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(54) APPARATUS AND METHOD FOR OUTPUTTING HEART SOUNDS

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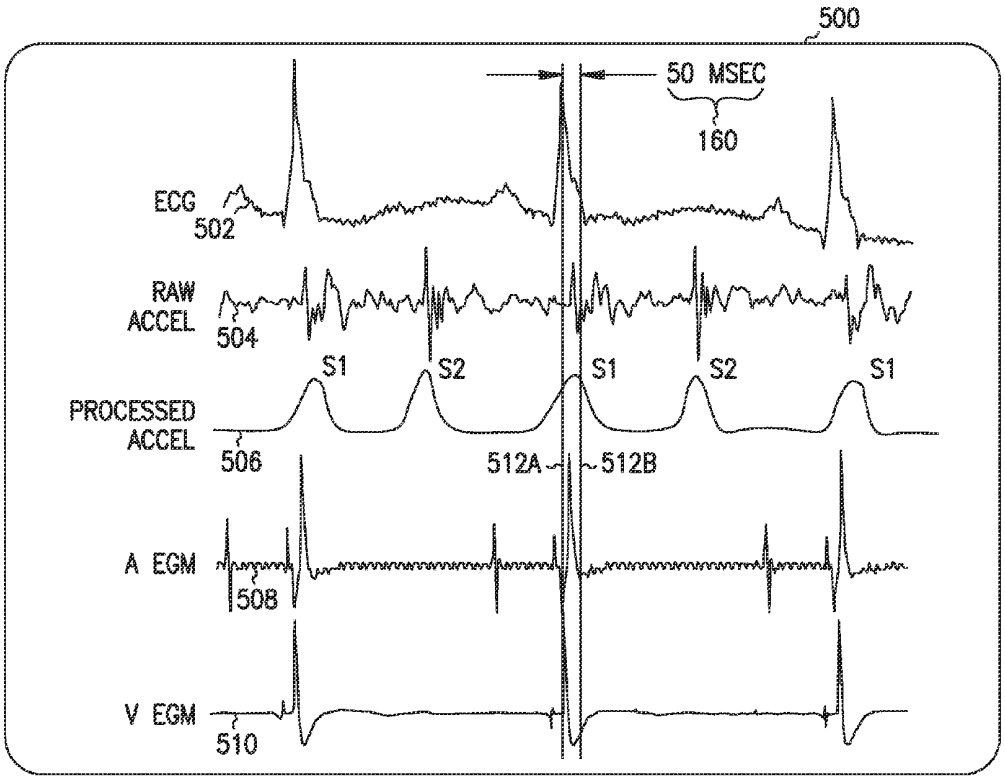
(57) **ABSTRACT**

An apparatus for outputting heart sounds includes an implantable system and an external system. The implantable system includes a sensor for generating sensed signals representing detected heart sounds, an interface circuit and a control circuit for receiving the sensed signals, generating data representing the heart sounds therefrom, and transmitting the data to the external system via the interface circuit. The external system includes an interface circuit for communicating with the implantable system, and a control circuit for receiving the data representing the heart sounds and for generating control signals that cause an output device to generate outputs representing the sounds. The implantable system may also include a sensor(s) for detecting cardiac electrical signals. In this case, outputs representing the cardiac electrical signals are also output.



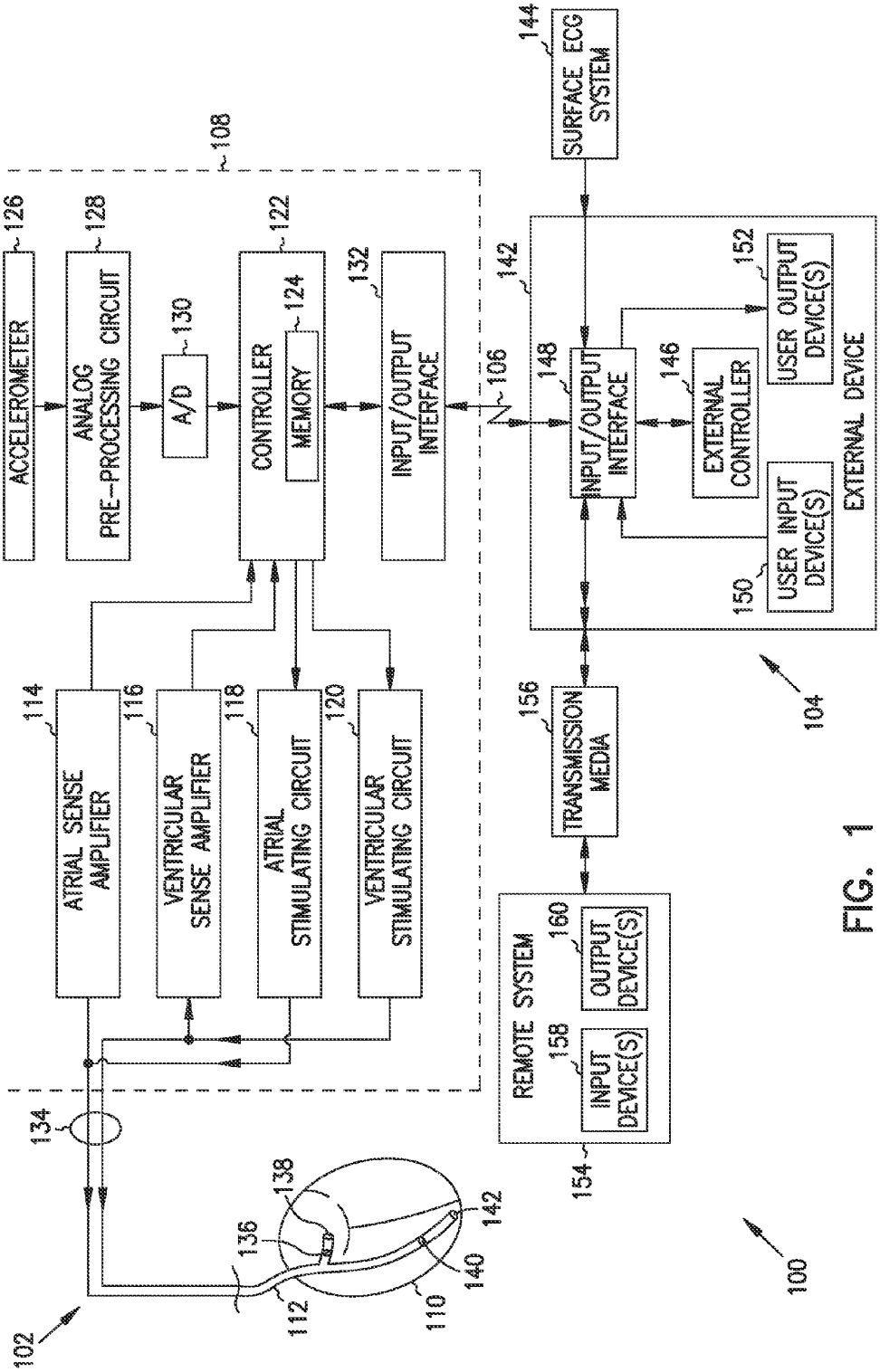

108
126
ACCELEROMETER
128
ANALOG PRE-PROCESSING CIRCUIT
130
A/D
122
CONTROLLER
124
MEMORY
132
INPUT/OUTPUT INTERFACE
106
114
ATRIAL SENSE AMPLIFIER
116
VENTRICULAR SENSE AMPLIFIER
118
ATRIAL STIMULATING CIRCUIT
120
VENTRICULAR STIMULATING CIRCUIT
134
138
136
142
140
112
110
102
144
SURFACE ECG SYSTEM
142
148
INPUT/OUTPUT INTERFACE
146
EXTERNAL CONTROLLER
152
USER OUTPUT DEVICE(S)
150
USER INPUT DEVICE(S)
EXTERNAL DEVICE
104
156
TRANSMISSION MEDIA
REMOTE SYSTEM
160
OUTPUT DEVICE(S)
158
INPUT DEVICE(S)
154
100

FIG. 1

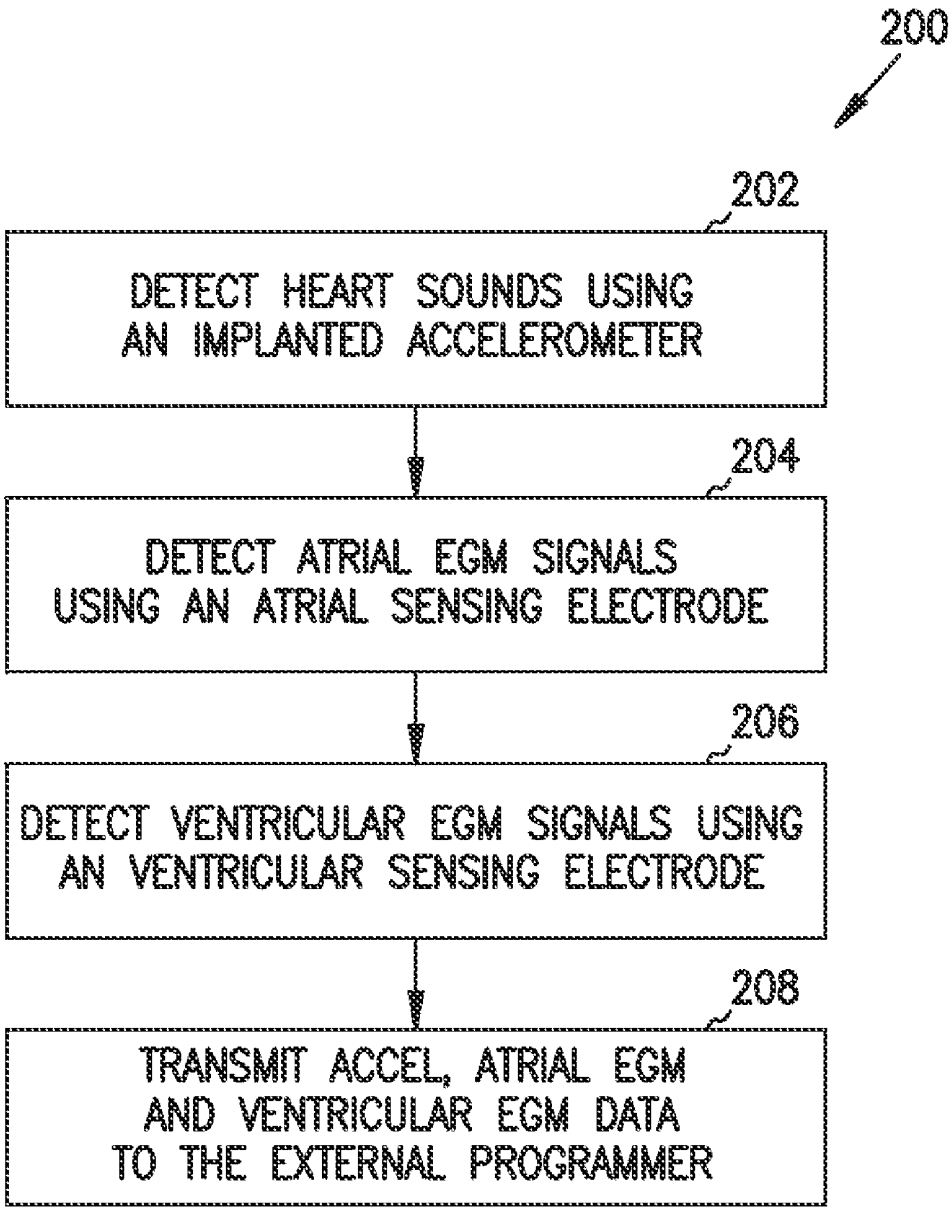

200
202
DETECT HEART SOUNDS USING AN IMPLANTED ACCELEROMETER
204
DETECT ATRIAL EGM SIGNALS USING AN ATRIAL SENSING ELECTRODE
206
DETECT VENTRICULAR EGM SIGNALS USING AN VENTRICULAR SENSING ELECTRODE
208
TRANSMIT ACCEL, ATRIAL EGM AND VENTRICULAR EGM DATA TO THE EXTERNAL PROGRAMMER

FIG. 2

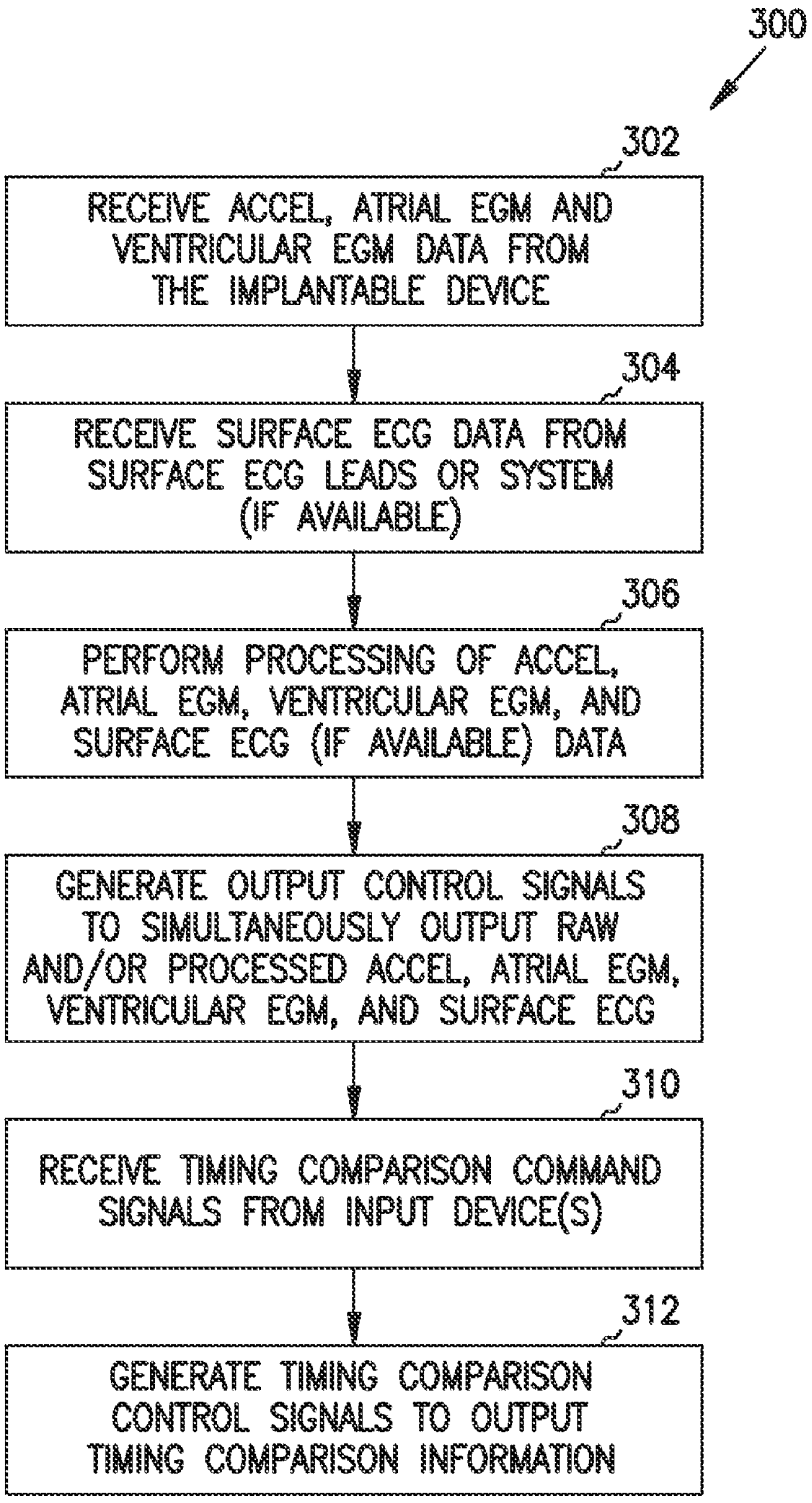

300
302
RECEIVE ACCEL, ATRIAL EGM AND VENTRICULAR EGM DATA FROM THE IMPLANTABLE DEVICE
304
RECEIVE SURFACE ECG DATA FROM SURFACE ECG LEADS OR SYSTEM (IF AVAILABLE)
306
PERFORM PROCESSING OF ACCEL, ATRIAL EGM, VENTRICULAR EGM, AND SURFACE ECG (IF AVAILABLE) DATA
308
GENERATE OUTPUT CONTROL SIGNALS TO SIMULTANEOUSLY OUTPUT RAW AND/OR PROCESSED ACCEL, ATRIAL EGM, VENTRICULAR EGM, AND SURFACE ECG
310
RECEIVE TIMING COMPARISON COMMAND SIGNALS FROM INPUT DEVICE(S)
312
GENERATE TIMING COMPARISON CONTROL SIGNALS TO OUTPUT TIMING COMPARISON INFORMATION

FIG. 3

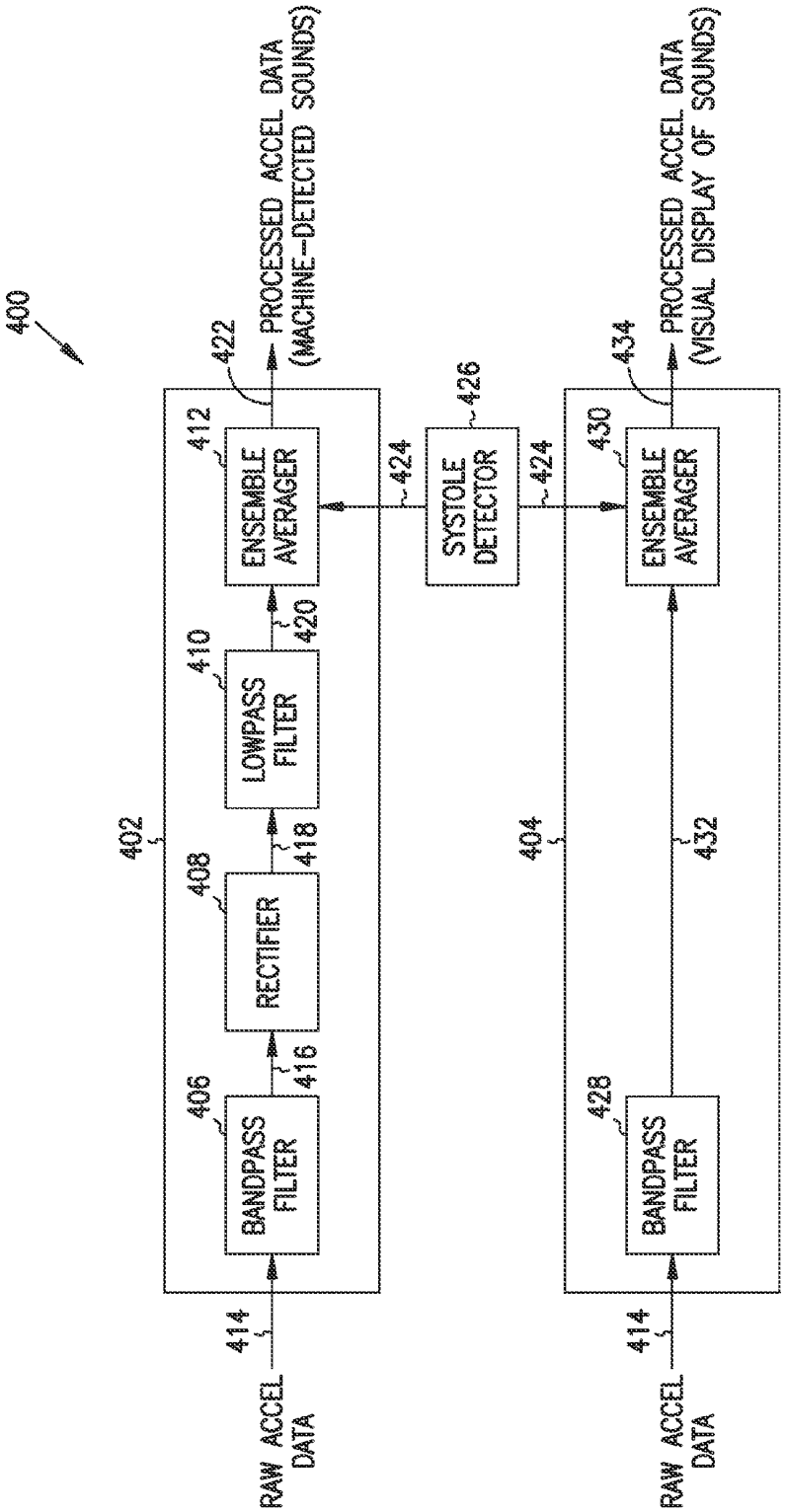

400
402
404
406
BANDPASS FILTER
408
RECTIFIER
410
LOWPASS FILTER
412
ENSEMBLE AVERAGER
414
RAW ACCEL DATA
416
418
420
422
PROCESSED ACCEL DATA (MACHINE-DETECTED SOUNDS)
424
426
SYSTOLE DETECTOR
428
BANDPASS FILTER
430
ENSEMBLE AVERAGER
432
434
PROCESSED ACCEL DATA (VISUAL DISPLAY OF SOUNDS)

FIG. 4

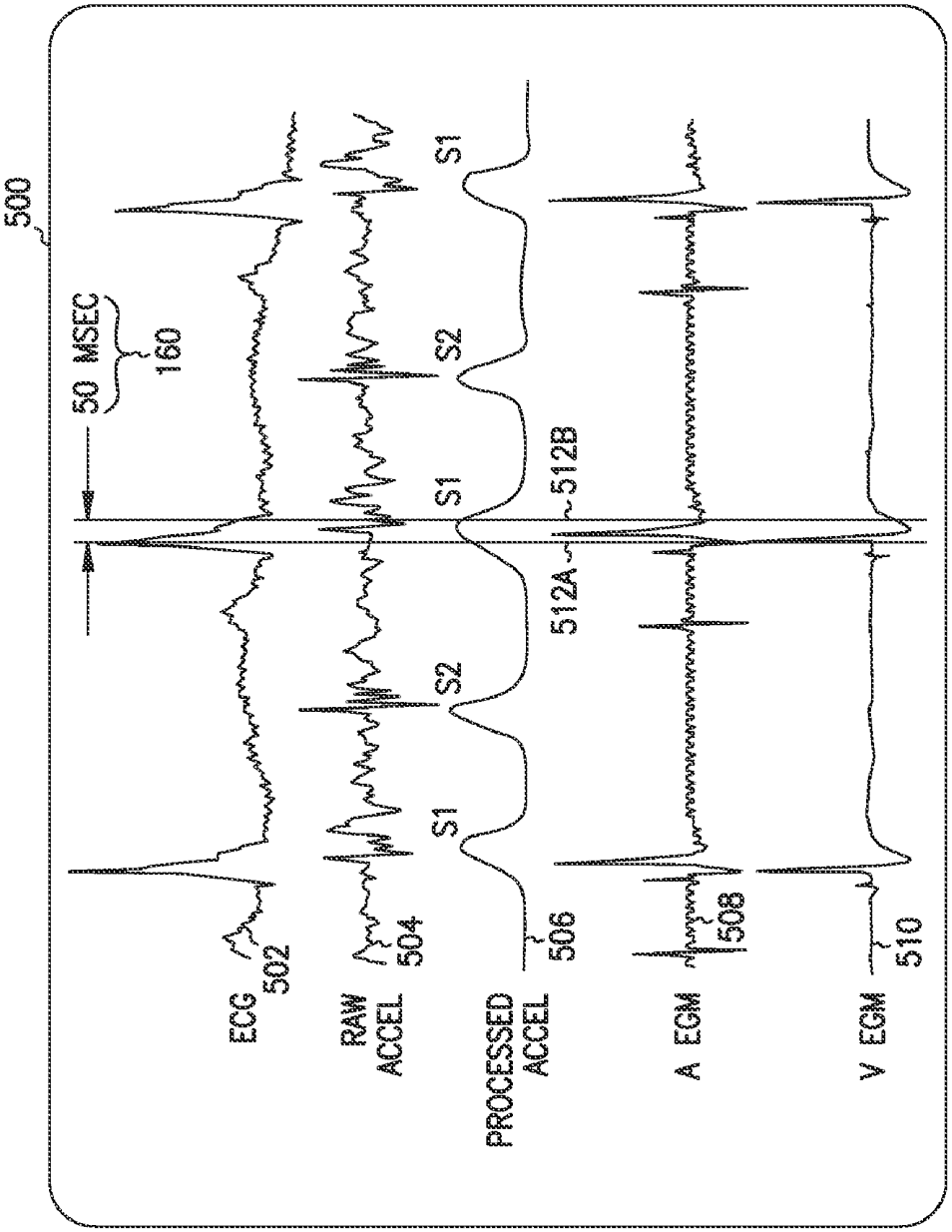

500
50 MSEC
160
ECG
502
RAW
ACCEL
504
PROCESSED
ACCEL
506
A EGM
508
V EGM
510
S1
S2
S1
S2
S1
512A
512B

FIG. 5

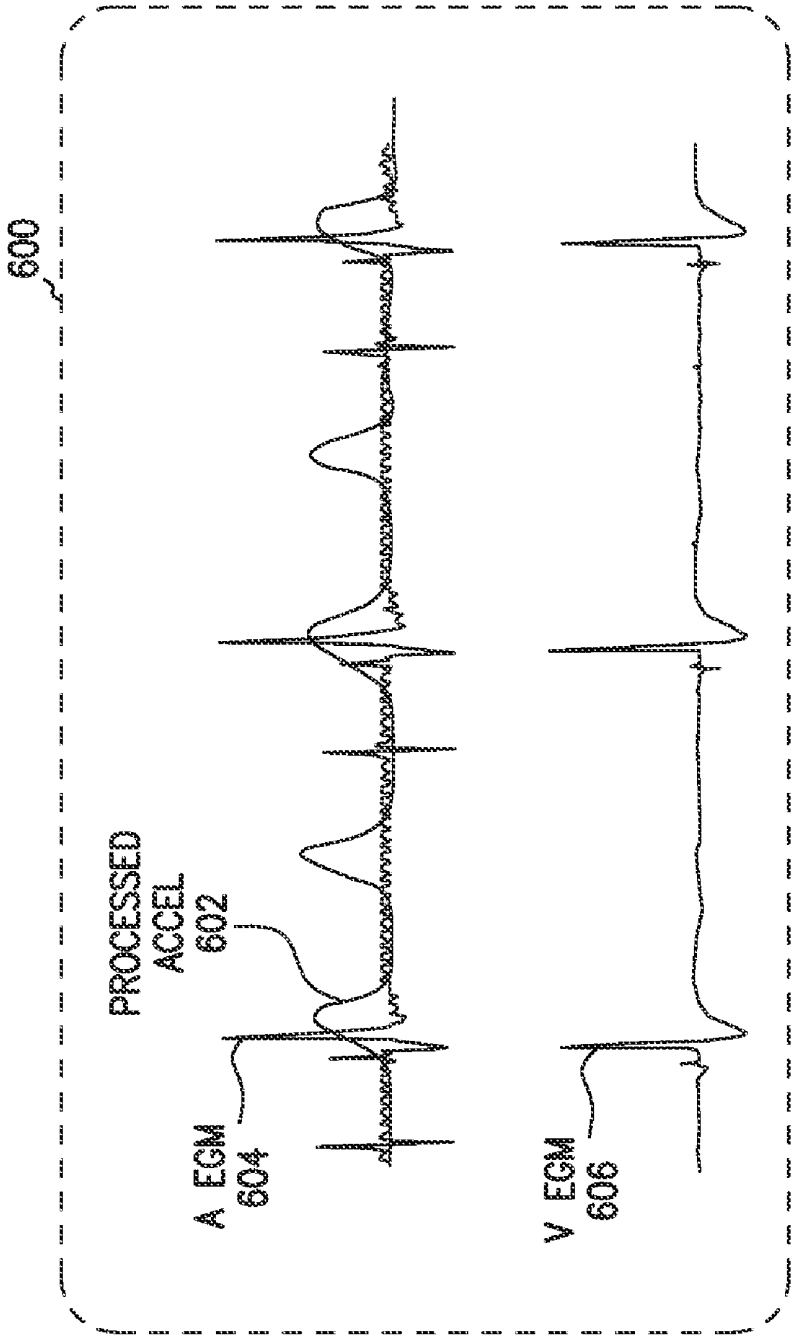


FIG. 6

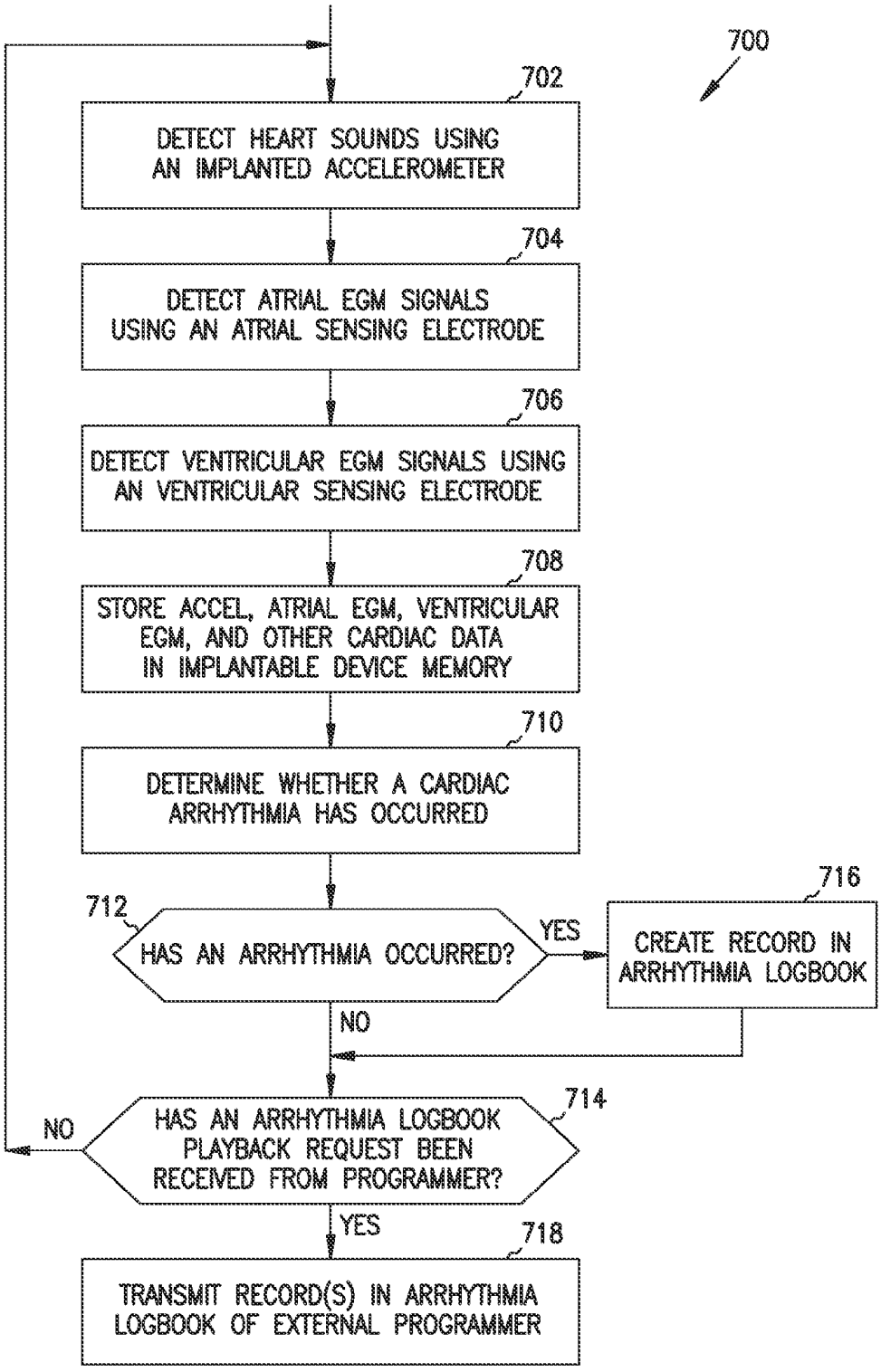

700
702
DETECT HEART SOUNDS USING AN IMPLANTED ACCELEROMETER
704
DETECT ATRIAL EGM SIGNALS USING AN ATRIAL SENSING ELECTRODE
706
DETECT VENTRICULAR EGM SIGNALS USING AN VENTRICULAR SENSING ELECTRODE
708
STORE ACCEL, ATRIAL EGM, VENTRICULAR EGM, AND OTHER CARDIAC DATA IN IMPLANTABLE DEVICE MEMORY
710
DETERMINE WHETHER A CARDIAC ARRHYTHMIA HAS OCCURRED
712
HAS AN ARRHYTHMIA OCCURRED?
YES
716
CREATE RECORD IN ARRHYTHMIA LOGBOOK
NO
714
HAS AN ARRHYTHMIA LOGBOOK PLAYBACK REQUEST BEEN RECEIVED FROM PROGRAMMER?
NO
YES
718
TRANSMIT RECORD(S) IN ARRHYTHMIA LOGBOOK OF EXTERNAL PROGRAMMER

FIG. 7

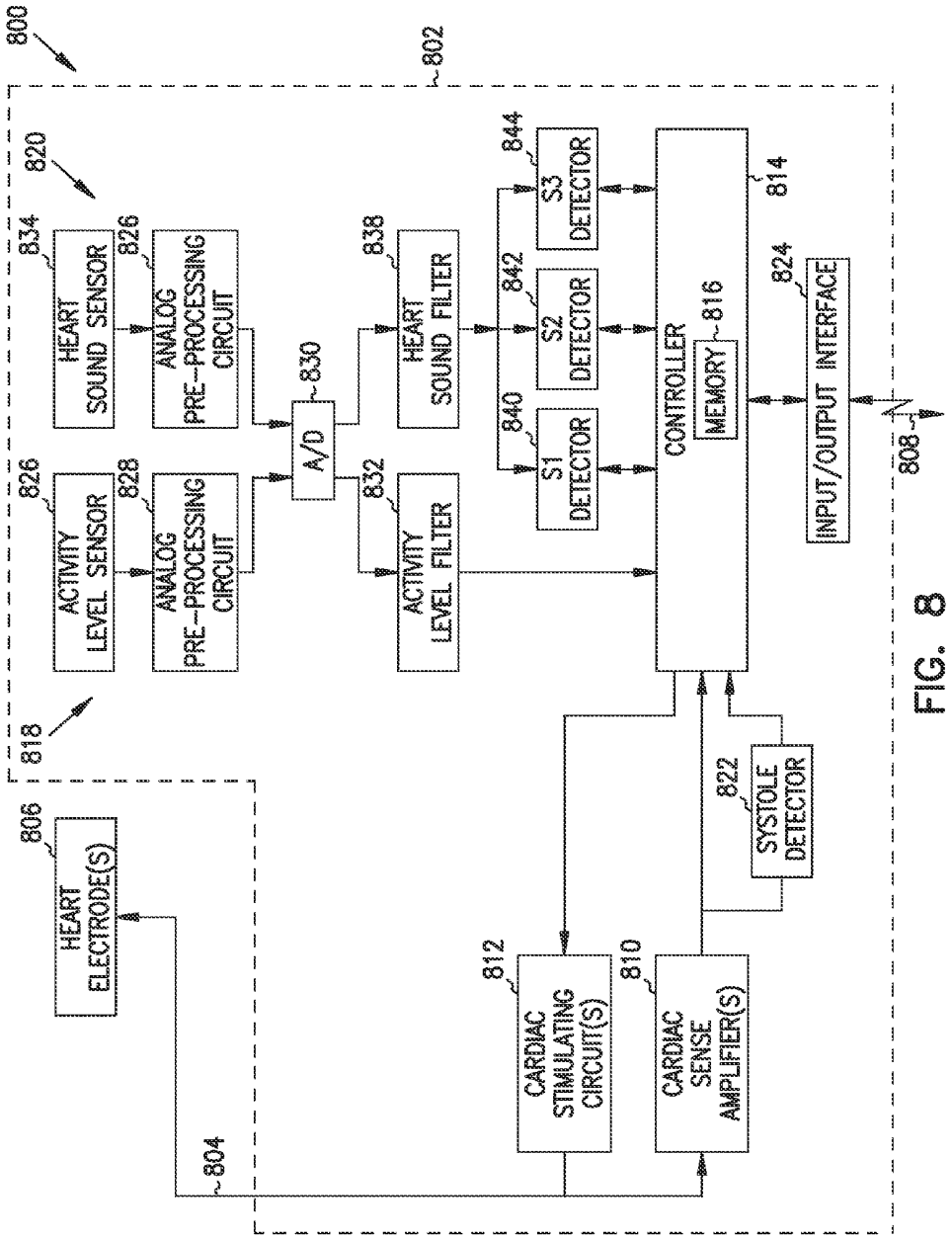

800
802
820
834
HEART SOUND SENSOR
826
ANALOG PRE-PROCESSING CIRCUIT
826
ACTIVITY LEVEL SENSOR
828
ANALOG PRE-PROCESSING CIRCUIT
830
A/D
838
HEART SOUND FILTER
832
ACTIVITY LEVEL FILTER
844
S3 DETECTOR
842
S2 DETECTOR
840
S1 DETECTOR
CONTROLLER
814
MEMORY
816
824
INPUT/OUTPUT INTERFACE
808
818
806
HEART ELECTRODE(S)
804
822
SYSTOLE DETECTOR
812
CARDIAC STIMULATING CIRCUIT(S)
810
CARDIAC SENSE AMPLIFIER(S)

FIG. 8

APPARATUS AND METHOD FOR OUTPUTTING HEART SOUNDS

CLAIM OF PRIORITY

[0001] This application is a continuation of application Ser. No. 13/004,543, filed on Jan. 11, 2011, which is a continuation of application Ser. No. 11/037,276, filed on Jan. 18, 2005, now U.S. Pat. No. 7,883,470, which is a continuation of application Ser. No. 09/833,229, filed on Apr. 11, 2001, now U.S. Pat. No. 7,052,466, the specifications of which are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

[0002] The present invention generally relates to the field of cardiac monitoring, and more particularly relates to detecting heart sounds using an implanted sensor, transmitting data indicative of the heart sounds to an external system, and outputting the heart sound data.

BACKGROUND

[0003] Cardiac pacemakers generally provide functions including sensing electrical signals generated by the heart, controlling stimulation of excitable tissues in the heart, sensing the response of the heart to such stimulation, and responding to inadequate or inappropriate stimulus or response (e.g., dysrhythmia) to deliver therapeutic stimuli to the heart. Some existing cardiac pacemakers also function to communicate with an external programmer device to support a variety of monitoring, diagnostic and configuration functions.

[0004] Certain cardiac pacemakers include an internal accelerometer for measuring the level of activity of the patient (e.g., movement caused by walking around, or by muscle twitches). Such pacemakers process (e.g., filter) the accelerometer signals to reduce noise interfering with the measurement of the patient's activity, such as the sounds generated by the heart itself, and then use the processed signals as inputs to algorithms for generating the signals used to control the stimulation of the heart. For example, if accelerometer signals indicate that a patient is walking briskly, the pacemaker may stimulate the heart to beat at a faster rate (often subject to an upper rate limit) than when the patient is at rest. While the accelerometer signal is used internally to control the heart rate, this signal is not transmitted by the pacemaker to an external programmer for subsequent display on a display device. Thus, the accelerometer signal itself is an internal signal which is not output to the user.

[0005] A common method of diagnosing heart problems involves comparing the electrical operation of the heart to its mechanical operation, and identifying electrical-mechanical disassociation. Typically, a physician listens to a patient's heart using a stethoscope placed on the surface of the patient's body, and compares the heart sounds to an electrocardiograph (ECG) trace generated by an ECG machine coupled to probes placed on the patient's chest. This method suffers from several disadvantages, including the need to use the stethoscope, the effect of various factors (e.g., the placement of the stethoscope, body fat, etc.) on the heart sounds, the need to electrically couple ECG probes to the patient's chest, the difficulties faced by the physician in accurately comparing the sounds heard using the stethoscope to the traces displayed by the ECG machine, and the relatively high level of skill needed to perform this comparison (especially if a physician is not available). This method also does not continuously monitor for electrical-mechanical disassociation, thus making it difficult to detect disassociation occurring between visits to the physician, and does not provide the ability to produce a written record showing a detected disassociation.

[0006] Thus, it would be desirable to provide a method and apparatus for outputting heart sounds, and/or for comparing electrical operation of the heart to mechanical operation of the heart, that overcome one or more of the above-described disadvantages.

SUMMARY OF THE INVENTION

[0007] According to one aspect of the invention, an implantable system includes a sensor for detecting heart sounds and generating sensed signals representative thereof, an interface circuit for communicating with an external system, and a control circuit coupled to the sensor and the interface circuit. The control circuit receives the sensed signals, generates data representative of the heart sounds therefrom, and transmits the data to the external system via the interface circuit. The sensor, interface circuit and control circuit are implantable. In another aspect, an implantable system also includes a second sensor for detecting cardiac electrical signals and generating second sensed signals representative thereof, and the control circuit also receives the second sensed signals, generates second data representative of the cardiac electrical signals therefrom, and transmits the second data to the external system. In another aspect, an implantable system also includes a third implantable sensor for detecting second cardiac electrical signals and generating third sensed signals representative thereof, and the control circuit receives the third sensed signals, generates third data representative of the second cardiac electrical signals therefrom, and transmits the third data to the external system.

[0008] According to another aspect, an external system includes an interface circuit to communicate with an implanted system, an output device, and a control circuit coupled to the interface circuit and output device. The control circuit receives data representing heart sounds detected by the implanted system, and generates control signals that, when applied to the output device, cause the output device to generate outputs which represent the heart sounds. In another aspect, a control circuit also receives data representing cardiac electrical signals from the implanted system, and generates control signals to cause the output device to generate outputs representing the heart sounds and cardiac electrical signals. In another aspect, a control circuit receives data representing second cardiac electrical signals from the implanted system, and causes the output device to generate outputs representing the heart sounds and the two cardiac electrical signals.

[0009] According to another aspect, a method of outputting heart sounds includes detecting heart sounds using an implanted sensor, and transmitting data representing the heart sounds to an external system. In another aspect, a method also includes detecting cardiac electrical signals using an implanted sensor and transmitting data representing the cardiac electrical signals to an external device. In another aspect, a method also includes detecting second cardiac electrical signals using an implanted sensor, and also transmitting data representing the second cardiac electrical signals to an external device.

[0010] According to another aspect, a method of outputting heart sounds includes receiving data representing heart sounds detected by an implanted system, generating control

signals using the data, and applying the control signals to an output device to cause the output device to generate outputs which represent the heart sounds. In another aspect, a method also includes receiving second data representing cardiac electrical signals from the implanted system, and generating the control signals using the second data to cause the outputs generated by the output device to represent the cardiac signals. In another aspect, a method also includes receiving third data representing second cardiac electrical signals from the implanted system, and generating the control signals using the third data to cause the outputs to also represent the second cardiac signals.

[0011] Other aspects of the present invention will be apparent upon reading the following detailed description of the invention and viewing the drawings that form a part thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is a block diagram of an exemplary system for detecting heart sounds using an implanted sensor, transmitting data representing the heart sounds to an external system, and outputting the heart sound data, according to one embodiment of the invention;

[0013] FIG. **2** is a flow chart illustrating one embodiment of the processing performed by the controller of the implantable device shown in FIG. **1**;

[0014] FIG. **3** is a flow chart illustrating one embodiment of the processing performed by the controller of the external device shown in FIG. **1**;

[0015] FIG. **4** is a block diagram illustrating one embodiment of the signal processing performed on the heart sound signals detected by the exemplary system shown in FIG. **1**;

[0016] FIG. **5** is an exemplary output display screen that is generated by the external device shown in FIG. **1**;

[0017] FIG. **6** is another exemplary output display screen that is generated by the external device shown in FIG. **1**;

[0018] FIG. **7** is a flow chart showing another embodiment of the processing performed by the controller of the implantable device shown in FIG. **1**, including a logbook feature; and

[0019] FIG. **8** is a block diagram of another exemplary system for outputting heart sounds.

DETAILED DESCRIPTION

[0020] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific embodiments in which the present invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the present invention, and it is to be understood that the embodiments may be combined, or that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the spirit and the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

[0021] Referring to FIG. **1**, an exemplary system **100** for outputting heart sounds in accordance with one embodiment of the present invention comprises an implantable system **102** and an external system **104**. Implantable system **102** and external system **104** are configured to communicate via a communications link **106**. In one embodiment, link **106** uses radio-frequency (RF) signals. In another embodiment, link **106** uses optical signals. These communications may support monitoring, diagnostic and configuration functions.

[0022] Implantable system **102** includes an implantable device **108** operatively coupled to a patient's heart **110** by a pacing lead **112**. The components of implantable device **108** include an atrial sense amplifier **114**, a ventricular sense amplifier **116**, an atrial stimulating circuit **118**, a ventricular stimulating circuit **120**, a controller **122**, a memory **124**, an accelerometer **126**, an analog pre-processing circuit **128**, an analog-to-digital (A/D) converter **130**, and an input/output (I/O) interface **132**. The components of implantable device **108** are housed within an implantable housing (indicated by the broken lined box in FIG. **1**.) which is implanted within the patient's chest cavity (e.g., in the pectoral region).

[0023] Atrial sense amplifier **114**, ventricular sense amplifier **116**, atrial stimulating circuit **118** and ventricular stimulating circuit **120** are operatively coupled to pacing lead **112** via a pair of conductors **134**. Pacing lead **112** includes an atrial sensing electrode **136** and an atrial stimulating electrode **138** adapted to be disposed in the right atrial chamber of heart **110**, and a ventricular sensing electrode **140** and a ventricular stimulating electrode **142** adapted to be disposed in the right ventricular chamber of heart **110**. Sensed atrial and ventricular electrical signals generated by sensing electrodes **136** and **140** are applied to atrial and ventricular sense amplifiers **114** and **116**, respectively, and atrial and ventricular stimulating signals generated by atrial and ventricular stimulating circuits **118** and **120** are applied to atrial and ventricular stimulating electrodes **138** and **142**, respectively. Atrial sense amplifier **114**, ventricular sense amplifier **116**, atrial stimulating circuit **118**, and ventricular stimulating circuit **120**, are each also operatively coupled to controller **122**.

[0024] In other embodiments, other sensing electrode configurations are used for internally sensing one or more electrical signals of heart **110**. In one example, only one of sensing electrodes **136** and **140** is used. In another example, one or more electrodes placed within the body but outside of heart **110** are used for generating sensed cardiac electrical signals. In yet another example, a sensing electrode is placed within the implantable housing. In each of these examples, the sensing electrodes are operatively coupled to controller **122**.

[0025] In the embodiment shown in FIG. **1**, the sensing electrodes **136** and **140** and the stimulating electrodes **138** and **142** are disposed in the right side of heart **110**. In other embodiments, one or more sensing electrode(s) and one or more stimulating electrode(s) are disposed in the left side of the heart (in lieu of being disposed in the right side of the heart, or in addition to sensing electrode(s) and stimulating electrode(s) disposed in the right side of the heart). The addition of left heart sensing may advantageously allow for the resolution of ambiguities due to disassociation of right and left heart conduction.

[0026] Controller **122** includes a micro-controller or microprocessor which is configured to execute a program stored in a read-only memory (ROM) portion of memory **124**, and to read and write data to and from a random access memory (RAM) portion of memory **124**. By executing the program stored in memory **124**, controller **122** is configured to process the atrial and ventricular electrical signals from atrial and ventricular sense amplifiers **114** and **116**, and to provide control signals to atrial and ventricular stimulating circuits **118** and **120**. In response, stimulating circuits **118** and **120** provide stimulating pulses to heart **110** via atrial and ventricular stimulating electrodes **138** and **142** at appropriate times. In

other embodiments, controller **122** may include other types of control logic elements or circuitry.

[0027] Implantable device **108** may be referred to as a dual-chamber pacemaker since pacemaking functions are provided to both atrial and ventricular chambers of heart **110**. In another embodiment, the implantable system includes a single-chamber pacemaker that senses electrical signals and provides stimulating pulses to a single chamber of heart **110**. In yet another embodiment, the implantable system does not provide any stimulation of heart tissues, but includes one or more sensing electrodes for sensing one or more electrical signals of heart **110**, and for providing corresponding sensed signals to controller **122**. In still another embodiment, the implantable system does not provide any sensing electrodes for sensing any cardiac electrical signals, but is configured to sense and transmit signals representing heart sounds using a sensor such as accelerometer **126**, as described below.

[0028] In the remainder of this description, implantable device **108** is described as a dual-chamber pacemaker since the present system may be used with patients who have already had a pacemaker implanted in their bodies, thereby alleviating the need to implant a device solely for the purpose of monitoring heart sounds and/or intra-cardial electrical signals. It is to be understood, however, that implantable system **102** need not provide the stimulation functions described herein, and may provide other functions which are not described herein.

[0029] Accelerometer **126** is configured to provide sensed signals to analog pre-processing circuit **128**, which generates an analog output signal which is digitized by A/D converter **130**. The digitized accelerometer signal is received by controller **122**. In the embodiment of FIG. **1**, accelerometer **126** is located internally to the housing of implantable device **108**. In another embodiment, accelerometer **126** is located externally to the implantable housing. Accelerometer **126** may include, for example, a piezo-electric crystal accelerometer sensor of the type used by pacemakers to sense the level of activity of the patient, or may include other types of accelerometers that are packaged to fit in the implantable housing. To detect heart sounds, other types of sound-detecting sensors or microphones may also be used, such as pressure sensors or vibration sensors configured to respond to sounds made by the heart.

[0030] In another embodiment, system **100** includes a plurality (two or more) of sound-detecting sensors. In this embodiment, the plurality of sensed heart sound signals from the plurality of sensors may be individually transmitted to external system **104** for display as individual traces, may be combined (e.g., averaged) by external system **104** before being displayed as a single trace, or may be combined by controller **122** before being transmitted to external system **104** as a single heart sound signal. These sensors may include different types of sensors, sensors that are located in different locations, or sensors that generate sensed signals which receive different forms of signal processing.

[0031] In one embodiment, accelerometer **126** is configured to generate sensed signals representative of two distinct physical parameters: (1) the level of activity of the patient; and (2) the heart sounds generated by heart **110**. Accordingly, analog pre-processing circuit **128** is configured to pre-process the sensed signals from accelerometer **126** in a manner which conforms to the signal characteristics of both of these physical parameters. For example, if the frequencies of interest for measuring the patient's level of activity are below 10 Hz, while the frequencies of interest for detecting heart sounds are between 0.05 Hz and 50 Hz, then analog pre-processing circuit **128** may include a low-pass filter having a cutoff frequency of 50 Hz. Controller **122** may then perform additional filtering in software using, for example, a low-pass filter with a cutoff frequency of 10 Hz to detect the level of activity of the patient, and a band-pass filter with cutoff frequencies of 0.05 Hz and 50 Hz to detect the heart sounds, although these signal processing functions could also be performed by external system **104**. Along with filtering, analog pre-processing circuit **128** may perform other processing functions including automatic gain control (AGC) functions.

[0032] In another embodiment, implantable device **108** has two pre-processing channels for receiving sensed signals from accelerometer **126**. In still another embodiment, implantable device **108** includes two accelerometers, with one accelerometer configured to generate sensed signals representative of the level of activity of the patient and the other accelerometer configured to generate sensed signals representative of heart sounds. In these latter two embodiments, any hardware and/or software processing performed on the sensed signals can conform to the specific characteristics of the respective sensed signals. For example, the analog pre-processing circuit used for the level-of-activity sensed signals can provide a low-pass filter with a cutoff frequency of 10 Hz, while the analog pre-processing circuit for the heart-sound sensed signals can provide a band-pass filter with cutoff frequencies of 0.05 and 50 Hz. In the latter case, each accelerometer can be selected, located and/or oriented to maximize the detection of the respective physical parameter. In yet another embodiment, if the implantable device does not need to sense the level of activity of the patient, accelerometer **126** may measure only the sounds made by heart **110**.

[0033] Controller **122** is capable of bi-directional communications with external system **104** via I/O interface **132**. In one embodiment, I/O interface **132** communicates using RF signals. In other embodiments, I/O interface **132** communicates using optical signals, or a combination of RF and optical signals (e.g., RF signals for receiving data from external system **104** and optical signals for transmitting data to external system **104**, or vice-versa). Controller **122** uses I/O interface **132** for bi-directional communications with external system **104** to support conventional monitoring, diagnostic and configuration pacemaker functions. Controller **122** also uses I/O interface **132** to telemeter data representative of the heart sounds sensed by accelerometer **126** to external system **104**. In various embodiments, controller **122** further uses I/O interface **132** to telemeter data representative of cardiac electrical signals (i.e., electrogram or EGM signals), which may include data representative of atrial electrical signals (i.e., A EGM signals) sensed by atrial sensing electrode **136**, and/or data representative of ventricular electrical signals (i.e., V EGM signals) sensed by ventricular sensing electrode **140**. Thus, implantable system **102** is capable of sensing heart sounds, atrial electrical signals and ventricular electrical signals, and of telemetering data representative of the heart sounds and/or cardiac electrical signals to external system **104**. In other embodiments, controller **122** telemeters data representative of cardiac electrical signals which were sensed by other configurations of internal cardiac sensing electrodes.

[0034] In one embodiment, external system **104** includes an external device **142** and a surface electrocardiograph (ECG) system **144**. External device **142** includes an external controller **146**, an I/O interface **148**, user input device(s) **150**, and

user output device(s) **152**. Using I/O interface **148**, external controller **146** is configured for bi-directional communications with implantable device **108**, for receiving input signals from input device(s) **150**, and for applying control signals to output device(s) **152**. Input device(s) **150** include at least one input device which allows a user (e.g., a physician, nurse, medical technician, etc.) to generate input signals to control the operation of external device **142**, such as at least one user-actuatable switch, knob, keyboard, pointing device (e.g., mouse), touch-screen, voice-recognition circuit, etc. Output device(s) **152** include at least one display device (e.g., CRT, flat-panel display, etc.), audio device (e.g., speaker, headphone), or other output device which generates user-perceivable outputs (e.g., visual displays, sounds, etc.) in response to control signals. External controller **146** is configured to receive the data representative of heart sounds, atrial electrical signals and/or ventricular electrical signals from implantable system **102**, and to generate control signals that, when applied to output device(s) **152**, cause the output device(s) to generate outputs that are representative of the heart sounds, the atrial electrical signals and/or the ventricular electrical signals.

[0035] Surface ECG system **144** includes electrodes adapted to be electrically coupled to the surface of the patient's chest for sensing cardiac electrical signals, and is configured to produce ECG output signals which are coupled to I/O interface circuit **148**. External controller **146** is configured to receive the ECG signals from I/O interface circuit **148**, and to generate control signals which, when applied to output device(s) **152**, cause the output device(s) to also generate outputs representative of the patient's ECG. Alternatively, in other embodiments, surface ECG electrodes are coupled directly to external device **142**, rather than being supplied by a surface ECG system. In another embodiment, external device **142** does not receive surface ECG signals, and does not output such ECG signals. (Note: "ECG" is used herein to refer to cardiac electrical signals measured from the surface of the body, and "EGM" is used to refer to internally-measured cardiac electrical signals.)

[0036] In one embodiment, external device **142** comprises an external programming device for a cardiac pacemaker, such as the ZOOM™ external programmer available from the Guidant Corporation, except that the external programmer is configured (i.e., programmed or otherwise set up) to perform the various functions described in the present application.

[0037] In one embodiment, system **100** further includes a remote system **154** operatively coupled to communicate with external system **104** via transmission media **156**. Remote system **154** includes one or more user input device(s) **158**, and one or more user output device(s) **160**, which allow a remote user to interact with remote system **154**. Transmission media **156** includes, for example, a telephone line, electrical or optical cable, RF interface, satellite link, local area network (LAN), wide area network (WAN) such as the Internet, etc. Remote system **154** cooperates with external system **104** to allow a user located at a remote location to perform any of the diagnostic or monitoring functions that may be performed by a user located at external system **104**. For example, data representative of heart sounds and/or cardiac electrical signals are communicated by external system **104** to remote system **154** via transmission media **156** to provide a visual display and/or an audio output on output device(s) **160**, thereby allowing a physician at the remote location to aid in the diagnosis of a patient. System **154** is "remote" in the sense that a user of remote system **154** is not physically capable of actuating input device(s) **150** and/or of directly perceiving outputs generated by output device(s) **152**. For example, system **154** may be located in another room, another floor, another building, another city or other geographic entity, across a body of water, at another altitude, etc., from external system **104**.

[0038] Referring to FIG. **2**, in one embodiment, the processing **200** performed by controller **122** of implantable device **108** includes detecting heart sounds by receiving sensed signals representative of the heart sounds from accelerometer **126** (at **202**), detecting atrial electrical signals by receiving sensed signals representative of the atrial electrical signals from atrial sensing electrode **136** (at **204**), detecting ventricular electrical signals by receiving sensed signals representative of the ventricular electrical signals from ventricular sensing electrode **140** (at **206**), and transmitting data representative of the heart sounds, atrial electrical signals, and ventricular electrical signals to external device **142** (at **208**).

[0039] In another embodiment, processing **200** further includes signal processing the accelerometer, atrial and ventricular sensed signals to generate processed sensed signals (between **206** and **208**), and then transmitting the processed sensed signals to external device **142** (at **208**). The signal processing may also be performed on only one or two of these sensed signals. However, performing the signal processing in implantable device **108** (rather than in external device **142**, as described below relative to FIG. **3**) may increase the computational requirements for implantable device **108**, and may also increase the transmission load between devices **108** and **142**. It is to be understood that the division of signal processing between implantable device **108** and external device **142** could be modified from that disclosed herein, as would be apparent to a person of skill in the art.

[0040] In another embodiment, processing **200** also includes storing one or more of the raw or processed sensed signals in memory **124** for later retrieval by external device **142**. In still another embodiment, the processing performed by controller **122** does not include detecting the atrial electrical signals (at **204**) and/or the ventricular electrical signals (at **206**), in which case the corresponding EGM data is not transmitted to external device **142** (at **208**). In yet another embodiment, the processing performed by controller **122** includes detecting other cardiac electrical signals sensed by other cardiac electrical signal sensors, and transmitting data representative of these other cardiac signals to external device **142**.

[0041] Referring to FIG. **3**, in one embodiment, the processing **300** performed by external controller **146** of external device **142** includes receiving the data representative of the heart sounds, atrial electrical signals and ventricular electrical signals from implantable device **108** (at **302**), receiving surface ECG data from surface ECG system **144** or directly from surface ECG leads (at **304**), processing the accelerometer, atrial electrical signals, ventricular electrical signals and surface ECG data (at **306**), and generating output control signals to simultaneously output the raw and/or processed accelerometer, atrial electrical signals, ventricular electrical signals, and surface ECG signals on output device(s) **152** (at **308**). Processing **300** may also include receiving timing comparison command signals from input device(s) **150** (at **310**), and generating control signals to output timing comparison information on output device(s) **152** (at **312**). Processing **300** may

also include storing one or more of the raw or processed sensed signals in memory for later analysis.

[0042] In other embodiments, the processing performed by external controller **146** does not include receiving the atrial and/or ventricular electrical signals (at **302**), or receiving surface ECG data (at **304**), in which case the corresponding EGM data or surface ECG data is not processed (at **306**) or output (at **308**). Further, it is contemplated that external controller **146** may not perform any processing of the accelerometer, atrial electrical signals and/or ventricular electrical signals (at **306**), and may instead receive corresponding processed data (rather than raw data) from implantable device **108**. The processing of these signals (at **306**) is illustrated in FIG. **3**, however, to indicate that the processing described below in relation to FIG. **4** may well be performed by external device **142** rather than implantable device **108**, thereby reducing the computational requirements for implantable device **108**.

[0043] Referring to FIG. **4**, the signal processing **400** performed on the heart sound data by external controller **146** in accordance with one embodiment of the invention is shown. In other embodiments, some or all of this signal processing could instead be performed by controller **122** of implantable device **108**, or by either external or implantable hardware. Signal processing **400** includes a first processing path **402** used for machine detection of heart sounds, and a second processing path **404** used for visual display of heart sounds. Alternatively, only one of heart sound signal processing paths **402** and **404** is provided.

[0044] First processing path **402** includes a band-pass filter **406**, a rectifier **408**, a low-pass filter **410**, and an ensemble averager **412**, coupled in series. Raw accelerometer data **414** (representative of the heart sounds) is applied to band-pass filter **406**, which has lower and upper cutoff frequencies set to pass frequencies indicative of heart sounds, to produce band-pass filtered data **416**. In one example, the lower and upper cutoff frequencies are 0.05 Hz and 50 Hz, respectively. The cutoff frequencies are also set to reject frequencies due to movement of the patient (e.g., walking around, muscle twitches, etc.) to the extent that the heart sound signals still pass. Band-pass filtered data **416** is then applied to rectifier **408** to produce rectified data **418** that is, in turn, applied to low-pass filter **410** to produce filtered data **420**. In one example, the cutoff frequency for low-pass filter **410** is 10 Hz.

[0045] Filtered data **420** is applied to ensemble averager **412** to produce processed accelerometer data **422**, which is used for machine detection of heart sounds. Ensemble averager **412** is triggered by an output **424** of a systole detector **426**, which is asserted to open a window of interest when the start of a cardiac cycle is detected based upon the electrical systole (which may be detected using the A EGM, V EGM and/or surface ECG signals). Ensemble averager **412** causes the repetitive heart sound data to be averaged over a number of cardiac cycles to accentuate the heart sounds (which are correlated to a particular frequency) while filtering out random or spurious noise (which are not correlated to a particular frequency). For example, ensemble averager **412** may average sequential heart sounds over a period of between 2 and 128 cardiac cycles, although other periods may also be used. In other embodiments, heart sounds are sequentially averaged over a period of time (e.g., one minute), or over the course of an event or condition (e.g., while the patient is performing an exercise), in which case only completed cardiac cycles will be averaged. Note that signal averaging the heart sound data includes the superposition and the summation of successive temporal samples of the pulsatile heart sound waveform.

[0046] Second processing path **404** includes a band-pass filter **428** and an ensemble averager **430**, coupled in series. Raw accelerometer data **414** (representative of the heart sounds) is applied to band-pass filter **428**, which has lower and upper cutoff frequencies set to pass frequencies indicative of heart sounds, to produce band-pass filtered data **432**. In one example, the lower and upper cutoff frequencies are 0.05 Hz and 50 Hz, respectively. The cutoff frequencies are also set to reject frequencies due to patient movement to the extent that the heart sound signals still pass. Band-pass filtered data **432** is then applied to ensemble averager **430** to produce processed accelerometer data **434**, which is used for visual display of heart sounds. Ensemble averager **430** is triggered by output **424** of systole detector **426**, which is asserted to open a window of interest when the start of a cardiac cycle is detected based upon the electrical systole. Ensemble averager **430** causes the heart sound data to be averaged over a number of cardiac cycles (e.g., between 2 and 128 cardiac cycles, or other range) to accentuate the heart sounds while filtering out random or spurious noise. By eliminating the rectifier and low-pass filter of processing path **402**, processing path **404** avoids eliminating information from the visual display of the heart sound data which may be useful to a physician, nurse, medical technician or other user of system **100**.

[0047] In one embodiment, ensemble averager **430** includes logic to reject data from cardiac cycles outside the range of normal as such cycles may be of non-physiologic origin (e.g., PVC's). However, in the case of frequent PVC's, the PVC interval may become the norm. Thus, this logic may be adaptive so as to include such PVC's.

[0048] The signal processing for the heart sound data illustrated in FIG. **4** is merely exemplary, and other types of signal processing may be used. For example, the cutoff frequencies described above for the band-pass and low-pass filters may be varied, one or both of these filters may be eliminated, or other filters may be added. In one embodiment, the raw accelerometer data could be applied directly to an ensemble averager.

[0049] Referring to FIG. **5**, an exemplary output screen display **500** generated by external device **142** on an output device **152** is shown. In this example, it is assumed implantable system **102** includes accelerometer **126**, atrial sensing electrode **136**, and ventricular sensing electrode **140**, and that implantable system **102** transmits the raw sensed signals from each of these sensors to external device **142**. It is also assumed that external device **142** generates display control signals that are output to a display to generate these outputs.

[0050] Output screen display **500** includes multiple horizontal traces, including a surface ECG trace **502**, a raw accelerometer trace **504**, a processed accelerometer trace **506**, an atrial electrical signal ("A EGM") trace **508**, and a ventricular electrical signal ("V EGM") trace **510**. Alternatively, one or more of traces **502-510** may not be displayed. For example, since raw accelerometer trace **504** includes a relatively large amount of noise, this trace may not be displayed since it may not be easily interpreted by a user. Thus, display **500** simultaneously shows a visual trace of all five of these signals, which may be used by a user (e.g., a physician) to diagnose an electrical/mechanical disassociation of heart **110**. Note that, if it is desirable for a user at a remote location to aid in the diagnosis of heart **110**, the data representative of the heart

sounds and electrical signals may be communicated by external device **142** to remote system **154** for display on one of output device(s) **160**.

[0051] In one embodiment, display **500** includes one or more traces for displaying one or more cardiac electrical signals that were sensed from the left side of the heart, such as an "LV EGM" signal sensed by a sensing electrode disposed in the left ventricle.

[0052] In one embodiment, to help the user determine timing relationships between the signals shown in FIG. **5**, external system **142** (and/or remote system **154**) generates timing comparison control signals which, when applied to the display device, cause the display device to output timing comparison information indicating timing between the displayed signals. For example, system **142** (and/or system **154**) may generate control signals which cause the display device to display a pair of vertical lines or calipers **512**A and **512**B, which can be moved horizontally by the user via a pair of input devices **150** (or input devices **158**), with each input device controlling the position of one caliper. The calipers can help the user to compare timing between any of the displayed signals. To further aid the user, external system **142** (and/or remote system **154**) may cause the display device to display a visual indicia **160** indicating the time period between the calipers. For example, indicia **160** indicates that the distance between calipers **512**A and **512**B represents 50 msec.

[0053] In one embodiment, to further aid the user in interpreting the display, heart sound data is automatically processed to identify one or more heart sounds, and visual indicia indicative of the identified sounds are also displayed on display **500**. For example, external controller **146** may automatically process the sensed accelerometer data (e.g., processed accelerometer data **422**) to detect the S1 and S2 heart sounds (and possibly the S3 heart sound), and to generate the display control signals so as to cause visual indicia (e.g., "S1" and "S2") to be displayed in association with the locations of the heart sounds on processed accelerometer trace **506** (or on raw accelerometer trace **504**), as in FIG. **5**. The S1 heart sound is associated with the closure of the AV valve and opening of the aortic valve in the heart, the S2 heart sound is associated with the subsequent closure of the aortic valve, and the S3 heart sound (less pronounced than the S1 and S2 sounds) is associated with the end of the heart's fast-filling phase during diastole. An exemplary method for automatically processing accelerometer signals to detect S1, S2 and S3 heart sounds is disclosed in U.S. Pat. No. 5,792,195, issued to Carlson et al. on Aug. 11, 1998, and incorporated by reference herein in its entirety. The heart sound indicia may help users to quickly and accurately identify these sounds, and may be especially helpful to less experienced users.

[0054] In one embodiment, to provide still additional aid to the user, the intra-cardiac EGM and/or surface ECG data may be automatically processed to identify one or more electrical cardiac events, and visual indicia indicative of the identified events may be displayed on display **500**. For example, external controller **146** may be configured to automatically process the sensed atrial electrical data, ventricular electrical data, and/or surface ECG data to identify the P waves, QRS complexes, T waves, U waves, or other electrical cardiac events, and to generate the display control signals so as to cause visual indicia (e.g., "P", "QRS", "T", "U", etc.) to be displayed in association with the locations of the corresponding events on A EGM trace **508**, V EGM trace **510**, and/or surface ECG trace **502**. The electrical cardiac event indicia may help users to quickly and accurately identify the electrical cardiac events, and may be especially helpful to less experienced users. External controller **146** may also provide additional processing (e.g., filtering) of the A EGM, V EGM and/or surface ECG signal to further delineate the events of interest (e.g., by low-pass filtering these signals to eliminate everything but the higher signal peaks).

[0055] To provide the user with additional operational control, the generation of the heart sound indicia and/or electrical cardiac event indicia on display **500** may be controlled by one or more of input devices **150** (or input devices **158**). For example, a first input device (e.g., a switch) may be provided to allow the user to turn the heart sound indicia on or off, and a second input device may be provided to turn the electrical event indicia on or off.

[0056] In other embodiments, external device **142** performs additional processing to aid the user in interpreting display **500**. For example, in one embodiment, external device **142** automatically calculates timing differences (e.g., electrical-to-mechanical time delay) for each heart beat, and outputs (e.g., lists, plots, etc.) the timing differences on a beat-to-beat basis. The user can examine the outputs to determine how the electrical-to-mechanical time delay changes over time (e.g., over a number of heart beats). In situations where electrical-to-mechanical disassociation occurs only in limited circumstances (e.g., when the patient is exercising), showing such timing differences over time may be useful to a physician.

[0057] In another embodiment, external controller **146** calculates and displays timing differences between automatically detected cardiac events, such as between automatically detected heart sounds, between automatically detected heart sounds and electrical cardiac events, between automatically detected electrical cardiac events, etc. For example, external controller **146** may calculate timing differences between the S1 and S2 heart sounds, between the QRS complex and S1 heart sound, or between the P wave and QRS complex, and then generate output control signals to cause visual indicia indicative of these timing differences (e.g., "n msec") to be displayed on display **500**. In one embodiment, the timing differences that are displayed on display **500** are selected by the user based upon input signals generated by user input device(s) **150** (or input device(s) **158**). In one example, a user employs a mouse to select a particular timing interval from a pull-down list of timing intervals that he or she would like to see calculated and displayed on display **500**.

[0058] In one embodiment, one or more of output devices **152** (or output devices **160**) comprises an audio device for generating audio outputs representative of the heart sounds. For example, raw accelerometer data **414** may be applied to a speaker to allow the user to hear and identify heart abnormalities. Alternatively, processed accelerometer data, such as processed accelerometer data **422** or **434**, may be applied to an audio device to allow the user to hear and identify heart abnormalities. Other types of processed accelerometer data, including filtered and signal-averaged accelerometer data, may also be applied to an audio device to allow the user to hear and identify heart abnormalities. In each case, the user is presented with the heart sounds in the audio domain, which may more familiar to a physician or other user who is used to listening to heart sounds using a stethoscope. In each case, the user may also be presented with any or all of the traces shown in FIG. **5**, such that the user may receive cardiac information in both the visual and the audio domains.

[0059] Referring to FIG. **6**, another exemplary output screen display **600** generated by external device **142** on an output device **152** is shown. In this example, it is again assumed that implantable system **102** includes accelerometer **126**, atrial sensing electrode **136**, and ventricular sensing electrode **140**, that implantable system **102** transmits the raw sensed signals from each of these sensors to external device **142**, and that external device **142** generates display control signals that are output to a display to generate these outputs. The displayed traces include a processed accelerometer trace **602**, an atrial electrical signal ("A EGM") trace **604**, and a ventricular electrical signal ("V EGM") trace **606**. Other traces, such as a surface ECG trace and/or a raw accelerometer trace, could also be displayed.

[0060] In this embodiment, to help the user determine timing relationships between the traces shown in FIG. **6**, external device **142** (and/or remote system **154**) is configured to generate timing comparison control signals which cause the display device to vertically move one or more of the traces under the control of the user via one or more of input devices **150** (or input devices **158**). For example, each input device may control the vertical position of one trace. By vertically moving one or more of the traces, the user can superimpose the traces over one another to show timing comparisons. For example, as illustrated by the dashed lines in FIG. **6**, the user has used an input device **150** to move A EGM trace **604** upward to superimpose this trace over processed accelerometer trace **602**. By doing so, timing comparisons between traces **602** and **604** become readily apparent. Thus, in this embodiment, visual outputs of heart sounds may be superimposed over visual outputs of cardiac electrical signals to show timing comparisons therebetween. Note that, since display **600** does not indicate which superimposed signal was moved "over" another, superimposing trace A "over" trace B is the same as superimposing trace B "over" trace A.

[0061] Referring to FIG. **7**, in another embodiment, implantable device **108** includes an arrhythmia logbook feature. With this feature, if an arrhythmia (e.g., an abnormally fast heart rate) is detected, implantable device **108** records data in memory for later examination by a physician for use in making a diagnosis. Implantable device **108** may, for example, continually record 10 seconds of data in an area of memory **124**, and may simply rewrite over that area of memory. If, however, an arrhythmia is detected (e.g., the V EGM signal indicates that heart **110** is beating at an abnormally high rate of 180 beats/minute), the 10 seconds of recorded data is saved in another area of memory **124**, along with an additional 20 seconds of data recorded after the arrhythmia. Other arrhythmia events may also be logged. Then, on the next visit of the patient to a doctor, the doctor can use external device **142** to read the data from the logbook, and can examine the data to look for arrhythmia events. For example, the logbook may indicate that, in the three months since the patient was last seen, heart **110** experienced five episodes of fast atrial heart beat, three atrial flutters, and one ventricular fibrillation. The data recorded by implantable device **108** in association with each arrhythmia event may include heart rate data, A EGM data, V EGM data and, in accordance with the present system, raw and/or processed heart sound data.

[0062] To provide the arrhythmia logbook feature, in one embodiment, controller **122** of implantable device **108** performs the processing **700** shown in FIG. **7**. In particular, controller **122** detects heart sounds by receiving sensed signals representative of the heart sounds from accelerometer **126** (at **702**), detects atrial electrical signals by receiving sensed signals representative of the atrial electrical signals from atrial sensing electrode **136** (at **704**), detects ventricular electrical signals by receiving sensed signals representative of the ventricular electrical signals from ventricular sensing electrode **140** (at **706**), and stores the accelerometer, atrial EGM and ventricular EGM data in memory **124** (at **708**). In one embodiment, controller **122** continually stores 10 seconds of such data (along with other desired data, such as heart rate data) in a particular area of memory **124**. If controller **122** determines that an arrhythmia has not occurred (at **712**) and that no arrhythmia logbook playback request has been received from external device **142** (at **714**), controller **122** loops back (to **702**), and repeats these operations. As new data is collected and stored in memory **124**, the oldest data is re-written by the new data such that the particular area of memory always stores the last 10 seconds of data. If an arrhythmia is detected (at **712**), however, controller **122** creates a record in another area of memory (i.e., the arrhythmia logbook), and copies the last 10 seconds of data into that record. Then, for the next 20 seconds, controller **122** continues to monitor data, and stores this data within that same record. Thus, for each detected arrhythmia, controller **122** creates a record in memory **124** that contains data for the 10 seconds leading up to the arrhythmia, and the 20 seconds after the arrhythmia. In other embodiments, less than or more than this amount of data is stored either before or after each arrhythmia occurs. Then, when controller **122** determines that an arrhythmia logbook playback command is received from external device **142**, controller **122** transmits the records from memory **124** to external device **142**. External device **142** then outputs the data from these records to output device(s) **152** (or output device(s) **160**). The physician can then examine the recorded data for each arrhythmia to aid in making a diagnosis. Thus, by using the arrhythmia logbook feature of the system, the physician is provided with heart sound information from both before and after the arrhythmia.

[0063] In one embodiment, system **100** may provide more sophisticated signal processing in cases of cardiac arrhythmia. For example, in the case of bigeminy, system **100** may be configured to use two averaging processes in order that like events are averaged separately. Exemplary signal processing techniques that could be employed by system **100** include, for example, those described in U.S. Pat. Nos. 4,799,493, 4,799,486, 4,793,361 and 4,721,114. In another embodiment, implantable device **108** may be configured to detect heart murmurs or extra heart sounds, to count such extra heart sounds, and to transmit such counts to external device **142** for output on one of output device(s) **150** (or devices **160**).

[0064] Referring to FIG. **8**, an exemplary system **800** for outputting heart sounds according to another embodiment comprises an implantable device **802** coupled to a patient's heart (not shown) by a pacing lead **804** and one or more heart electrode(s) **806**, and operatively coupled to an external device (not shown) via a communications link **808**. In one embodiment, heart electrode(s) **806** includes an atrial sensing electrode, ventricular sensing electrode, atrial stimulating electrode and ventricular stimulating electrode as in FIG. **1**.

[0065] Implantable device **802** includes one or more cardiac sense amplifier(s) **810** and one or more cardiac stimulating circuit(s) **812** operatively coupled to heart electrode(s) **806** via lead **804**. In another embodiment, where device **802** does not provide heart stimulation, device **802** does not

include cardiac stimulating circuit(s) **812**. Device **802** also includes a controller **814**, a memory **816** operatively coupled to controller **814**, an activity level detecting path **818**, a heart sound detecting path **820**, a systole detector **822**, and an I/O interface **824**. Activity level detecting path **818** includes an activity level sensor **826** for sensing patient activity, an analog pre-processing circuit **828** for pre-processing signals generated by activity level sensor **826**, an A/D converter **830** for digitizing the activity level signals, and an activity level filter **832** for filtering the digitized signals to eliminate sources of noise such as those caused by heart sounds. Heart sound detecting path **820** includes a heart sound sensor **834** for sensing heart sounds, an analog pre-processing circuit **836** for pre-processing signals generated by heart sound sensor **834**, A/D converter **830** for digitizing the heart sound signals (e.g., using a different channel than the channel used for the activity level signals), a heart sound filter **838** for filtering the digitized signals to eliminate sources of noise such as those caused by patient activity, an S1 heart sound detector **840** for detecting the S1 heart sound, an S2 heart sound detector **842** for detecting the S2 heart sound, and an S3 heart sound detector **844** for detecting the S3 heart sound. Controller **814** transmits data representing the patient's activity level and the S1, S2 and S3 heart sounds to the external device via I/O interface **824**. Where S1, S2 and S3 heart sound detectors **840**, **842** and **844** ensemble average the heart sound signals, controller **814** provides an output signal indicative of the start of a cardiac cycle from systole detector **822** to heart sound detectors **840**, **842** and **844** for use as a trigger. In one embodiment, the outputs from S1, S2 and S3 heart sound detectors **840-844** comprise a sequence of pulses, each pulse representing a detected heart sound. The external device receives the heart sound and cardiac electrical signal data via link **808**, and simultaneously outputs this data.

[0066] In one embodiment, activity level filter **832**, heart sounds filter **838**, heart sound detectors **840-844** and systole detector **822** are implemented by controller **814** through appropriate programming commands. In another embodiment, one or more of filters **832** and **838**, and detectors **840-844**, **822**, are implemented by one or more hardware circuits. In another embodiment, some or all of the processing functions of FIG. **8** are performed by the external device instead of device **802**. In another embodiment, system **800** includes S1 and S2 detectors **840** and **842**, but does not include S3 detector **844**. In another embodiment, system **800** includes other sound detectors for detecting other heart sounds. In another embodiment, when an electrical-mechanical disassociation is detected, stimulation timing provided by stimulating electrodes **138** and **142** is changed.

CONCLUSION

[0067] Thus, exemplary embodiments of an improved apparatus and method for outputting heart sounds, and/or for comparing electrical operation of the heart to mechanical operation of the heart, are disclosed herein. The disclosed apparatus and method for outputting heart sounds do not require the use of a stethoscope placed on the body of the patient, and are not subject to various factors which affect the heart sounds heard using a stethoscope. The disclosed apparatus and method for comparing electrical and mechanical operations of the heart also do not require the use of a stethoscope, are not subject to various factors which affect the heart sounds heard using a stethoscope, do not require ECG probes to be electrically coupled to the patient's chest, increase the accuracy of comparisons between heart sounds and electrical signals, decrease the level of skill needed to identify electrical-mechanical disassociation, provide for continuous monitoring of such electrical-mechanical disassociation, and are capable of producing a written record showing such disassociation.

[0068] As indicated above, the outputs generated by system **100** may be used by a physician to diagnose problems with heart **110** such as electrical-mechanical disassociation, or problems leading to cardiac arrhythmia. The outputs may also be used by a physician located remotely from the patient to diagnose the patient by checking the patient's heart sounds through a telephone, Internet or other communication connection. The sensed heart sound signals generated by system **100** may also be used for other purposes. For example, the heart sound signals may be useful in optimization of timing for CHF pacing, for determining the best AV delay, or for identifying the upper rate limit for a pacemaker.

[0069] Also, while the above description has focused on the relative timing of the various cardiac signals, the morphology or amplitude of the heart sound and cardiac electrical signals may also provide diagnostic information. For example, a heart sound signal with an amplitude lower than normal may be suggestive of certain heart abnormalities.

[0070] The above description is intended to be illustrative, and not restrictive. Many other embodiments will be apparent to those of ordinary skill in the art upon reviewing the present specification. For example, the implantable device described herein need not be a cardiac pacemaker, but may be another type of implantable device. Also, the external device described herein need not be an external pacemaker programmer, but may be another type of external device such as a cardiac monitor. The processing described herein as being performed by external controller **146** may also be performed by the implantable device, or by other combinations of hardware and software. Other signal processing routines may also be used. Further, while the system described herein outputs heart sounds, A EGM, V EGM and surface ECG signals, one or more of these signals need not be output, or may be replaced by the output of another internal or external cardiac signal. The scope of the present invention should therefore be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. An external system for communicating with an implantable system configured to transmit first data representative of heart sounds and second data representative of cardiac electrical signals to the external system, comprising:

an interface circuit configured to communicate with the implantable system;

an output device configured to generate outputs in response to control signals; and

a control circuit coupled to the interface circuit and the output device, the control circuit configured to receive the first and the second data from the implantable system through the interface circuit, process the first data using a first processing path configured for machine detection of the heart sounds using the first data and a second processing path configured for presentation of the heart sounds, and generate control signals causing the output device to generate outputs representative of the heart sounds and the cardiac electrical signals.

2. The external system of claim 1, wherein the output device comprises a display device configured to generate visual outputs representative of the heart sounds and the cardiac electrical signals.

3. The external system of claim 1, wherein the output device comprises an audio device configured to generate audio outputs representative of at least the heart sounds.

4. The external system of claim 1, wherein the control circuit is further configured to receive surface electrocardiograph (ECG) signals and generate the control signals causing the output device to further generate surface ECG outputs representative of the surface ECG signals.

5. The external system of claim 1, wherein the control circuit is further configured to generate timing comparison control signals causing the output device to output timing comparison information indicative of relative timing between the heart sounds and the cardiac electrical signals.

6. The external system of claim 5, wherein the output device comprises a display device configured to generate visual outputs representative of the heart sounds and the cardiac electrical signals, and the control circuit is further configured to generate the timing comparison control signals causing the output device to display calipers for indicating time intervals between the heart sounds and the cardiac electrical signals.

7. The external system of claim 6, further comprising an input device coupled to the control circuit, the input device configured to allow control of the display of the calipers.

8. The external system of claim 1, wherein the output device comprises a display device configured to generate visual outputs representative of the heart sounds and visual outputs representative of the cardiac electrical signals, with the visual outputs representative of the heart sounds superimposed over the visual outputs representative of the cardiac electrical signals.

9. The external system of claim 8, further comprising an input device coupled to the control circuit, the input device configured to allow control of the superimposition of the visual outputs representative of the heart sounds over the visual outputs representative of the cardiac electrical signals.

10. The external system of claim 1, comprising a further interface circuit configured to communicate with a remote system, and the control circuit is further configured to transmit third data representative of the heart sounds to the remote system.

11. The external system of claim 10, wherein the first data and the third data comprise same data.

12. The external system of claim 10, wherein the control circuit is further configured to transmit fourth data representative of the cardiac electrical signals to the remote system.

13. A method of outputting heart sounds and cardiac electrical signals using data transmitted from an implantable system, comprising

receiving first data representative of the heart sounds and second data representative of the cardiac electrical signals from the implantable system;

processing the first data using a first processing path configured for machine detection of the heart sounds using the first data and a second processing path configured for presentation of the heart sounds; and

generating outputs representative of the heart sounds and the cardiac electrical signals.

14. The method of claim 13, further comprising transmitting third data representative of the heart sounds and fourth data representing the cardiac electrical signals to a remote system.

15. The method of claim 13, wherein generating the outputs comprises generating audio outputs representative of at least the heart sounds.

16. The method of claim 13, wherein generating the outputs comprises generating visual outputs representative of the heart sounds and visual outputs representative of the cardiac electrical signals.

17. The method of claim 16, further comprising outputting timing comparison information indicative of relative timing between the heart sounds and the cardiac electrical signals.

18. The method of claim 17, wherein outputting the timing comparison information comprises displaying calipers for indicating time intervals between the heart sounds and the cardiac electrical signals.

19. The method of claim 16, further comprising superimposing the visual outputs representative of the heart sounds over the visual outputs representative of the cardiac electrical signals.

20. The method of claim 19, further comprising allowing control of the superimposition of the visual outputs representative of the heart sounds over the visual outputs representative of the cardiac electrical signals by a user using a user input device.

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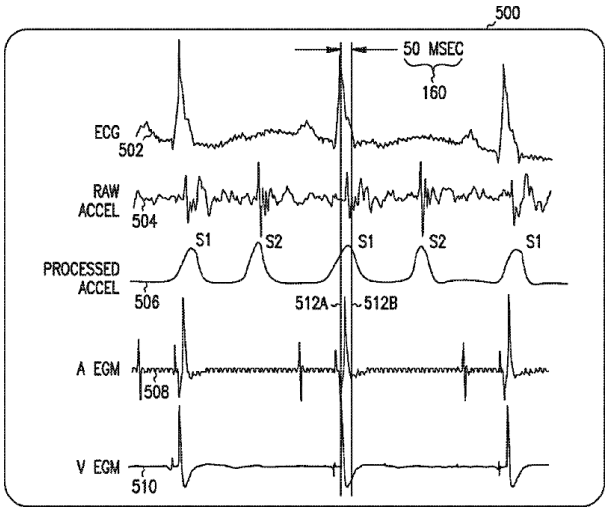
用于输出心音的装置包括可植入系统和外部系统。可植入系统包括用于产生表示检测到的心音的感测信号的传感器，接口电路和用于接收感测信号的控制电路，产生表示心音的数据，以及经由接口电路将数据发送到外部系统。外部系统包括用于与可植入系统通信的接口电路，以及用于接收表示心音的数据并用于产生控制信号的控制电路，该控制信号使输出装置产生表示声音的输出。可植入系统还可以包括用于检测心脏电信号的传感器。在这种情况下，还输出表示心电信号的输出。