DSP), as described with respect to FIGS. **4**-**5**, below. At least a portion of the sensors **110** generate acoustic signals, which may be directly utilized by the processors **130** or recorded onto or played back from storage media **160** or both.

The processors **130** include an audio processor **132** that outputs audio waveforms **142**, a parameter processor **134** that derives physiological parameters **144** from sensor signals **112** and an acoustic data processor **136** that stores, retrieves and communicates acoustic data **146**. Parameters include, as examples, respiration rate, heart rate and pulse rate. Audio waveforms include body sounds from the heart, lungs, gastrointestinal system and other organs. These body sounds may include tracheal air flow, heart beats and pulsatile blood flow, to name a few. Displays allow parameters **144** and acoustic data **146** to be visually presented to a user in various forms such as numbers, waveforms and graphs, as examples. Audio **152** allows audio waveforms to be reproduced through speakers, headphones or similar transducers. Raw audio **122** allows acoustic sensor signals **112** to be continuously reproduced through speakers, headphones or similar transducers, bypassing A/D conversion **120** and digital signal processing **130**.

Storage media **160** allows acoustic data **146** to be recorded, organized, searched, retrieved and played back via the processors **130**, communications **156** and audio output **152**. Communications **156** transmit or receive acoustic data or audio waveforms via local area or wide area data networks or cellular networks **176**. Controls **158** may cause the audio processor **132** to amplify, filter, shape or otherwise process audio waveforms **142** so as to emphasize, isolate, deemphasize or otherwise modify various features of an audio waveform or spectrum. In addition, controls **158** include buttons and switches **178**, such as a "push to play" button that initiates local audio output **152** or remote transmission **176** of live or recorded acoustic waveforms.

As shown in FIG. **1**, acoustic data **146** is initially derived from one or more acoustic sensor signals **112**, along with, perhaps, other data inputs, such as from optical, blood pressure, EEG and ECG sensors, to name a few. The acoustic data **146** provides audio outputs **142**, including audio respiration indicators, described with respect to FIGS. **7-10**, below. The acoustic data **146**, when analyzed, provides physiological parameters **144** that provide an indication of patient status, such as respiration rate or heart rate. Such analyses may result in visual or audible alerts or alarms **154** that are viewed locally or via notifications transmitted over local or wide area networks **176** to medical staff or other persons. Acoustic data **146** is utilized in real time or stored and retrieved for later use. Acoustic data **146** may be written on various storage media **160**, such as a hard drive, and organized for convenient search and retrieval. In an embodiment, acoustic data **146** is advantageous organized on one or more hard drives as virtual magnetic tape so as to more easily manage, search, retrieve and playback acoustic data volumes. Further, the virtual tape volumes and/or the acoustic data itself may be entered into a database and organized as an acoustic library according to various search parameters including patient information, dates, corresponding physiological parameters and acoustic waveform features, to name a few. Applications for a physiological acoustic monitoring system include auscultation of body sounds by medical staff or by audio processors or both; SIDS monitoring; heart distress monitoring including the early detection and mitigation of myocardial infarction and cardiopulmonary arrest, as examples; and elder care, to name a few.

In an embodiment, sensor sounds **142** may be continuously "piped" to a remote device/listener or a central monitor or both. Listening devices may variously include pagers, cell phones, PDAs, electronic pads or tablets and laptops or other computers to name a few. Medical staff or other remote listeners are notified by the acoustic monitoring system according to flexible pre-programmed protocols to respond to the notification so as to hear breathing sounds, voice, heart sounds or other body sounds.

FIGS. **2A-B** illustrate physiological acoustic monitoring system **200** embodiments each having dual channel acoustic sensors **201**, **202** in communications with a physiological monitor **205**. As shown in FIG. **2A**, a first acoustic sensor **210** is utilized for deriving one or more physiological parameters, such as respiration rate. A second acoustic sensor **220** is utilized to continuously monitor body sounds. In an embodiment, the second acoustic sensor **220** has a different color or shape than the first acoustic sensor **210** so as identify the sensor as a body sound listening device rather than an acoustic sensing device for determining a physiological parameter. In an embodiment, the body sound sensor **220** is placed over the heart to allow the monitoring of heart sounds or for determination of heart rate. In an embodiment, the body sound sensor **220** generates a signal that bypasses monitor digitization and signal processing so as to allow continuous listening of the unprocessed or "raw" body sounds. In particular, the first acoustic sensor **210** is neck-mounted so as to determine one or more physiological parameters, such as respiration rate. The second acoustic sensor **220** is chest-mounted for monaural heart sound monitoring. As shown in FIG. **2B**, first and second acoustic sensors **260**, **270** are mounted proximate the same body site but with sufficient spatial separation to allow for stereo sensor reception. In this manner, the listener can more easily distinguish and identify the source of body sounds.

FIGS. **3A-B** illustrate a body sound sensor **300** having acoustic **310**, interconnect (not visible) and attachment **350** assemblies. The acoustic assembly **310** has an acoustic coupler **312** and a piezoelectric subassembly **314**. The acoustic coupler **312** generally envelops or at least partially covers some or all of the piezoelectric subassembly **314**. The piezoelectric subassembly **314** includes a piezoelectric membrane and a support frame (not visible). The piezoelectric membrane is configured to move on the frame in response to acoustic vibrations, thereby generating electrical signals indicative of body sounds. The acoustic coupler **312** advantageously improves the coupling between the acoustic signal measured at a skin site and the piezoelectric membrane. The acoustic coupler **312** includes a contact portion **316** placed against a person's skin.

Further shown in FIGS. **3A-B**, the acoustic assembly **310** communicates with the sensor cable **340** via the interconnect assembly. In an embodiment, the interconnect assembly is a flex circuit having multiple conductors that are adhesively bonded to the attachment assembly **350**. The interconnect assembly has a solder pad or other interconnect to interface with the sensor cable **340**, and the attachment assembly **350** has a molded strain relief for the sensor cable. In an embodiment, the attachment assembly **350** is a generally circular, planar member having a top side **3511**, a bottom side **352**, and a center. A button **359** mechanically couples the acoustic assembly **310** to the attachment assembly center so that the acoustic assembly **310** extends from the bottom side **352**. The sensor cable **340** extends from one end of the interconnect and attachment assemblies to a sensor connector at an opposite end so as to provide communications between the sensor and a monitor, as described in further detail with respect to, below. In an embodiment, an adhesive along the bottom side **352** secures the acoustic assembly **310** to a person's skin, such as at a neck, chest, back, abdomen site. A removable backing can be provided with the adhesive to protect the adhesive surface prior to affixing to a person's skin. In other embodiments, the attachment assembly **350** has a square, oval or oblong shape, so as to allow a uniform adhesion of the sensor to a measurement site. In a resposable embodiment, the attachment assembly **350** or portions thereof are removably detachable and attachable to the acoustic assembly **310** for disposal and replacement. The acoustic assembly **310** is reusable accordingly.

FIG. **4** illustrates acoustic **401** and optical **402** sensors and sensor drive elements **403** and a corresponding digital signal processor **440** and I/O drive elements **404**. A multi-acoustic sensor configuration **401** includes a power interface **413**, piezo circuits **416** and a piezoelectric membrane **417** corresponding to each sensor head **406**, **407**. The piezoelectric membrane **417** senses vibrations and generates a voltage in response to the vibrations, as described with respect to the sensor of FIGS. **3A-B**, above. The signal generated by the piezoelectric membrane is communicated to the piezo circuit **416**, described immediately below, and transmits the signal to the monitor **205** (FIG. **2A**) for signal conditioning and processing. The piezo circuit **416** decouples the power supply **413** and performs preliminary signal conditioning. In an embodiment, the piezo circuit **416** includes clamping diodes to provide electrostatic discharge (ESD) protection and a mid-level voltage DC offset for the piezoelectric signal to ride on, to be superimposed on or to be added to. The piezo circuit may also have a high pass filter to eliminate unwanted low frequencies such as below about 100 Hz for breath sound applications, and an op amp to provide gain to the piezoelectric signal. The piezo circuit **416** may also have a low pass filter on the output of the op amp to filter out unwanted high frequencies. In an embodiment, a high pass filter is also provided on the output in addition to or instead of the low pass filter. The piezo circuit may also provide impedance compensation to the piezoelectric membrane, such as a series/parallel combination used to control the signal level strength and frequency of interest that is input to the op amp. In one embodiment, the impedance compensation is used to minimize the variation of the piezoelectric element output. The impedance compensation can be constructed of any combination of resistive, capacitive and inductive elements, such as RC or RLC circuits.

As shown in FIG. **4**, a physiological acoustic monitor **400** embodiment drives and processes signals from a multi-acoustic sensor **401** and an optical sensor **402**. The monitor **400** includes one or more acoustic front-ends **421**, **422**, an analog-to-digital (A/D) converter **431**, an audio driver **470** and a digital signal processor (DSP) **440**. The DSP **440** can comprise a wide variety of data and/or signal processors capable of executing programs for determining physiological parameters from input data. An optical front-end **425**, digital-to-analog (D/A) converters **434** and an A/D converter **435** drive emitters **408** and transform resulting composite analog intensity signal(s) from light sensitive detector(s) **409** received via a sensor cable **410** into digital data input to the DSP **440**. The acoustic front-ends **421**, **422** and A/D converter **431** transform analog acoustic signals from piezoelectric elements **401** into digital data input to the DSP **440**. The A/D converter **431** is shown as having a two-channel analog input and a multiplexed digital output to the DSP. In another embodiment, each front-end, communicates with a dedicated single channel A/D converter generating two independent digital outputs to the DSP. An acoustic front-end **421** can also feed an acoustic sensor signal **411** directly into an audio driver **470** for direct and continuous acoustic reproduction of an unprocessed (raw) sensor signal by a speaker, earphones or other audio transducer **462**, as described with respect to FIG. **9**, below.

Also shown in FIG. **4**, the physiological acoustic monitor **400** may also have an instrument manager **450** that communicates between the DSP **440** and input/output **460**. One or more I/O devices **460** have communications with the instrument manager **450** including displays, alarms, user I/O and instrument communication ports. Alarms **466** may be audible or visual indicators or both. The user I/O **468** may be, as examples, keypads, touch screens, pointing devices or voice recognition devices, to name a few. The displays **464** may be indicators, numerics or graphics for displaying one or more of various physiological parameters or acoustic data. The instrument manager **450** may also be capable of storing or displaying historical or trending data related to one or more of parameters or acoustic data.

Further shown in FIG. **4**, the physiological acoustic monitor **400** may also have a "push-to-talk" feature that provides a "listen on demand" capability. That is, a button **468** on the monitor is pushed or otherwise actuated so as to initiate acoustic sounds to be sent to a speaker, handheld device, or other listening device, either directly or via a network. The monitor **400** may also has a "mode selector" button or switch **468** that determines the acoustic content provided to a listener, either local or remote. These controls may be actuated local or at a distance by a remote listener. In an embodiment, push on demand audio occurs on an alarm condition in lieu of or in addition to an audio alarm. Controls **468** may include output filters like on a high quality stereo system so that a clinician or other user could selectively emphasize or deemphasize certain frequencies so as to hone-in on particular body sounds or characteristics.

In various embodiments, the monitor **400** may be one or more processor boards installed within and communicating with a host instrument. Generally, a processor board incorporates the front-end, drivers, converters and DSP. Accordingly, the processor board derives physiological parameters and communicates values for those parameters to the host instrument. Correspondingly, the host instrument incorporates the instrument manager and I/O devices. A processor board may also have one or more microcontrollers (not shown) for board management, including, for example, communications of calculated parameter data and the like to the host instrument. A processor board embodiment is described with respect to FIG. **9**, below.

Communications **469** may transmit or receive acoustic data or audio waveforms via local area or wide area data networks or cellular networks. Controls may cause the audio processor to amplify, filter, shape or otherwise process audio waveforms so as to emphasize, isolate, deemphasize or otherwise modify various features of the audio waveform or spectrum. In addition, switches, such as a "push to play" button can initiate audio output of live or recorded acoustic data. Controls may also initiate or direct communications.

FIG. **5** illustrates processor modules **500** that may execute on a DSP **440** (FIG. **4**) and/or instrument manager **450** (FIG. **4**) in various physiological acoustic monitoring system embodiments and the corresponding functionality of these modules. Module functionality includes processing sensor input **510**, storage **520** and playback **530** of acoustic data, acoustic data analysis **540**, communication of acoustic data and derived physiological parameters **550** and specific applications **560**. Sensor input **510** related modules include dynamic range **512** and noise reduction **513**. Dynamic range **512** functionality is described with respect to the processor board codec and FIG. **9**, below. Storage **520** related modules include virtual tape **523** and database **524** functionality, described with respect to FIG. **6**, below. Playback **530** functionality includes audio filters **532**, sound reproduction **534** including mono/stereo/quadraphonic **533** modes and auscultation **535** enhancement. Analysis **540** related modules include audio parameters **542**, multi-sensor parameters **543** and corresponding alarms **544**. Communications **550** related modules include cellular **553**, wireless **554** and network **555** modes. Wireless is described with respect to FIG. **11**, below, and cellular **553** and networks **555** are described with respect to FIG. **6**, below. Applications **560** include elder care **561** and SIDS **562**, described with respect to FIG. **12**, below.

FIG. **6** illustrates a physiological acoustic monitoring system **600** embodiment having a shared or open network architecture interconnecting one or more physiological monitors **610**, monitoring stations **620** and mass storage **660**. This interconnection includes proximity wireless devices **612** in direct wireless communication with a particular physiological monitor **610**; local wireless devices **632** in communications with the monitors **610** via a wireless LAN **630**; and distant wired or wireless devices **642**, **652** in communications with the monitors **610** via WAN, such as Internet **640** or cellular networks **650**. Communication devices may include local and remote monitoring stations **620** and wired or wireless communications and/or computing devices including cell phones, lap tops, pagers, PDAs, tablets and pads, to name a few. Physiological information is transmitted/received directly to/from end users over LAN or WAN. End users such as clinicians may carry wireless devices **632** in communications with the WLAN **630** so as to view in real-time physiological parameters or listen to audio data and waveforms on demand or in the event of an alarm or alert.

The network server **622** in certain embodiments provides logic and management tools to maintain connectivity between physiological monitors, clinician notification devices and external systems, such as EMRs. The network server **622** also provides a web based interface to allow installation (provisioning) of software related to the physiological monitoring system, adding new devices to the system, assigning notifiers to individual clinicians for alarm notification, escalation algorithms in cases where a primary caregiver does not respond to an alarm, interfaces to provide management reporting on alarm occurrences and internal journaling of system performance metrics such as overall system uptime. The network server **622** in certain embodiments also provides a platform for advanced rules engines and signal processing algorithms that provide early alerts in anticipation of a clinical alarm.

As shown in FIG. **6**, audio data and corresponding audio files are advantageously stored on virtual tape **662**, which provides the storage organization of tape cartridges without the slow, bulky, physical storage of magnetic tape and the corresponding human-operator intervention to physically locate and load physical cartridges into an actual tape-drive. A virtual tape controller **662** emulates standard tape cartridges and drives on modern, high capacity disk drive systems, as is well-known in the art. Accordingly, virtual "audio tapes" appear the same as physical tapes to applications, allowing the use of many existing cartridge tape storage, retrieval and archival applications. Further, while the upper-limit of a physical tape cartridge may be a few hundred megabytes, a virtual tape server **662** can be configured to provide considerably larger "tape" capacity. Mount-time is near-zero for a virtual tape and the data is available immediately. Also, while traditional physical tape systems have to read a tape from the beginning, moving sequentially through the files on the tape, a virtual drive can randomly access data at hard-disk speeds, providing tape I/O at disk access speeds.

Additionally shown in FIG. **6**, a sound processing firmware module of certain embodiments accesses a database **670** of sound signatures **660** and compares the received signal with the entries in the database to characterize or identify sounds in the received signal. In another embodiment, the sound processing module generates and/or accesses a database **670** of sound signatures specific to a patient, or specific to a particular type of patient (e.g., male/female, pediatric/adult/geriatric, etc.). Samples from a person may be recorded and used to generate the sound signatures. In some embodiments, certain signal characteristics are used to identify particular sounds or classes of sounds. For example, in one embodiment, signal deviations of relatively high amplitude and or sharp slope may be identified by the sound processing module. Sounds identified in various embodiments by the sound processing module include, but are not limited to, breathing, speech, choking, swallowing, spasms such as larynx spasms, coughing, gasping, etc.

Once the sound processing module characterizes a particular type of sound, the acoustic monitoring system can, depending on the identified sound, use the characterization to generate an appropriate response. For example, the system may alert the appropriate medical personnel to modify treatment. In one embodiment, medical personnel may be alerted via an audio alarm, mobile phone call or text message, or other appropriate means. In one example scenario, the breathing of the patient can become stressed or the patient may begin to choke due to saliva, mucosal, or other build up around an endotracheal tube. In an embodiment, the sound processing module can identify the stressed breathing sounds indicative of such a situation and alert medical personnel to the situation so that a muscle relaxant medication can be given to alleviate the stressed breathing or choking.

According to some embodiments, acoustic sensors described herein can be used in a variety of other beneficial applications. For example, an auscultation firmware module may process a signal received by the acoustic sensor and provide an audio output indicative of internal body sounds of the patient, such as heart sounds, breathing sounds, gastrointestinal sounds, and the like. Medical personnel may listen to the audio output, such as by using a headset or speakers. In some embodiments the auscultation module allows medical personnel to remotely listen for patient diagnosis, communication, etc. For example, medical personnel may listen to the audio output in a different room in a hospital than the patient's room, in another building, etc. The audio output may be transmitted wirelessly (e.g., via Bluetooth, IEEE 802.11, over the Internet, etc.) in some embodiments such that medical personnel may listen to the audio output from generally any location.

FIGS. **7**A-B illustrate sound processing embodiments **701**, **702** for generating an audio output for an acoustic sensor. As shown in FIG. **7**A, in one embodiment, acoustic sensor data is A/D converted **710**, down-sampled with a decimation filter **720** and compressed **730**. The compressed audio data **732** is transmitted to a monitor, which decompresses the data **740** and outputs it to a speaker **742** or similar audio transducer. However, compressed audio data **732** from a physiological acoustic sensor has too high a bit rate to transmit over monitor data channels shared with other physiological processors or patient networks shared by multiple patient monitors all communicating physiological parameters, waveforms and other real-time medical data. Acoustic sensor data rates are described in further detail with respect to FIG. **9**, below.

As shown in FIG. **7**B, an envelope-based sound processing **702** embodiment advantageously allows respiration-related acoustic data to be transmitted at significantly reduced data rates compared with data compression so as to allow shared transmission over monitor data channels (**990** FIG. **9**) and patient networks. Respiration-related acoustic data is A/D converted **710** and input to an envelope detector **750**. The detected envelopes are idealized and represented by a small number set or "tag" corresponding to each breath. In an embodiment, a breath tag represents the time-of-occurrence of the breath envelope peak for each inspiration and expiration cycle. These breath tags **760** are then transmitted over standard multiple parameter patient monitor data channels and/or patient networks. At the receiving end, a patient monitor, multiple patient monitoring system or like monitoring device synthesizes the envelopes **770** from the breath tags **760** according to the respiration rate (RR). The envelopes **770** are then filled with white noise **780** so as to simulate the original respiration acoustic data **782**.

FIGS. **8**A-C further illustrate envelope processing for acoustic sensor data. FIG. **8**A illustrates a representative acoustic signal **801** derived by a neck sensor detecting vibrations resulting from tracheal air flow during respiration. A breath sound **810** has an envelope **820** "pulse" corresponding to either inhalation or exhalation. An envelope detector **750** (FIG. **7**B) generates breath tags that numerically describe the envelope **820**. As shown in FIG. **8**B, in one embodiment, breath tags describe an idealized envelope **830**. For example, a breath tag may be an amplitude value and a duration value for each idealized pulse. In other embodiments, a breath tag may include leading/trailing slope values for a pulse **830**. As shown in FIG. **8**C, in other embodiments, breath tags include detected envelope features **842**, **843**, **844** that are characteristic of known acoustically-related phenomena such as wheezing or coughing, as examples. At a receiving device, envelop synthesis **770** (FIG. **7**B) reproduces an envelope **830**, **840** and fills the envelope with an artificial waveform, such as white noise. This reconstructed or simulated breath signal is then output to a speaker or similar device. In other embodiments, breath tags are transmitted over a network to a remote device, which reconstructs breathing waveforms from the breath tags in like manner.

In various other embodiments, acoustic breathing waveforms are detected by an acoustic sensor, processed, transmitted and played on a local or remote speaker or other audio output from actual (raw) data, synthetic data and artificial data. Actual data may be compressed, but is a nearly complete or totally complete reproduction of the actual acoustic sounds at the sensor. Synthetic data may be a synthetic version of the breathing sound with the option of the remote listener to request additional resolution. Artificial data may simulate an acoustic sensor sound with minimal data rate or bandwidth, but is not as clinically useful as synthetic or actual data. Artificial data may be, for example, white noise bursts generated in sync with sensed respiration. Synthetic data is something between actual data and artificial data, such as the acoustic envelope process described above that incorporates some information from the actual sensor signal. In an embodiment breath sounds are artificially hi/lo frequency shifted or hi/lo volume amplified to distinguish inhalation/exhalation. In an embodiment, dual acoustic sensors placed along the neck are responsive to the relative time of arrival of tracheal sounds so as to distinguish inhalation and exhalation in order to appropriately generate the hi/lo frequency shifts. Raw and compressed acoustic respiration data is described with respect to FIG. **9**, below. Artificial data "breath beeps" are described with respect to FIGS. **10**A-B, below.

FIG. **9** illustrates a processor board **900** embodiment of an acoustic monitoring system that generates both optical and acoustic data. An optical portion has D/A converters **958** responsive to emitter drives **954** and an emitter control **950** so as to alternately activate optical sensor **902** LEDs of multiple wavelengths so as to illuminate blood perfused tissue. An A/D converter **960** and demodulator **964** are responsive to sensor **902** detectors so as to generate plethysmographic data **968** to a digital signal processor (DSP) **980**. Corresponding blood parameter algorithms **970** generate blood parameter outputs **972**, such as oxygen saturation (SpO_2), to a data channel **990**.

Also shown in FIG. **9**, an acoustic portion has an A/D converter **910**, a decimation filter and mixer **920**, a coder/compressor **930** and a decoder/decompressor **935** so as to generate acoustic data to the DSP **980**. The A/D **910**, decimation filter/mixer **920** and a D/A converter **925** are responsive to an acoustic sensor **901** so as to generate an analog "raw" audio **909** output. In an embodiment, the A/D **910** is a 48 Khz, 16-bit, 2-channel variable gain device that provides higher resolution at lower signal amplitudes and lower resolution and higher signal amplitudes. In an embodiment, the decimation filter/mixer generates 2 KHz, 32-bit (64 Kbps) digitized raw audio **922**. Advantageously, the raw audio **909** is routed to a proximate amplifier/speaker **122** (FIG. **1**). The digitized raw audio **922** is also input to the coder/compressor **930**. A 3:1 (approx.) compression generates a 20 Kbps compressed (digitized) audio **908** output. The compressed audio **908** is immediately input into a decoder/decompresser **935** for use by acoustic algorithms **940** to generate respiration rate (RR) and breath tag **942** outputs to a data channel **990**, as described above, among other acoustic-related parameters. Advantageously, the compression and immediate decompression of the digitized raw audio **922** provides a compressed audio output **908** that can be stored and retrieved for accurate off-line reproduction and troubleshooting of device behavior. Also, the compressed audio output **908** can be advantageously transmitted via Wi-Fi or other communication links to remote locations for processing and patient analysis.

FIGS. **10**A-B illustrate a "respiration beep" embodiment **1001** for communicating reduced-rate respiration data over relatively low bandwidth monitor data channels and patient networks. As shown in FIG. **10**A, in some situations, acoustic respiration data **1000** presents an inspiration (I) **1010** pulse relatively closely followed by an expiration (E) **1020** pulse, where each I/E pair is separated by a relatively longer pulseless interval. That is, these I/E pairs are relatively easily distinguished. As such, I/E pairs can be transmitted as simply time-of-occurrence values.

As shown in FIG. **10**B, at an inspiration time **1062**, a high (HI) frequency tone **1064** is generated. At an expiration time **1062**, a low (LO) frequency tone **1064** is generated. A mixer **1050** combines colored noise **1042** with the HI/LO tones **1064** to generate higher-pitched followed by lower-pitched noise pulses representative of the original acoustic waveform **1000**. These respiration "beeps" are roughly analogous to pulse oximeter-generated "beeps" that coincide with optical sensor detected arterial blood pulses. In an advantageous embodiment, a processor board **900** (FIG. **9**) having optical and acoustic sensors generates simultaneously occurring respiration beeps and pulse beeps, where the pulse beep tone is easily distinguished from the respiration beep HI/LO noise pulses. These combined pulse/respiration beeps advantageously allow a care provider to "monitor" a patient's respiration and pulse by sound alone.

FIG. **11** illustrates a wireless physiological acoustic monitor **1100** embodiment, which is particular advantageous for out-patient applications, such as sudden infant death syndrome (SIDS) prevention and elder care. The monitor **1100** has a sensor section **1101** and a remote section **1102**. The sensor section **1101** has a sensor **1110**, a sensor interface **1120** and a communications element **1130**. In an embodiment, the sensor **1110** is an adhesive substrate integrated with a piezoelectric assembly and interconnect cable, such as described with respect to FIGS. **3**A-B, above. The sensor interface **1120** provides power to and receives the sensor signal from the sensor piezo circuit, as described with respect to FIG. **4**, above. The wireless communications element **1130** receives the sensor signal from the sensor interface **1120** and transmits the signal to the corresponding communications element **1140** in the remote section **1102**, which provides an amplified sensor signal sufficient to drive a small speaker. In an embodiment, the communications link **1160** conforms with IEEE 802.15 (Bluetooth).

A physiological acoustic monitoring system has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only and are not to limit the scope of the claims that follow. One of ordinary skill in art will appreciate many variations and modifications.

What is claimed is:

1. An acoustic monitoring system inputs an acoustic sensor signal responsive to tracheal sounds of a person and generates breath tags and a respiration rate, the breath tags representing the acoustic envelope of the tracheal sounds and the respiration rate representing the inverse period of the acoustic envelope, the breath tags and respiration rate having a sufficiently low bandwidth to share a data channel with other physiological parameters, the acoustic monitor comprising:

an acoustic sensor input;

an A/D converter that digitizes the sensor input and outputs a digitized sensor signal;

a decimation filter and mixer that reduces the data rate of the digitized sensor signal and outputs a digitized raw audio; and

an acoustic parameter processor that generates a respiration rate and breath tags in response to the digitized raw audio.

2. The acoustic monitoring system according to claim **1** further comprising a coder/compressor that compresses the digitized raw audio to generate compressed audio data, the compressed audio data is stored and retrieved so as to generate respiration-related parameters in non-real-time.

3. The acoustic monitoring system according to claim **2** further comprising a decoder/decompressor that decompresses the compressed audio data for the acoustic parameter processor.

4. The acoustic monitoring system according to claim **3** further comprising a D/A converter that inputs the digitized raw audio and generates a raw audio analog signal for local playback and listening to the acoustic sensor signal.

5. The acoustic monitoring system according to claim **4** further comprising a transmission of the compressed audio to a remote location as a troubleshooting aid at a remote monitor.

6. An acoustic monitoring method comprising:

receiving a sensor signal responsive to respiratory sounds of a living being;

digitizing the sensor signal so as to generate acoustic data;

extracting an envelope from the acoustic data;

defining an idealized envelope from the extracted envelope;

describing the idealized envelope as a plurality of breath tags; and

transmitting the breath tags over a data channel.

7. The acoustic monitoring method according to claim **6** further comprising:

receiving the breath tags from the data channel;

synthesizing a reconstructed envelope in response to the breath tags; and

generating reconstructed acoustic data by filling the envelope with an artificial waveform.

8. The acoustic monitoring method according to claim **7** wherein the artificial waveform is white noise.

9. The acoustic monitoring method according to claim **8** further comprising:

detecting a physiological feature in the extracted envelope; and

including the physiological feature in the breath tags.

10. The acoustic monitoring method according to claim **9** wherein the synthesizing further comprises modifying the reconstructed envelope with the detected physiological feature.

11. The acoustic monitoring method according to claim **10** wherein the physiological feature is at least one of wheezing and coughing.

12. The acoustic monitoring method according to claim **11** further comprising approximately reproducing the respiratory sounds by playing the reconstructed acoustic data on an audio transducer.

13. An acoustic monitor comprising:

a sensor signal responsive to respiratory sounds of a living being;

an A/D converter that digitizes the sensor signal into acoustic data; and

a parameter generator that extracts a respiratory sound envelope from the acoustic data so as to generate a breath tag,

the breath tag transmitted over a data channel as a representation of the respiratory sounds.

14. The acoustic monitor according to claim **13** further comprising a remote monitoring station that receives the breath tag and a corresponding respiration rate, the monitoring station synthesizing an envelope from the breath tag and the respiration rate and filing the envelope with an artificial waveform so as to generate reconstituted respiratory sounds.

15. The acoustic monitoring method according to claim **14** wherein the artificial waveform is white noise.

16. The acoustic monitor according to claim **15** further comprising:

a decimation filter and mixer that down-samples the acoustic data to raw audio data;

a D/A converter that converts the raw audio data to a raw audio signal; and

a speaker that plays the raw audio signal.

17. The acoustic monitor according to claim **16** further wherein the parameter generator detects a physiological feature in the extracted envelope and includes the physiological feature in the breath tag.

18. The acoustic monitor according to claim **17** wherein the remote monitor modifies the reconstructed envelope with the detected physiological feature.

19. The acoustic monitor according to claim **18** further comprising an audio transducer that approximately reproduces the reconstructed acoustic data as compared to the raw audio signal.

20. The acoustic monitor according to claim **19** further comprising a compressor that generates compressed audio data, the compressed audio data stored and retrieved so as to generate respiration-related parameters in non-real-time.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,870,792 B2
APPLICATION NO. : 13/650775
DATED : October 28, 2014
INVENTOR(S) : Ammar Al-Ali

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

In column 2 (page 5, item 56) at line 19, Under Other Publications, change "Sheete," to --Sheet,--.

In the Drawings

Sheet 5 of 11 (Reference Numeral 535, FIG. 5) at line 1, Change "ASCULTATION" to --AUSCULTATION--.

In the Specification

In column 1 at line 46 (approx.), Change "##/######" to --12/904,907--.

In column 1 at line 47 (approx.), Change "##/######" to --12/904,789--.

In column 1 at line 52 (approx.), Change "##/######" to --12/904,775--.

In column 1 at line 54 (approx.), Change "##/######" to --12/905,036--.

In column 9 at line 51, Change "and or" to --and/or--.

Signed and Sealed this
Twenty-second Day of September, 2015

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office

patsnap

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摘要(译)

生理声学监测系统从声学传感器接收生理数据，对数据进行下采样以生成呼吸声音的原始音频并压缩原始音频。声学监测系统具有响应于人的气管声音的声学传感器信号。 A / D转换器响应传感器信号以产生呼吸声数据。抽取滤波器和混频器将呼吸声音数据下采样到原始音频数据。编码器/压缩器从原始音频数据生成压缩音频数据。解码器/解压缩器将压缩的音频数据解码和解压缩成解压缩的音频数据。解压缩的音频数据用于实时生成呼吸相关参数。存储和检索压缩的音频数据，以便非实时地生成与呼吸相关的参数。比较实时和非实时参数以验证多个监视器之间的匹配结果。