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(54) **QUANTITATIVE SEISMOCARDIOGRAPHY**

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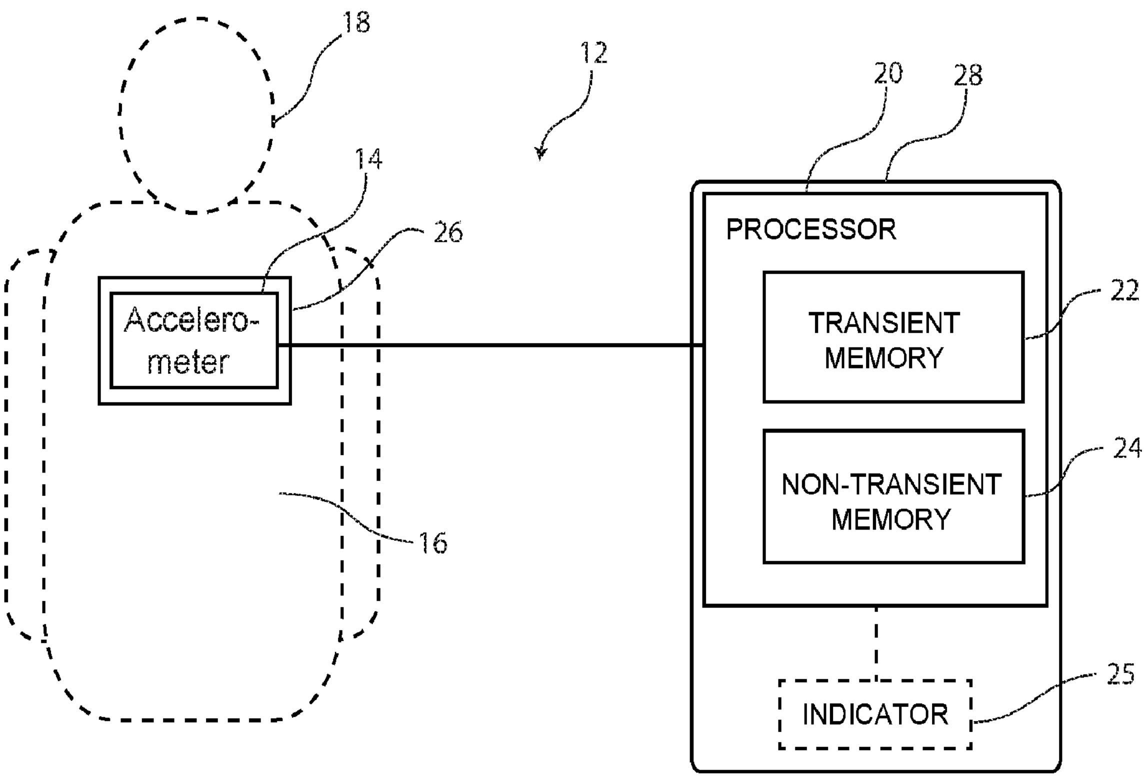
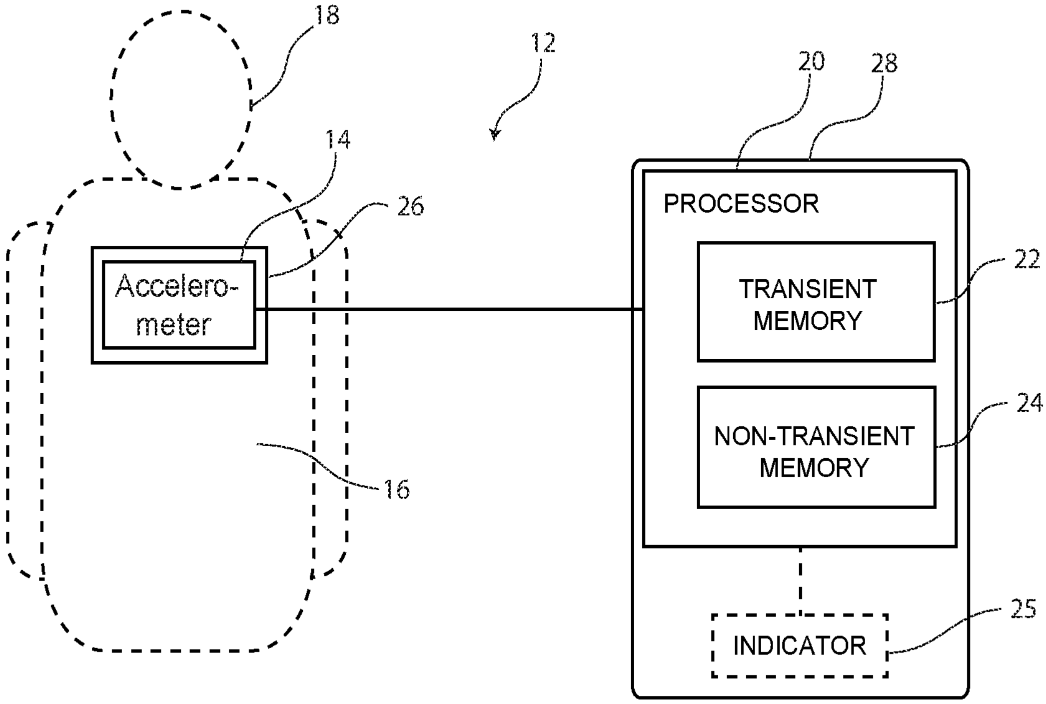
(57) **ABSTRACT**

A quantifying of the function of a beating heart is disclosed, in which a signal is recorded with an accelerometer placed on the chest of a person. A plurality of segments of the signal are formed, which are aligned and filtered with a band-pass filter having a lower cutoff frequency below 1 Hz and an upper cut-off frequency in the range 100-250 Hz. A mean segment is then determined, in which a first temporal feature is determined. A measure is then determined based on at least one of the signal value, or amplitude, of the first temporal feature and the location in time of the first temporal feature. The determined measure is then provided as output information.

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PROCESSOR
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INDICATOR
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Fig.1

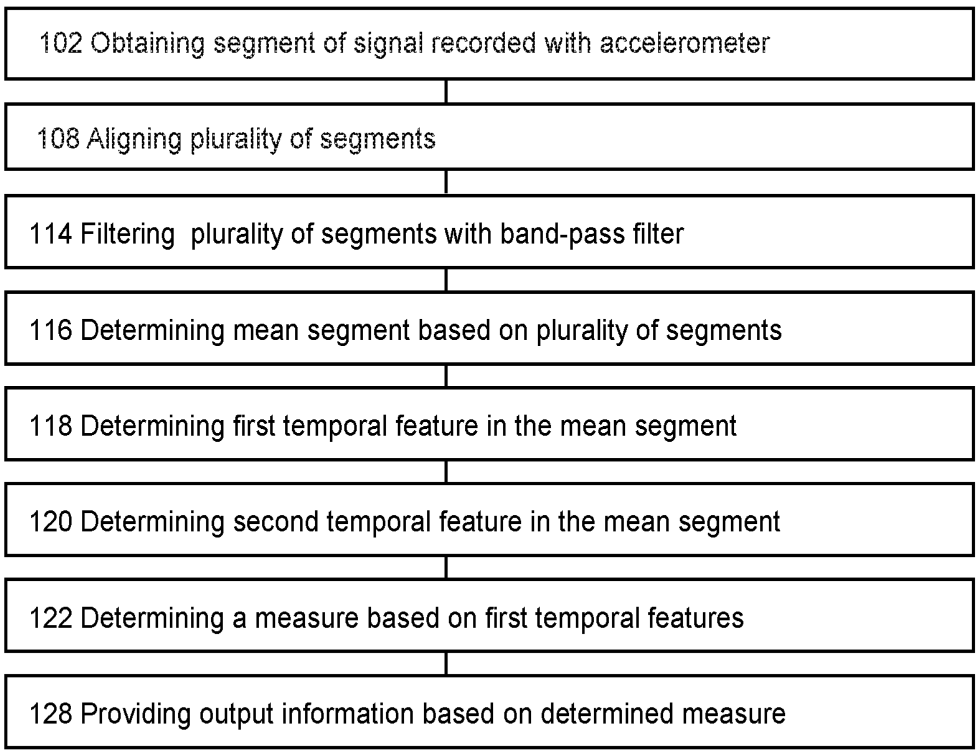
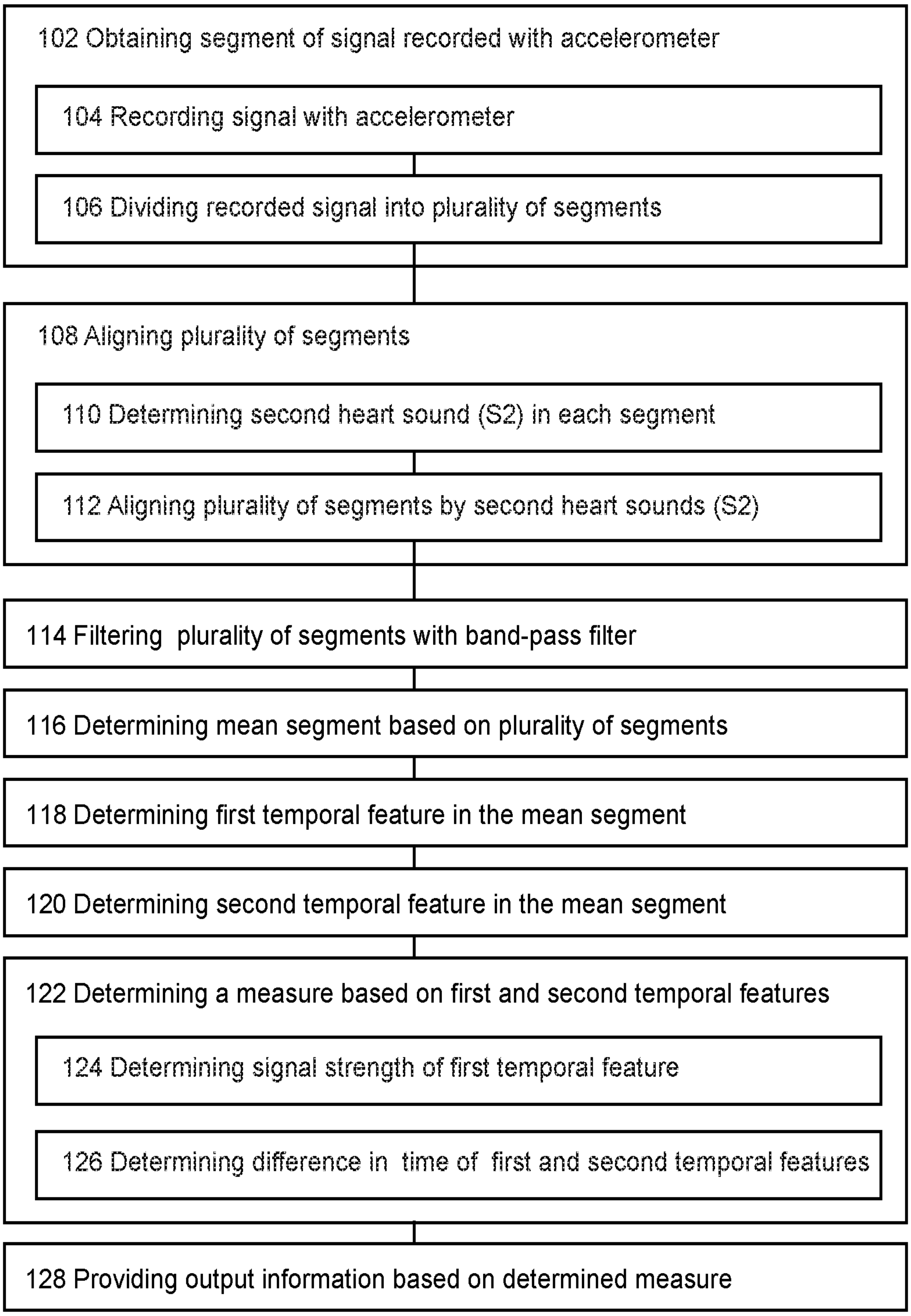

102 Obtaining segment of signal recorded with accelerometer
108 Aligning plurality of segments
114 Filtering plurality of segments with band-pass filter
116 Determining mean segment based on plurality of segments
118 Determining first temporal feature in the mean segment
120 Determining second temporal feature in the mean segment
122 Determining a measure based on first temporal features
128 Providing output information based on determined measure

Fig.2



102 Obtaining segment of signal recorded with accelerometer
104 Recording signal with accelerometer
106 Dividing recorded signal into plurality of segments
108 Aligning plurality of segments
110 Determining second heart sound (S2) in each segment
112 Aligning plurality of segments by second heart sounds (S2)
114 Filtering plurality of segments with band-pass filter
116 Determining mean segment based on plurality of segments
118 Determining first temporal feature in the mean segment
120 Determining second temporal feature in the mean segment
122 Determining a measure based on first and second temporal features
124 Determining signal strength of first temporal feature
126 Determining difference in time of first and second temporal features
128 Providing output information based on determined measure

Fig.3

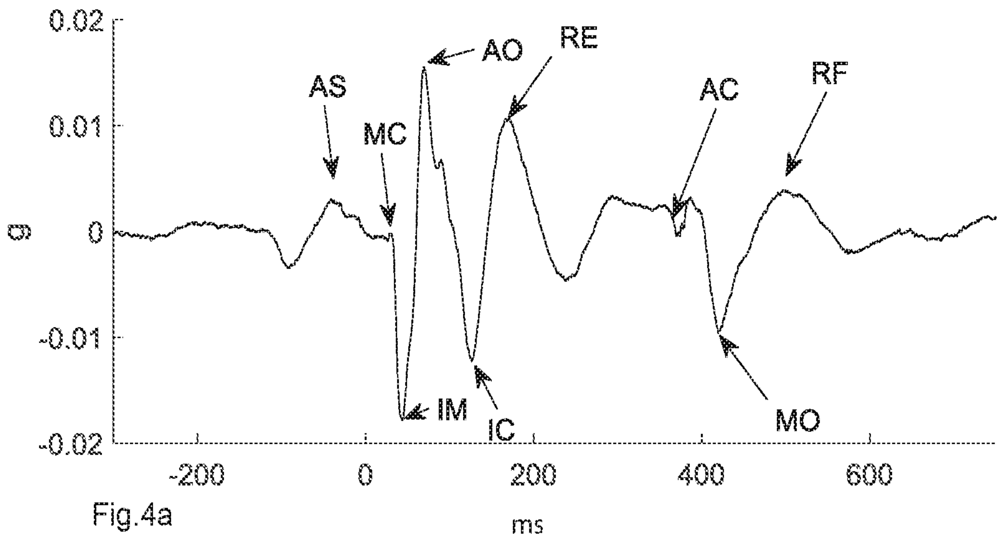

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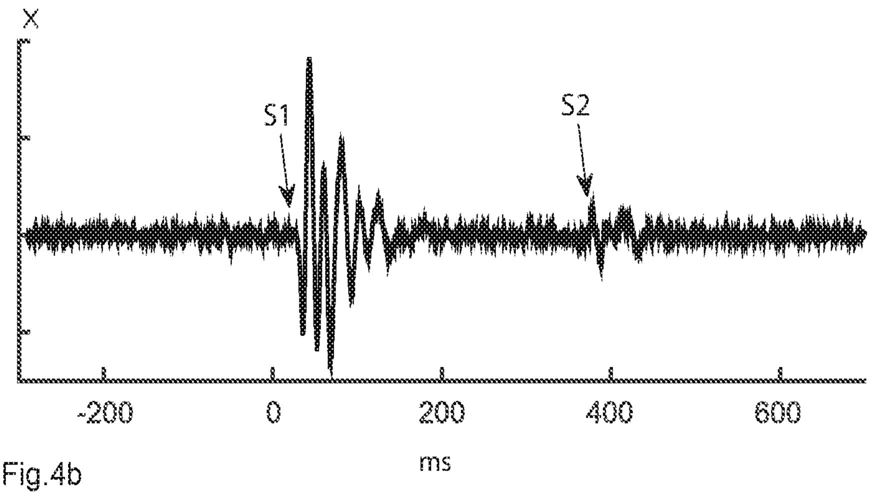
Fig.4a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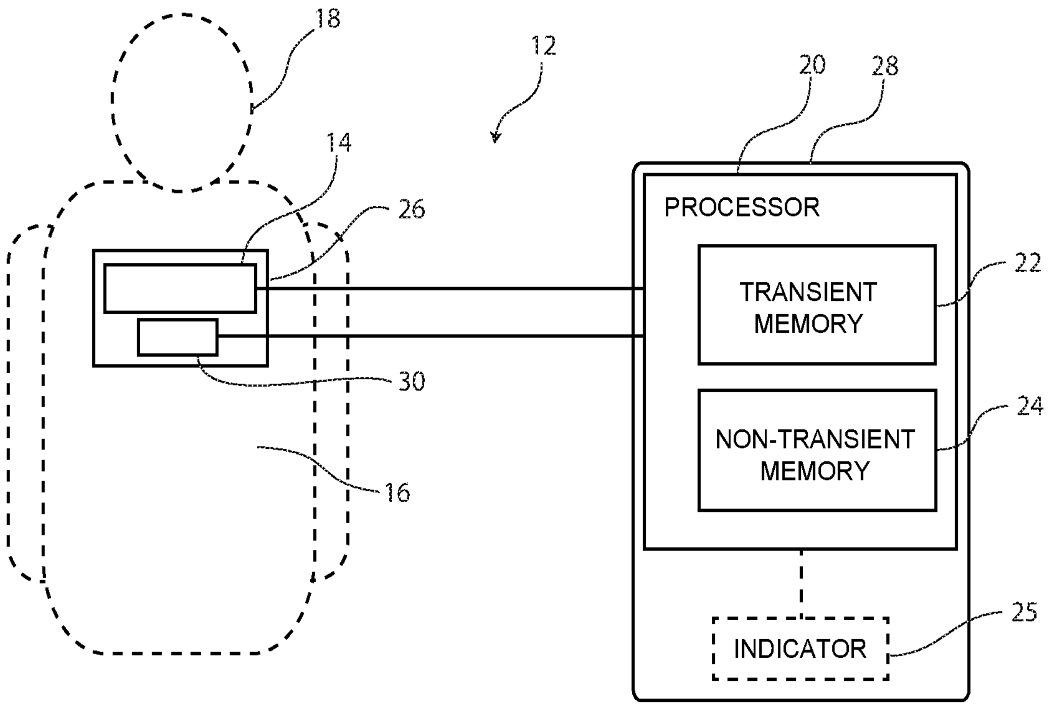
ms

Fig.4b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NON-TRANSIENT MEMORY
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INDICATOR

Fig.5

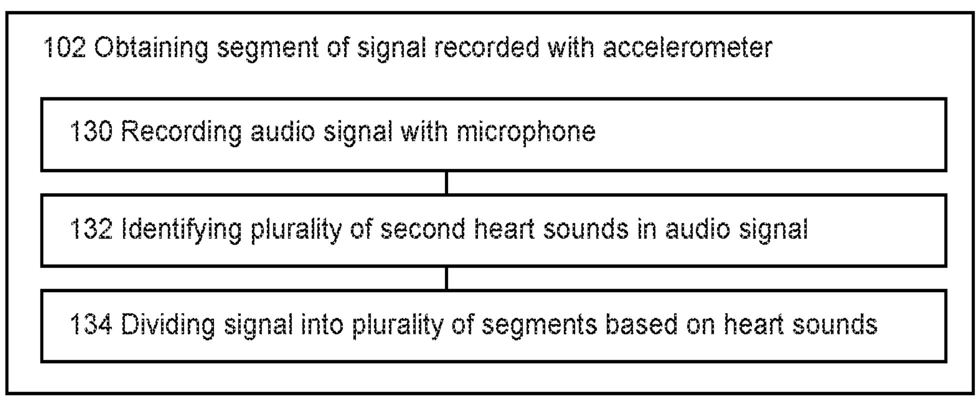
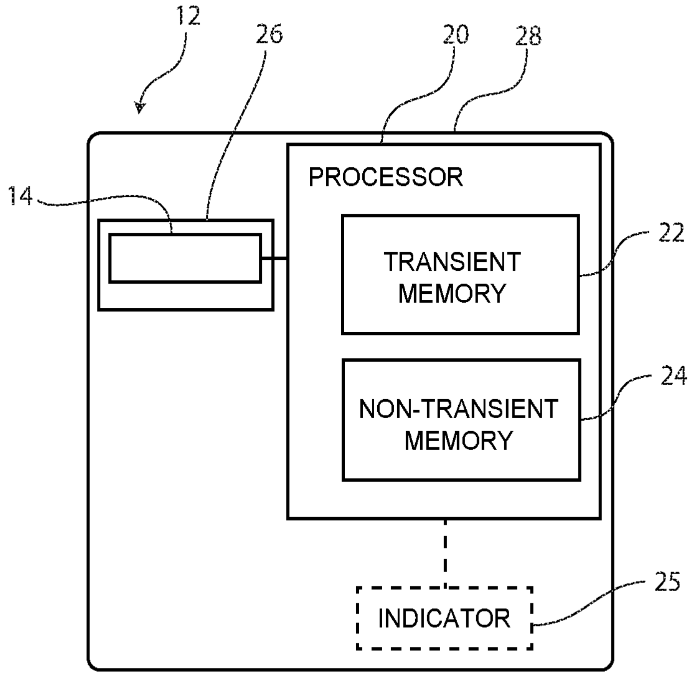

102 Obtaining segment of signal recorded with accelerometer
130 Recording audio signal with microphone
132 Identifying plurality of second heart sounds in audio signal
134 Dividing signal into plurality of segments based on heart sounds

Fig.6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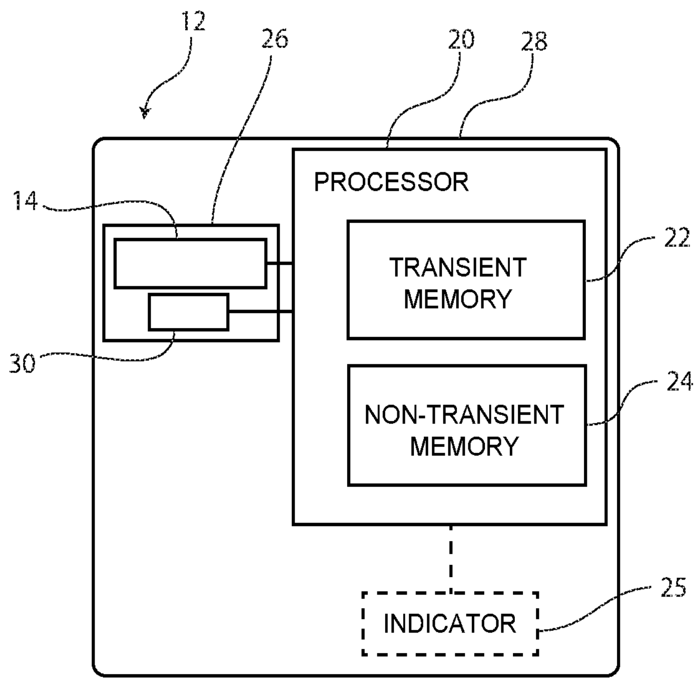
INDICATOR

Fig.7a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PROCESSOR
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TRANSIENT MEMORY
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NON-TRANSIENT MEMORY
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INDICATOR

Fig.7b

QUANTITATIVE SEISMOCARDIOGRAPHY

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention generally relates to techniques for diagnostic purposes relating to cardiovascular function, and in particular to techniques for assisting in diagnosing systolic and diastolic dysfunction that could lead to heart failure.

BACKGROUND OF THE INVENTION

[0002] Diastolic dysfunction is a frequent occurring heart defect in persons older than 45 years. Diastolic dysfunction can lead to severe heart failure and is associated with increased mortality. Current methods for diagnosis of diastolic dysfunction are complicated and expensive, which typically means that they are used only on patients with high risk of diastolic dysfunction.

[0003] Seismocardiography (SCG) is the analysis of subaudible low-frequency vibrations at the chest wall caused by the beating heart. More generally, SCG relates to non-invasive measurement of accelerations in the chest wall produced by myocardial movement. Heart sounds are audible components of the chest wall vibrations that typically are above 40-60 Hz, while SCG vibrations typically are below 5 Hz.

[0004] SCG is typically measured using an accelerometer. However, when an accelerometer is used, both low frequency SCG components and audible components are simultaneously sampled. The SCG components and the audible components reveal different cardiovascular functions, thus enabling different approaches to diagnosing a cardiovascular function. For example, SCG is typically suitable for estimation of time intervals between features in the cardiac cycle, while heart sounds are appropriate for detection of murmurs caused by flow disturbances.

[0005] When using an accelerometer, the heart sounds or audio components in the accelerometer signal are dominated by the high intensity of the low-frequency vibrations, or SCG waves. If the accelerometer signal is high pass filtered, for example with a lower cutoff of 50 Hz, the heart sounds are revealed. In the heart sound, the most dominating sounds are the first heart sound (S**1**) and second heart sounds (S**2**), which are related to the mitral valve closure (MC) and the aortic valve closure (AC), respectively.

[0006] A problem for General Practitioners is that heart failure shares symptoms with other common diseases, such as respiratory disease. Thus, there is a need for a reliable or accurate tool that can assist in diagnosing or determining a probability of heart failure.

OBJECT OF THE INVENTION

[0007] An object of the present invention is to provide an improved tool for quantifying the function of a beating heart. It is also an object to provide an improved technology for identifying heart failure.

SUMMARY OF THE INVENTION

[0008] According to a first aspect, the aforementioned objects are accomplished by a method for quantifying the function, or cardiovascular function, of a beating heart. The method comprises: obtaining a plurality of segments of a signal recorded with an accelerometer, e.g. placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, wherein each segment covers, or corresponds to, a cardiac cycle. The method further comprises: aligning the plurality of segments, determining a mean segment based on the plurality of segments, and filtering the plurality of segments prior to determining the mean segment, or filtering the mean segment, with a band-pass filter having a lower cutoff frequency below 5 Hz, preferably below 1 Hz, and an upper cut-off frequency in the range 100-500 Hz. The method further comprises: determining a first temporal feature in the filtered mean segment, determining a measure based on at least one of the signal strength, or amplitude, of the first temporal feature and the location in time of the first temporal feature, and providing output information based on the determined measure.

[0009] Here, and throughout these specifications, quantifying the function, or cardiovascular function, is understood to be limited to quantifying, or determining an indication of, an abnormal cardiovascular function, condition or structure, and/or a cardiovascular disorder. Thus, quantifying the function is understood to encompass quantifying, or determining an indication of, a heart disease relating to myocardial performance, such as heart failure.

[0010] Quantifying the function, or cardiovascular function, is understood to not include quantifying, or determining an indication of, fitness, such as cardiovascular or cardiorespiratory fitness. Thus, quantifying the function is understood to not encompass quantifying, or determining an indication of, aerobic fitness, such as maximal oxygen consumption or uptake (VO_2 Max). Here, fitness is understood to be related to a normal cardiovascular function, and to be disassociated with, an abnormal cardiovascular function, condition or structure, or a cardiovascular disorder.

[0011] The specified band-pass filtering has the effect that the temporal feature is determined from mean segment including both low-frequency SCG components and audible components, as compared to when only low-frequency SCG components are considered. It has been found the specified band-pass filtering contributes to a reliable, and thus improved, quantifying of heart failure.

[0012] Throughout these specifications, a temporal feature may correspond to a feature or stage in a cardiac cycle. A temporal feature may correspond to a peak, valley, local extremum, local minima, local maxima, maximal change, maximal increase, or maximal decrease of the filtered mean segment. A measure may, throughout these specifications, correspond to, or be based on a signal strength or an amplitude, or a difference in time. The signal strength or amplitude of a temporal feature may correspond to an acceleration affecting the accelerometer. Signal strength of a temporal feature is here, and throughout these specifications, understood to encompass a signal sample or a signal value of the temporal feature. The amplitude may be determined relative to the mean signal in the mean segment. An amplitude is understood to encompass a peak value, or the extreme value of a temporal feature, such as a local maxima or minima.

[0013] The accelerometer may comprise a piezoelectric element. The signal may represent a voltage generated by the piezoelectric element. Thus, the signal strength or amplitude of a temporal feature may represent a voltage value for the temporal feature.

[0014] According to a second aspect, the objects are achieved by system for quantifying the function, or cardiovascular function, of a beating heart. The system comprises: (A) an accelerometer, e.g. configured to be placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, and (B) a processor operatively connected to the accelerometer. The processor is configured to: obtain a plurality of segments of a signal recorded with the accelerometer, wherein each segment covers, or corresponds to, a cardiac cycle. The processor is also configured to: align the plurality of segments, determine a mean segment based on the plurality of segments, and filter the plurality of segments prior to determining the mean segment, or filter the mean segment, with a band-pass filter having a lower cutoff frequency below 1 Hz and an upper cut-off frequency in the range 100-500 Hz. The processor is further configured to: determine a first temporal feature in the mean segment, determine a measure based on at least one of the signal strength, or amplitude, of the first temporal feature and the location in time of the first temporal feature, and provide output information based on the determined measure.

[0015] In the above aspects, to obtain a plurality of segments of a signal may comprise: obtaining the signal and forming the plurality of segments from the signal.

[0016] According to a third aspect, the objects are achieved by a system for quantifying the function, or cardiovascular function. The system comprises: an accelerometer, e.g. configured to be placed on the chest of a person for obtaining a signal representing accelerations and vibrations of the chest wall of the person caused by myocardial movement, and a segmentation module for forming a plurality of segments from the signal, wherein each segment covers, or corresponds to, a cardiac cycle. It further comprises: an align module for aligning the plurality of segments, a first calculation module for determining a mean segment based on the plurality of segments, and a filter module for filtering the plurality of segments prior to determining the mean segment, or for filtering the mean segment, with a band-pass filter having a lower cutoff frequency below 1 Hz and an upper cut-off frequency in the range 100-500 Hz. The system also comprises: a second calculation module for determining a first temporal feature in the mean segment and, a third calculation unit for determining a measure based on at least one of the signal strength, or amplitude, of the first temporal feature and the location in time of the first temporal feature, and an output module for providing output information based on the determined measure.

[0017] According to a fourth aspect, the objects are achieved by a computer program product for being used in a system for quantifying heart failure comprising: (A) an accelerometer, e.g. for being placed on, or configured to be placed on, the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, and (B) a processor operatively connected with the accelerometer. The computer program product comprising program code instructions configured to, when executed by the processor of the system, cause the processor to: obtain a signal with the accelerometer, and forming a plurality of segments from the signal, wherein each segment covers, or corresponds to, a cardiac cycle. The program code instructions further causes the processor to: align the plurality of segments, determine a mean segment based on the plurality of segments, and filter the plurality of segments prior to determining the mean segment, or filter the mean segment, with a band-pass filter having a lower cutoff frequency below 1 Hz and an upper cut-off frequency in the range 100-500 Hz. The program code instructions are further configured to cause the processor to: determine a first temporal feature in the mean segment, determine a measure based on at least one of the signal strength, or amplitude, of the first temporal feature and the location in time of the first temporal feature, and provide output information based on the determined measure.

[0018] According to a fifth aspect, the objects are achieved by a non-transient memory on which a computer program product according to the fourth aspect is stored.

[0019] In the different aspects above, the output information may represent the actual determined measure. Alternatively, the output information may represent a score based on the determined measure. The output information may indicate function, cardiovascular function, heart failure, or risk for heart failure or another abnormal condition, for example as one or more numerical values. Additionally or alternatively, the aligning may be performed prior to the filtering, and the filtering may be performed prior to determining the mean segment.

[0020] In the different aspects above, the step of filtering the plurality of segments prior to determining the mean segment, or filtering the mean segment, may be omitted, in particular if a microphone is used in addition to the accelerometer. Additionally or alternatively, the accelerometer placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement may be replaced with a accelerometer for measuring accelerations and vibrations caused by myocardial movement, and the accelerometer may be configured to be placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person, or for being inserted into the body of the person, for example as an implantable device, or inside a blood vessel, such a blood vessel at the heart.

[0021] In the method of the first aspect, the accelerometer may be placed on the chest of a person and attached to the skin of the person by an adhesive for measuring the accelerations and vibrations. The systems of the second, third and fourth aspects may further comprise an adhesive patch configured for supporting the accelerometer, or a housing described below, and for being attached to the skin of the person. By attaching the accelerometer, or housing, to the skin, the quality of the recorded signals is improved.

DETAILED DESCRIPTION

[0022] The different aspects described above may be modified as described below.

[0023] The step of obtaining a plurality of segments of a signal recorded with an accelerometer may comprise: recording a signal with an accelerometer, e.g. placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, wherein the signal is recorded over a period of time covering a plurality of cardiac cycles of the person. The step further may comprise: dividing the recorded signal into the plurality of segments, wherein each segment covers a single cardiac cycle.

[0024] The accelerometer may be placed on the front of the chest of the person. The accelerometer being placed on the chest of a person means that it is placed on the outside and not on the inside of the body. This has the advantage of a simple application that does not require any chirurgical skills and that it can be used in non-sterile environments.

[0025] Alternatively, obtaining a plurality of segments of a signal recorded with an accelerometer may comprise: recording the signal with the accelerometer, e.g. placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, and recording an audio signal with a microphone placed on the chest of the person simultaneously to recording the signal with the accelerometer. The microphone may be configured for measuring cardiovascular sounds, or sounds generated by the beating heart. Obtaining a plurality of segments may further comprise: identifying a plurality of heart sounds in the audio signal, wherein each heart sound relates to a single cardiac cycle, and dividing the recorded signal into the plurality of segments based on the identified plurality of heart sounds. Alternatively, obtaining a plurality of segments of a signal recorded with an accelerometer may comprise: recording the signal with the accelerometer, e.g. placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, and filtering the signal to obtain an audio signal. Obtaining a plurality of segments may further comprise: identifying a plurality of heart sounds in the audio signal, wherein each heart sound relates to a single cardiac cycle, and dividing the recorded signal into the plurality of segments based on the identified plurality of heart sounds. The filtering may comprise a high-pass filtering having lower cut-off frequency in the range 40-80 Hz, or approximately equal to 50 Hz or 65 Hz.

[0026] Here, the plurality of heart sounds may be the first heart sound (S1). Alternatively, the plurality of heart sounds may be the second heart sound (S2). Throughout these specifications, a microphone is understood as a transducer that converts sound into an electrical signal.

[0027] The aligning the plurality of segments may comprise: determining a heart sound in each of the plurality of segments, and aligning the plurality of segments by the determined heart sound of each segment. The heart sound may be the first heart sound (S1) or the second heart sound (S2). The first heart sound (S1) may correspond to the closing of the atrioventricular valves. The second heart sound (S2) may correspond to the closing of the semilunar valves. It has been found that the specified aligning, together with the specific filtering, contributes to a reliable quantifying of heart failure.

[0028] Further, determining a measure may comprise: determining the signal strength, or amplitude, of the first temporal feature. The first temporal feature may correspond to: the aortic valve opening (AO) of a heart cycle, the atrial systole (AS) of a heart cycle, the isometric contraction (IM) of a heart cycle, or the rapid ventricular ejection or rapid emptying event (RE) of a heart cycle. It has been found that these features are particularly suitable for quantifying heart failure. A possible explanation is that heart failure cause weaker cardiac contraction, and thus influences the signal strength.

[0029] The method according to the first aspect may further comprise: determining a second temporal feature in the filtered mean segment, and wherein determining a measure is further based on at least one of the signal strength, or amplitude, of the second temporal feature and on the location in time of the second temporal feature. By having two or more temporal features, additional measures can be used, thus contributing to an improved technology for identifying heart failure.

[0030] The measure may further be based on the location in time of the first temporal feature and on the location in time of the second temporal feature. Determining a measure may comprise: determining the difference between the location in time of the first temporal feature and the location in time of the second temporal feature, wherein the measure is based on the determined difference. Alternatively, determining a measure may comprise: determining the time interval between the first temporal feature and the second temporal feature, wherein the measure is based on the determined time interval.

[0031] Alternatively or additionally, the measure may be based on the signal strength, or amplitude, of the first temporal feature and on the signal strength, or amplitude, of the second temporal feature. The signal strength, or amplitude, of the first temporal feature may be normalized by the signal strength, or amplitude, of the second temporal feature. Determining a measure may comprise: determining the difference or ratio between the signal strength, or amplitude, of the first temporal feature and the signal strength, or amplitude, of the second temporal feature, wherein the measure is based on the determined difference or ratio.

[0032] The first temporal feature may correspond to the mitral valve closure (MC) and the second temporal feature may correspond to the rapid ventricular ejection or rapid emptying event (RE). Alternatively, the first temporal feature may correspond to the atrial systole (AS) in the cardiac cycle and the second temporal feature may correspond to the mitral valve closure (MC) in the cardiac cycle. Alternatively, the first temporal feature may correspond to the aortic valve closing (AC) and the second temporal feature may correspond to the mitral valve opening (MO). Alternatively, the first temporal feature may correspond to the aortic valve opening (AO) and the second temporal feature may correspond to the aortic valve closing (AC). Alternatively, the first temporal feature may correspond to the mitral valve closure (MC) and the second temporal feature may correspond to the aortic valve opening (AO). It has been found that these features are particularly suitable for quantifying heart failure. A possible explanation is that heart failure cause slower cardiac contraction, and thus influences the timing in the heart cycle.

[0033] The method according to the first aspect may further comprise: determining a third temporal feature in the filtered mean segment, and wherein determining a measure is further based on at least one of the signal strength, or amplitude, of the third temporal feature and on the location in time of the third temporal feature. Determining a measure may comprise: determining a first difference between the location in time of the first temporal feature and the location in time of the second temporal feature, wherein the measure is based on the first difference and the signal strength, or amplitude, of the third temporal feature. The first, second, and third temporal feature may correspond to the mitral valve closure (MC), the aortic valve closing (AC), and the rapid emptying event (RE), respectively.

[0034] The method according to the first aspect may further comprise: determining a fourth temporal feature in the filtered mean segment, and wherein determining a measure is further based on at least one of the signal strength, or amplitude, of the fourth temporal feature and on the location in time of the fourth temporal feature. Determining a measure may comprise: determining a second difference between the location in time of the second temporal feature and the location in time of the fourth temporal feature, wherein the measure is further based on the second difference. The fourth temporal feature may correspond to the aortic valve opening (AO).

[0035] The method according to the first aspect may further comprise: determining a fifth temporal feature in the filtered mean segment, and wherein determining a measure is further based on at least one of the signal strength, or amplitude, of the fifth temporal feature and on the location in time of the fifth temporal feature. Determining a measure may comprise: determining a third difference between the location in time of the first temporal feature and the location in time of the fifth temporal feature, wherein the measure is further based on the third difference. The fifth temporal feature may correspond to the atrial systole (AS).

[0036] The method, or determining the first temporal feature, may further comprise: determining a first point in time in the mean segment corresponding to the onset of a heart sound. Determining the first temporal feature may further comprise: determining the first temporal feature relative to the first point in time. Similarly, determining the second temporal feature may further comprise: determining the second temporal feature relative to the first point in time. The heart sound may be the first heart sound (S**1**) or the second heart sound (S**2**). As mentioned above, the first heart sound (S**1**) may correspond to the closing of the atrioventricular valves and the second heart sound (S**2**) may correspond to the closing of the semilunar valves.

[0037] If the heart sound is the first heart sound (S**1**), determining a first temporal feature may comprise: determining the first local minima (IM) subsequent to the first point in time, and assigning the first local minima to represent the isovolumic movement (IM), and/or determining the maximum negative deviation (MC) prior to the first local minima (IM) subsequent to the first point in time, and assigning the maximum negative deviation to represent the mitral valve closure (MC). Alternatively or additionally, determining a first temporal feature may comprise: determining the global maxima subsequent to the first point in time, and assigning the global maxima to represent the aortic valve opening (AO), and/or determining the global maxima (RE) subsequent to the global minima (IC) subsequent to the global maxima (AO) subsequent to the first point in time, and assigning the global maxima (RE) subsequent to the global minima to represent the rapid ventricular ejection or rapid emptying event (RE). Here, a global extremum on one side of an event only relate to the local extrema on the same side of the event. It has been found that these definitions are advantageous for determining an indication of heart failure.

[0038] The lower cutoff frequency of the band-pass filter may be below 0.5 Hz, 0.2 Hz, or approximately 0.1 Hz. The upper cutoff frequency may be the range of 60-500 Hz, 60-250 Hz, 150-250 Hz, 175-225 Hz, or approximately 200 Hz, or in one of the ranges 60-100 Hz, 100-150 Hz, 150-200 Hz, 200-250 Hz, and 250-300 Hz. Preferably, the upper cutoff frequency is in the range 100-250 Hz. These frequencies for providing the SCG signal have been found to give reliable results.

[0039] The method may further comprise: determining a heart rate of the beating heart. Similarly, the processor may be configured to: determine a heart rate of the beating heart, and the computer program product may comprising program code instructions configured to, when executed by the processor of the system, cause the processor to: determine a heart rate of the beating heart. The heart rate may be determined based on the signal recorded with the accelerometer. The heart rate may indicate the number of contraction of the heart per minute or another suitable period of time.

[0040] Determining the measure may further be based on the heart rate. For example, determining the measure may comprise: determining the difference between the location in time of a first temporal feature and the location in time of a second temporal feature and dividing the difference with the heart rate. It is contemplated that by taking the heart rate into account, the measure can be determined more accurately for persons having a high heart rate at rest and for persons that are active or exercising when the signal is recorded with the accelerometer.

[0041] The system of the above aspects may comprise: (C) a non-transient memory storing program code instructions that, when executed by the processor, configures the processor to perform the described steps and/or have the described functions.

[0042] The system may comprise a smart-phone. The processor and/or the non-transient memory may be integral parts of the smart-phone. Further, the accelerometer may be an integral part of the smart-phone. The system may also comprise a casing or holder for supporting the smart-phone, and the casing or holder may comprise an adhesive patch configured for attaching the casing or holder to the skin of the person. Alternatively to the accelerometer being an integral part of the smart-phone, the accelerometer may form part of an auxiliary unit configured to communicate with the smart-phone by wire or wirelessly, such as a band that can be strapped around the chest of person.

[0043] The processor may be further configured to: operate the accelerometer to record a signal, e.g. with the accelerometer placed on the chest of a person, wherein the signal is recorded over a period of time covering a plurality of cardiac cycles of the person. The processor may be further configured to: divide the recorded signal into a plurality of segments to obtain the plurality of segments of a signal, wherein each segment covers a single cardiac cycle.

[0044] Alternatively, the system of the above aspects may comprise: (D) a microphone configured to be placed on the chest of the person for measuring sounds generated by the beating heart, wherein the processor is further operatively connected to the microphone and configured to: operate the accelerometer to record a signal with the accelerometer, e.g. placed on the chest of a person; operate the microphone to record an audio signal with the microphone placed on the chest of a person simultaneously to the signal being recorded with the accelerometer; identify a plurality of heart sounds in the audio signal, wherein each heart sound relates to a single cardiac cycle; and divide the recorded signal into the plurality of segments based on the identified plurality of heart sounds to obtain the plurality of segments. Alternatively, the processor may be further configured to: operate the accelerometer to record a signal, e.g. with the accelerometer placed on the chest of a person; filtering the signal to obtain an audio signal; identify a plurality of heart sounds in the audio signal, wherein each heart sound relates to a single cardiac cycle; and divide the recorded signal into the plurality of segments based on the identified plurality of heart sounds to obtain the plurality of segments. The filtering may comprise a high-pass filter having lower cut-off frequency in the range 40-60 Hz, or approximately equal to 50 Hz.

[0045] Here, the plurality of heart sounds may be the first heart sound (**S1**). Alternatively, the plurality of heart sounds may be the second heart sound (**S2**).

[0046] The system may comprise a housing or cover that supports and encloses or covers the processor. The housing or cover may further enclose or cover at least a portion of, or the whole of, the accelerometer and/or enclose or cover at least a portion of, or the whole of, the microphone.

[0047] Providing the output information may further comprise: storing the plurality of segments, the mean segment and/or the measure in the non-transient memory or in the auxiliary non-transient memory. The auxiliary non-transient memory may form part of computer server system, which may be at a remote location.

[0048] Providing the output information may further comprise: providing a previously obtained measure and the output information may further be based on the previously obtained measure. The previously obtained measure may be stored in the non-transient memory or in the auxiliary non-transient memory. The output information may be based on the difference between the measure and the previously obtained measure. For example, the output information may be the difference in amplitude between a first heart sound (**S1**) and a previously obtained heart sound.

[0049] Additionally or alternatively, providing the output information may further comprise: providing a previously obtained mean segment and the output information may further be based on the mean segment and the previously obtained mean segment. The previously obtained mean segment may be stored in the non-transient memory or in the auxiliary non-transient memory. The output information may comprise: a graph overlying the mean segment with the previously obtained mean segment. More specifically, the output information may comprise: a graph overlying a portion of the mean segment and the corresponding portion of the previously obtained mean segment. For example, the portion may cover the first heart sound (**S1**). The graph may be displayed on the screen of abovementioned smart-phone.

[0050] The previously obtained measure or previously obtained mean segment may have been determined in the same manner as the measure or the mean segment, or by the same steps as performed for determining the measure or the mean segment. The previously obtained measure or previously obtained mean segment may have been determined at an earlier point in time, such as more than five days or ten days prior to determining the measure or the mean segment.

[0051] Further advantages with and features of the different aspects will be apparent from the following description of the drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0052] A more complete understanding of the abovementioned and other features and advantages of the present invention will be apparent from the following detailed description of the drawings, wherein:

[0053] FIG. **1** is a schematic illustration of an embodiment of a system for quantifying the function of a beating heart,

[0054] FIG. **2** is a flow chart illustrating the basic steps of a method employed in the system described in relation to FIG. **1**,

[0055] FIG. **3** is a flow chart illustrating sub-steps and additional steps of a method based on the method described in relation to FIG. **2**,

[0056] FIGS. **4***a* and **4***b* shows a segment that has been filtered by a band-pass filter and to a high-pass filter, respectively,

[0057] FIG. **5** is a schematic illustration of an embodiment of a system an alternative embodiment for quantifying the function of a beating heart,

[0058] FIG. **6** is a schematic illustration of alternative sub-steps employed in the system described in relation to FIG. **5**, and

[0059] FIGS. **7***a* and *b* are schematic illustrations of alternative embodiment of a system for quantifying the function of a beating heart.

DETAILED DESCRIPTION OF DRAWINGS

[0060] FIG. **1** schematically illustrates an embodiment of a system **12** for quantifying the function of a beating heart, or more specifically for determining an indication of heart failure. The system **12** has an accelerometer **14** in the form of a piezoelectric element that can be placed on the chest of a person **18** and for measuring vibrations of the chest wall caused by movements of the heart. A processor **20** is connected with the accelerometer **14**. The processor **20** has a transient memory **22** which can store a signal received from the accelerometer **14**, and by which it can execute program code instructions. The system **12** comprises a support **26** that supports the accelerometer **14** and a housing **28** that accommodates the processor **20**. The system **12** also has a non-transient memory **24** storing program code instructions for the processor **20**. For example, the system **12** as a whole can be an integral part of a smart-phone, or all parts except the accelerometer **20** and the support **26** can form part of a smart-phone. In one embodiment, the accelerometer is an integrated accelerometer of a smart-phone.

[0061] In one embodiment of the system **12**, it additionally has an indicator **25** operatively connected with the processor **20**. The indicator **25** can, for example, have an LCD display, or the like, that can display output information from the processor **20**, such as a number.

[0062] The program code instructions in the non-transient memory **24** cause the processor **20** to perform a method that is shown in FIG. **2**. The accelerometer is placed on the chest of a person and a signal is recorded. A plurality of segments is then obtained **102**, where each segments corresponds to a heartbeat or a cardiac cycle. This is followed by an alignment **108** and a filtering **114**. Here, a band-pass filter is employed having a lower cut-off frequency of approximately 0.1 Hz, and an upper cut-off frequency of approximately 200 Hz. Subsequently, a mean segment is determined **118** from the plurality of segments.

[0063] With the mean segment formed, a temporal feature is determined **120**. The temporal feature in turn is used to determine **122** a measure. Examples of temporal features and measures are described below. Output information is then provided **128** based on the determined measure. In one embodiment, the output information is a number that is displayed on the abovementioned indicator **25**.

[0064] Further details of the method are shown in the flow chart of FIG. **3**. The step of obtaining **102** the plurality of segments includes the sub-steps of recording **104** the signal with the accelerometer, and dividing **106** the recorded signal into the plurality of segments, for example by a technique as described in U.S. Pat. No. 8,235,912 B2 and U.S. Pat. No. 8,469,896 B2 relying on audible components of the accelerometer signal. The audible components are obtained by filtering the recorded signal.

[0065] In an alternative embodiment, an electrocardiography (ECG) signal is acquired simultaneously to the accelerometer signal, and the ECG signal is used for the segmentation of the latter. For example, a segmentation as described in Jensen et al. (Computing in Cardiology 2014; 41:29-32) can be used.

[0066] When obtaining **102** the plurality of segments, a method similar to the method described in Jensen et al. is employed to remove noisy segments. A high-pass filter with a lower cut-off of 65 Hz is applied to the segments and the onset of the first heart sound **S1** is then determined by a known technique. Similarly, a high-pass filter with a lower cut-off of 50 Hz is applied to the segments and the onset of the second heart sound **S2** is then determined by a known technique. The segments are then aligned according to the determined second heart sound **S2**. In alternative embodiment, the first heart sound is used instead.

[0067] The mean segment is determined **116** by summing the aligned segments to a single segment and dividing the resulting signal by the number of segments in the sum.

[0068] FIG. **4***a* shows a segment that has been subjected to the above described band-pass filtering. The abscissa represents an acceleration in g (ms^{-2}) and the ordinate the time in milliseconds (ms). Here, g is proportional to the voltage from the accelerometer **14**. The zero point of the ordinate corresponds to the R peak in a simultaneously recorded segment of an ECG signal. A number of temporal features are indicated in FIG. **4***a*, which are further described below.

[0069] FIG. **4***b* shows a segment that has been subjected to a high-pass filter with a lower cut-off of 50 Hz, as described above. The abscissa represents the signal strength X (no unit) and the ordinate the time in milliseconds (ms). The latter has been aligned by the simultaneously recorded segment of an ECG signal in the same manner as described in relation to FIG. **4***a*. The onset of the first heart sound (**S1**) and the second heart sound (**S2**) are indicated in FIG. **4***b*.

[0070] In the steps of determining **118** the first temporal feature and determining **120** the second temporal feature **120** in the mean segment, the following temporal features are identified in the mean segment: the mitral valve closure (MC), isovolumic movement (MO), aortic valve opening (AO), the rapid ventricular ejection (RE), the aortic valve closure (AC), the mitral valve opening (MO), the rapid ventricular filling (RF), and the atrial systole (AS).

[0071] For example, with the first point in time determined to be the onset of the first heart sound (**S1**), see FIG. **4***b*, the isovolumic movement (IM) is determined as the first local minima (IM) subsequent to the first point in time, the mitral valve closure (MC) is determined as the maximum negative deviation (MC) prior to the first local minima (IM) subsequent to the first point in time, the aortic valve opening (AO) is determined as the global maxima subsequent to the first point in time, and the rapid ventricular ejection (RE) is determined as the global maxima (RE) subsequent to the global minima (IC) subsequent to the global maxima (AO) subsequent to the first point in time. For example, the first point in time can be determined by a technology similar to the technology described in U.S. Pat. No. 8,235,912 B2 and U.S. Pat. No. 8,469,896 B2.

[0072] One measure that is determined is the amplitude or signal strength of the above mentioned temporal features. For example, the signal strengths of the following temporal features can be determined, the aortic valve opening (AO), the atrial systole (AS), the isometric contraction (IM), and the rapid ventricular ejection (RE) of a heart cycle.

[0073] Another measure that is determined is based on the locations in time, or positions on the abscissa of the FIG. **4***a*, of a first temporal feature and a second temporal feature. The measure is then determined as the difference in time between a first temporal feature and a second temporal feature, wherein the measure is based on the determined difference. The following measures can be determined, the difference in time between the mitral valve closure (MC) and the rapid ventricular ejection (RE), the difference in time between the atrial systole (AS) and the mitral valve closure (MC), the difference in time between the aortic valve closing (AC) and the mitral valve opening (MO), the difference in time between the aortic valve opening (AO) and the aortic valve closing (AC), and the difference in time between the mitral valve closure (MC) and the aortic valve opening (AO).

[0074] Output is then provided **128** in the form of values that are displayed on an LCD display of the indicator **206**, where the values represents the determined signal strengths and differences in time in the examples above.

[0075] FIG. **5** schematically illustrates an alternative embodiment of a system for quantifying the function of a beating heart, or more specifically for determining an indication of heart failure. The system **12** is similar to the system described in relation to FIG. **1** and features having the same or related functions have been given the same number indices. In addition, the system has a microphone **30** in the form of a transducer that can convert sound into an electrical signal. The microphone **30** is supported by the support **26**.

[0076] The program code instructions in the non-transient memory **24** correspond to those described in relation to FIGS. **2** and **3**, but with different steps for obtaining **102** the plurality of segments, as illustrated in FIG. **6**. With the microphone placed on the chest of the person, the program code instructions additionally causes the processor **20** to operate the microphone **30** to record **130** an audio signal with the microphone **30** simultaneously to the signal being recorded **104** with the accelerometer **14**. A plurality of second heart sounds (**S2**) are then identified **132** in the audio signal. The recorded signal is then divided **134** into the plurality of segments based on the time correlation between the signal and the audible signal, and the identified plurality of second heart sounds (**S2**) in the audible signal to obtain the plurality of segments. The identification of the second heart sounds (**S2**) and the segmentation is based on the technologies described in U.S. Pat. No. 8,235,912 B2 and U.S. Pat. No. 8,469,896 B2.

[0077] The subsequent alignment **108** is then also based on the plurality of second heart sounds (**S2**) determined from the audio signal.

[0078] FIG. **7***a* illustrates an alternative embodiment of the system **12** described in relation to FIG. **1**, with the only difference that the support **26** forms part of the housing **28** such that the housing **28** covers at least a portion of the accelerometer **14**. In this embodiment, the housing **28** is placed on the chest of a person, which means that the accelerometer **14** is also placed on the chest of a person. Similarly, FIG. **7***b* illustrates an alternative embodiment of the system **12** described in relation to FIG. **5**, with the only difference that the support **26** forms part of the housing **28** such that the housing **28** covers at least a portion of the accelerometer **14** and the microphone **30**. In this embodiment, the housing **28** is placed on the chest of a person, which means that the accelerometer **14** and the microphone **30** are also placed on the chest of the person.

PROOF OF CONCEPT

[0079] A custom lightweight 8 g piezoelectric accelerometer was developed for acquisition of the SCG signals. The low weight provides a better signal and the miniaturization allows for the accelerometer to be incorporated in another device. The accelerometer was used in a system as described above in relation to FIGS. **1-4**.

[0080] It should be noted that the system identifies AO and MO and the resulting measures are not consistent. However, despite this disadvantage, AO and MO were used, since they have diagnostic importance.

[0081] The system was used on a first group of healthy subjects and on a second group of heart failure (HF) subjects undergoing pacemaker optimization. The majority of the heart failure subjects suffered from diastolic dysfunction. As is evident from Table 1 below, the amplitudes, or signal strength, and differences in time, or time intervals, of the temporal features provide a clear discrimination between heart failure patients and the normal subjects included.

Measure	Normal subjects Mean (STD)	HF subjects Mean (STD)	Classification AUC
Amplitudes	[mg]	[mg]	
AO	21.9 (13.1)	3.0 (2.2)	98.0%
AS	5.4 (2.5)	1.5 (0.9)	97.1%
IM	−23.7 (14.1)	−3.5 (3.5)	95.0%
RE	7.3 (4.1)	2.6 (2.5)	86.1%
Time Intervals	[ms]	[ms]	
MC-RE	140.6 (26.2)	184.8 (27.8)	89.5%
AS-MC	65.6 (39.6)	137.9 (71.1)	83.4%
AC-MO	43.1 (13.3)	59.7 (24.8)	74.6%
AO-AC	296.6 (38.5)	311.7 (57.2)	63.2%
MC-AO	41.7 (19.7)	43.8 (31.8)	42.2%

Table 1 shows average values and classification performance of the measures using the area under the receiving operating curve (AUC). The measures are sorted in decreasing classification performance.

[0082] Some of the measures of Table 1 were combined to improve the classification further. This exemplified in Tables 2-4

	AUC
Amplitude	
RE	86.1% (73.4-98.8%)
Time interval	
MC-AC	63.8% (47-80.6%)
Combined score	
RE + MC-AC	90.7% (80-100%)

Table 2 shows the combination of two measures, or three temporal features.

	AUC
Amplitude	
RE	86.1% (73.4-98.8%)
Time intervals	
AO-AC	63.2% (46.3-80%)
MC-AC	63.8% (47-80.6%)
Combined score	
RE + AO-AC + MC-AC	92.8% (83.2-100%)

Table 3 shows the combination of three measures, or four temporal features.

	AUC
Amplitude	
RE	86.1% (73.4-98.8%)
Time intervals	
AO-AC	63.2% (46.3-80%)
MC-AC	63.8% (47-80.6%)
AS-MC	83.4% (69.8-97%)
Combined score	
RE + AO-AC + MC-AC + AS-MC	95.1% (87.1-100%)

Table 4 shows the combination of four measures, or five temporal features.

FEASIBLE MODIFICATIONS OF THE INVENTION

[0083] The invention is not limited only to the embodiments described above in relation to the drawings, which primarily have an illustrative and exemplifying purpose. This patent application is intended to cover all adjustments and variants of the preferred embodiments described herein, thus the present invention is defined by the wording of the appended claims and the equivalents thereof. Thus, the equipment may be modified in all kinds of ways within the scope of the appended claims and the detailed description.

1. A method for quantifying heart failure, wherein the method comprises:

obtaining a plurality of segments of a signal recorded with an accelerometer placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, wherein each segment covers a cardiac cycle,

aligning the plurality of segments, filtering the plurality of segments with a band-pass filter having a lower cutoff frequency below 1 Hz and an upper cut-off frequency in the range 100-250 Hz, and determining a mean segment based on the plurality of segments,

determining a first temporal feature in the mean segment,

determining a measure based on at least one of the signal value, or amplitude, of the first temporal feature and the location in time of the first temporal feature, and

providing output information based on the determined measure.

2. The method according to claim **1**, wherein obtaining a plurality of segments of a signal recorded with an accelerometer comprises:

recording a signal with an accelerometer placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, wherein the signal is recorded over a period of time covering a plurality of cardiac cycles of the person, and

dividing the recorded signal into the plurality of segments, wherein each segment covers a single cardiac cycle.

3. The method according to claim **1**, wherein obtaining a plurality of segments of a signal recorded with an accelerometer comprises:

recording the signal with the accelerometer placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement,

recording an audio signal with a microphone placed on the chest of the person simultaneously to recording the signal with the accelerometer

identifying a plurality of heart sounds in the audio signal, wherein each heart sound relates to a single cardiac cycle, and dividing the recorded signal into the plurality of segments based on the identified plurality of heart sounds.

4. The method according to claim **1**, wherein

aligning the plurality of segments comprises: determining the second heart sound (S**2**) in each of the plurality of segments, and aligning the plurality of segments by the determined second heart sound (S**2**) of each segment.

5. The method according to claim **1**, wherein the measure is based on the signal value, or amplitude, of the first temporal feature.

6. The method according to claim **5**, wherein the first temporal feature corresponds to:

the aortic valve opening (AO) of a heart cycle,

the atrial systole (AS) of a heart cycle,

the isometric contraction (IM) of a heart cycle, or

the rapid ventricular ejection or rapid emptying event (RE) of a heart cycle.

7. The method according to claim **1**, wherein the method further comprises:

determining a second temporal feature in the mean segment, and wherein

determining a measure is further based on at least one of the signal value, or amplitude, of the second temporal feature and on the location in time of the second temporal feature.

8. The method according to claim **7**, wherein the measure is based on the location in time of the first temporal feature and on the location in time of the second temporal feature, and wherein determining a measure comprises: determining the difference between the location in time of the first temporal feature and the location in time of the second temporal feature, and wherein the measure is based on the determined difference.

9. The method according to claim **7**, wherein:

the first temporal feature corresponds to the mitral valve closure (MC) and the second temporal feature corresponds to the rapid ventricular ejection or rapid emptying event (RE), or

the first temporal feature corresponds to the atrial systole (AS) in the cardiac cycle and the second temporal feature corresponds to the mitral valve closure (MC) in the cardiac cycle, or

the first temporal feature corresponds to the aortic valve closing (AC) and the second temporal feature corresponds to the mitral valve opening (MO), or

the first temporal feature corresponds to the aortic valve opening (AO) and the second temporal feature corresponds to the aortic valve closing (AC), or

the first temporal feature corresponds to the mitral valve closure (MC) and the second temporal feature corresponds to the aortic valve opening (AO).

10. The method according to claim **1**, wherein the method further comprises: determining a first point in time in the mean segment corresponding to the onset of a heart sound (S**1** or S**2**), and determining a first temporal feature and/or the second temporal feature further comprises: determining the first temporal feature and/or the second temporal feature relative to the first point in time.

11. The method according to claim **1**, wherein the lower cutoff frequency is below 0.5 Hz, 0.2 Hz, or approximately 0.1 Hz.

12. The method according to claim **1**, wherein the upper cutoff frequency is in the range 175-225 Hz, or approximately 200 Hz, or in one of the ranges 100-150 Hz, 150-200 Hz, and 200-250 Hz.

13. A system for quantifying heart failure, wherein the system comprises:

(A) an accelerometer configured to be placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement,

(B) a processor operatively connected to the accelerometer and configured to:

obtain a plurality of segments of a signal recorded with the accelerometer,

align the plurality of segments, filter the plurality of segments with a band-pass filter having a lower cutoff frequency below 1 Hz and an upper cut-off frequency in the range 100-250 Hz, and determine a mean segment based on the plurality of segments,

determine a first temporal feature in the mean segment,

determine a measure based on at least one of the signal value, or amplitude, of the first temporal feature and the location in time of the first temporal feature, and

provide output information based on the determined measure.

14. A computer program product for being used in a system for quantifying heart failure comprising: (A) an accelerometer for being placed on the chest of a person for measuring accelerations and vibrations of the chest wall of the person caused by myocardial movement, and (B) a processor operatively connected with the accelerometer, the computer program product comprising program code instructions configured to, when executed by the processor of the system, cause the processor to:

obtain a signal with the accelerometer and form a plurality of segments from the signal, wherein each segment covers, or corresponds to, a cardiac cycle.

record a plurality of segments of a signal with the accelerometer,

align the plurality of segments, filter the plurality of segments with a band-pass filter having a lower cutoff frequency below 1 Hz and an upper cut-off frequency in the range 100-250 Hz, and determine a mean segment based on the plurality of segments,

determine a first temporal feature in the mean segment, determine a measure based on at least one of the signal value, or amplitude, of the first temporal feature and the location in time of the first temporal feature, and

provide output information based on the determined measure.

15. A non-transient memory on which a computer program product according to claim **14** is stored.

16. The method according to claim **8**, wherein:

the first temporal feature corresponds to the mitral valve closure (MC) and the second temporal feature corresponds to the rapid ventricular ejection or rapid emptying event (RE), or

the first temporal feature corresponds to the atrial systole (AS) in the cardiac cycle and the second temporal feature corresponds to the mitral valve closure (MC) in the cardiac cycle, or

the first temporal feature corresponds to the aortic valve closing (AC) and the second temporal feature corresponds to the mitral valve opening (MO), or

the first temporal feature corresponds to the aortic valve opening (AO) and the second temporal feature corresponds to the aortic valve closing (AC), or

the first temporal feature corresponds to the mitral valve closure (MC) and the second temporal feature corresponds to the aortic valve opening (AO).

* * * * *

patsnap

专利名称(译)	定量心动图
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[标]申请(专利权)人(译)	ACARIX
申请(专利权)人(译)	ACARIX A / S
当前申请(专利权)人(译)	ACARIX A / S
[标]发明人	SCHMIDT SAMUEL EMIL SOEGAARD PETER STRUIJK JOHANNES JAN
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摘要(译)

公开了对跳动的心脏的功能的量化，其中，通过放置在人的胸部上的加速度计来记录信号。形成信号的多个片段，这些片段被具有低截止频率低于1 Hz和高截止频率在100-250 Hz范围内的带通滤波器对准和滤波。然后确定平均分段，其中确定第一时间特征。然后基于第一时间特征的信号值或幅度和第一时间特征的时间位置中的至少一个来确定度量。然后将确定的度量作为输出信息提供。