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(54) Title: METHOD AND APPARATUS FOR DETERMINING INFORMATION INDICATIVE OF CARDIAC MALFUNCTIONS AND ABNORMALITIES

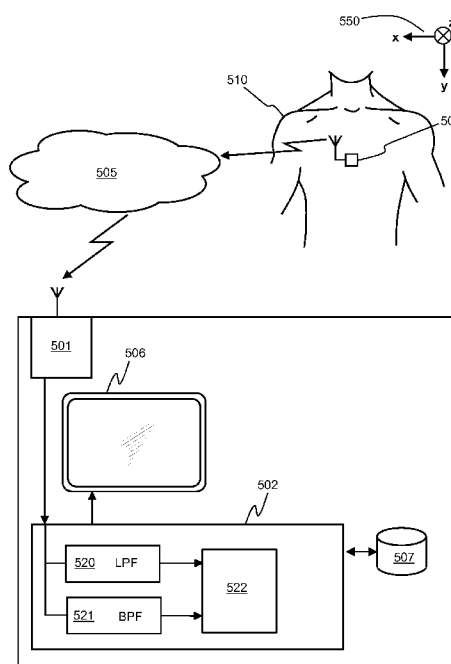


Figure 5

(57) Abstract: An apparatus for determining information indicative of cardiac malfunctions and abnormalities comprises a processing device (502) configured to detect amplitude variation from a signal indicative of cardiovascular motion, where the amplitude variation means variation of the amplitude of a wave pattern, e.g. the AO-peak, repeating on the heart-beat rate on the signal. The processing device is configured to determine, at least partly on the basis of the detected amplitude variation, an indicator of cardiac malfunction and abnormality.



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Method and apparatus for determining information indicative of cardiac malfunctions and abnormalities

Field of the invention

5 The invention relates generally to determining information indicative of cardiac malfunctions and abnormalities, such as for example atrial fibrillation. More particularly, the invention relates to an apparatus and to a method for determining information indicative of cardiac malfunctions and abnormalities. Furthermore, the invention relates to a computer program for determining information indicative of
10 cardiac malfunctions and abnormalities.

Background

Malfunctions and abnormalities that may occur in the cardiovascular system, if not diagnosed and appropriately treated or remedied, may progressively decrease the ability of the cardiovascular system to supply, inter alia, sufficient oxygen to satisfy
15 the coronary oxygen demand when the individual encounters stress. Currently, methods such as cardiography based on electromagnetic phenomena related to cardiac activity, echocardiography, and cardiography based on cardiovascular motion are used in the identification and assessment of various cardiac malfunctions and abnormalities. A well-known example of the cardiography based on electro-
20 magnetic phenomena related to cardiac activity is the electrocardiography "ECG", and examples of the cardiography based on cardiovascular motion are ballistocardiography "BCG" and seismocardiography "SCG". The echocardiography provides images of sections of the heart and can provide comprehensive information about the structure and function of the heart, but requires expensive equipment and specialised operating personnel. The ECG provides a fairly rapid electrical assessment of the heart but an inconveniency related to the ECG is the need to attach electrodes to the skin of the individual, which may result in skin irritation especially in long lasting and/or frequently repeating use. On the other hand, certain cardiac malfunctions and abnormalities such as, for example, atrial fibrillation may require
25 long lasting and/or repetitive measuring of cardiograph data. The cardiography
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based on cardiovascular motion involves measurement of a signal indicative of cardiovascular motion. Earlier, the signal was obtained while an individual lay on a bed that was provided with an apparatus for measuring movements or there was a facilitating apparatus that was attached across the shin area of the legs. Currently, the signal can be obtained using small sensor elements, e.g. accelerometers, which are suitable for measuring minute movements which are representative of movements of the heart.

Figures 1a and 1b show the relationship between rhythmic electrical functions and related cardiovascular motions. Figure 1a shows an example of an ECG waveform and figure 1b shows a waveform of an exemplifying signal indicative of cardiovascular motion and measured with an accelerometer in the “head-to-foot”-direction that is typically referred to as the y-direction. For the sake of illustrative purposes, a brief explanation of basic heart functions is provided below.

The heart includes four chambers. The right atrium is interconnected with the right ventricle by the tricuspid valve, and the left atrium is interconnected with the left ventricle by the mitral valve. Blood is delivered to the right atrium from the upper half of the body via the superior vena cava, and from the lower half of the body via the inferior vena cava. The tricuspid valve is opened by concurrent contraction of the right atrium myocardium and the right ventricular papillary muscles thereby allowing blood flow from the right atrium into the right ventricle. Then the tricuspid valve closes when the papillary muscles relax. When the myocardium of the right ventricle contracts, blood is forced from the right ventricle through the pulmonary valve into the pulmonary artery which delivers the blood into the lungs wherein it is oxygenated. The oxygenated blood is then delivered to the left atrium via pulmonary veins. The oxygenated blood flows from the left atrium into the left ventricle when the mitral valve is opened by concurrent contraction of the left atrium myocardium and the left ventricular papillary muscles thereby allowing blood flow from the left atrium into the left ventricle. Then the mitral valve is closed when the papillary muscles relax. The oxygenated blood is then forced out from the left ventricle through the aortic valve into the aorta which delivers the oxygenated blood to the peripheral vascular system.

Each heart-beat period involves three major stages: the atrial systole, the ventricular systole and the cardiac diastole. The atrial systole is the period of contraction of the heart muscles encompassing the right and left atria. Both atria contract concurrently with the papillary muscle contraction thereby forcing open the tricuspid valve and the mitral valve. The electrical activity, i.e. the electrical systole, which stimulates the muscle tissue of the chambers of the heart to make them contract begins in the sinoatrial node located in the right atrium. The conduction electrical depolarization continues to travel as a wave downwards, leftwards, and posteriorly through both atria depolarising each atrial muscle cell in turn. This propagation of charge can be seen as the P-wave on the ECG waveform shown in figure 1a. This is closely followed by mechanical contraction of the atria that is detected as an impact which corresponds to the h-peak of the waveform shown in figure 1b and to a recoil which corresponds to the i-valley of the waveform shown in figure 1b. When the right and left atria begin to contract, there is a high velocity flow of blood into the right and left ventricles, which is represented by the j-peak on the waveform shown in figure 1b. The continuing atrial contraction, when the tricuspid valve begins to close, causes an additional lower velocity flow of blood into the right and left ventricles. The additional flow of blood is called the "atrial kick", which corresponds to the "a-a¹"-wave complex in the waveform shown in figure 1b. After the atria are emptied, the tricuspid and mitral valves close thereby giving rise to the downward g-wave on the waveform shown in figure 1b. The ventricular systole is the contraction of the muscles of the left and right ventricles, and is caused by the electrical depolarization of the ventricular myocardia giving rise to the "Q-R-S" - wave complex in the ECG waveform shown in figure 1a. The downward Q-wave is caused by the downward flow of depolarisation through the septum along a specialized group of cells called "the bundle of His". The R-peak is caused by depolarization of the ventricular muscle tissue, and the S-wave is produced by depolarization of the heart tissue between the atria and ventricles. As the depolarization travels down the septum and throughout the ventricular myocardia, the atria and sinoatrial node start to polarise. The closing of the tricuspid and mitral valves mark the beginning of ventricular systole and cause the first part of the "lub-dub" sound made by the heart as it beats. This sound is typically known as the "first heart tone". When the electrical depolarization of the ventricular myocardia peaks, the

atrioventricular "AV" septum separating the right and left ventricles contracts causing an impact, which corresponds to the H-peak on the waveform shown in figure 1b, and a recoil which corresponds to the I-valley on the waveform shown in figure 1b. The ventricular contraction forces the blood from the right ventricle into the pulmonary artery through the pulmonary valve, and from the left ventricle into the aorta through the aortic valve under very high velocity thereby causing the J-peak on the waveform shown in figure 1b. The deceleration of blood flow from the left ventricle into the aorta causes the downward K-wave on the waveform shown in figure 1b. When the left ventricle empties, its pressure falls below the pressure in the aorta and the aortic valve closes. Similarly, when the pressure in the right ventricle falls below the pressure in the pulmonary artery, the pulmonary valve closes. The second part of the "lub-dub" sound, which is typically known as the "second heart tone", is caused by the closure of the pulmonary and aortic valves at the end of ventricular systole thereby causing the upward L-wave on the waveform shown in figure 1b. Concurrently with the closing of the pulmonary and aortic valves, the atrioventricular "AV" septum relaxes and moves upward, and the ventricular myocardia is re-polarized giving rise to the T-wave on the ECG waveform shown in figure 1a. The cardiac diastole, which includes the atrial diastole and the ventricular diastole, is the period when the heart relaxes after contraction and prepares for being refilled with circulating blood. Atrial diastole is when the right and left atria are relaxing, and the ventricular diastole is when the right and left ventricles are relaxing. During the period of the atrial diastole, the right atrium is re-filled by de-oxygenated blood while the left atrium is re-filled with oxygenated blood. Re-filling of the atria causes the downward M-wave on the waveform shown in figure 1b early in the diastole which coincides with repolarization of the bundle of His cells, which is shown as the U-wave in the ECG waveform. When the right and left atria are filled to their maximum capacities, the reflux of blood against the tricuspid valve and mitral valve cause the upward N-wave on the waveform shown in figure 1b.

Publication WO2012149652 describes a method for assessment of cardiac contractility in a subject by recording precordial acceleration signals.

Publication US2008194975 describes a method for monitoring an individual's physiological condition and detecting abnormalities therein. The method comprises concurrently receiving a first signal that is an ECG signal and a second signal indicative of cardiovascular motion.

- 5 Analysis of waveforms indicative of cardiovascular motion is typically performed visually by qualified diagnosticians in order to distinguish abnormal cardiovascular function from normal cases. In many cases, however, it may be challenging to find out certain cardiac malfunctions and abnormalities, such as for example atrial fibrillation, by visual analysis. Thus, a need exists for methods and apparatuses for
10 determining information indicative of cardiac malfunctions and abnormalities.

Summary

- The following presents a simplified summary in order to provide a basic understanding of some aspects of various invention embodiments. The summary is not an extensive overview of the invention. It is neither intended to identify key or critical elements of the invention nor to delineate the scope of the invention. The following summary merely presents some concepts of the invention in a simplified form as a prelude to a more detailed description of exemplifying embodiments of the invention.
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- In accordance with the invention, there is provided a new method for determining information indicative of cardiac malfunctions and abnormalities, e.g. atrial fibrillation. The method according to the invention comprises:
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- detecting amplitude variation from a signal indicative of cardiovascular motion, the amplitude variation being variation of amplitude of a wave pattern repeating on the heart-beat rate on the signal so that the amplitude variation includes a plurality of increases of the amplitude and a plurality of decreases of the amplitude, and
25
- determining, at least partly on the basis of the detected amplitude variation, an indicator of cardiac malfunction and abnormality.

The above-mentioned wave pattern can be, for example but not necessarily, the J-peak on the waveform shown in figure 1b, and the amplitude of the wave pattern can be the signal value of the top of the J-peak. For another example, the wave pattern can be the wave complex constituted by the J-peak and the downward K-wave on the waveform shown in figure 1b, and the amplitude of the wave pattern can be the peak-to-peak value from the bottom of the downward K-wave to the top of the J-peak. For one example, the wave pattern can be the AO-peak caused by openings of the aortic valve on a waveform measured in the "through chest"-direction that is typically referred to as the z-direction. For one example, the wave pattern can be the wave complex constituted by the AO-peak and the downward wave that follows the AO-peak.

Such cardiac malfunctions and abnormalities, e.g. atrial fibrillation, which may be sometimes challenging to diagnose, may however cause irregularities on the waveform of the signal indicative of cardiovascular motion. These irregularities may be difficult to detect from waveforms of one or two heart-beat periods but they may manifest themselves in longer time periods covering several heart-beat periods so that the amplitude of the wave pattern repeating on the heart-beat rate varies more strongly than in a normal case. Therefore, the amplitude variation represents information indicative of cardiac malfunction and abnormality.

A method according to an exemplifying embodiment of the invention further comprises detecting time variation from the signal, where the time variation is the variation of temporal lengths of heart-beat periods. The indicator of cardiac malfunction and abnormality can be determined on the basis of both the amplitude variation and the time variation in order to improve the reliability of the information indicative of cardiac malfunctions and abnormalities.

A method according to an exemplifying embodiment of the invention comprises low-pass filtering a signal indicative of cardiovascular motion and detecting AO-peaks from the low-pass filtered signal and/or band-pass filtering the signal indicative of the cardiovascular motion and detecting AC-peaks from the band-pass filtered signal, where the AO-peaks are caused by the openings of the aortic valve and the AC-peaks are caused by the closures of the aortic valve. The upper limit

- frequency of the low-pass filtering can be, for example but not necessarily, 30 Hz, and the pass-band of the band-pass filtering can be, for example but not necessarily, from 40 Hz to 100 Hz. The low-pass filtering and/or the pass-band filtering facilitate the detection of the AO- and/or AC-peaks. Especially during atrial fibrillation, the AC-peaks are easier to find when the band-pass filtering is used than when there is no band-pass filtering. The detected AO- and/or AC-peaks can be utilized when detecting for example the above-mentioned amplitude variation, the above-mentioned time variation, the heart-beat rate, the systolic intervals, and/or the diastolic intervals.
- 5
- 10 In accordance with the invention, there is provided also a new apparatus for determining information indicative of cardiac malfunctions and abnormalities. The apparatus according to the invention comprises:
- a signal interface for receiving a signal indicative of cardiovascular motion, and
 - 15 - a processing device coupled to the signal interface and configured to:
 - a) detect amplitude variation from the signal, the amplitude variation being variation of amplitude of a wave pattern repeating on the heart-beat rate on the signal so that the amplitude variation includes a plurality of increases of the amplitude and a plurality of decreases of the amplitude, and
 - 20 b) determine, at least partly on the basis of the detected amplitude variation, an indicator of cardiac malfunction and abnormality.

The apparatus may further comprise a sensor element for measuring the signal indicative of cardiovascular motion. The sensor element may comprise, for example, an accelerometer, a piezo-electronic sensor, an inclinometer, a pressure sensor, or any other element suitable for measuring force, acceleration, displacement, or any other quantity related to and indicative of cardiovascular motion. It is also possible that the signal interface is capable of receiving the signal from an external device comprising a sensor element, i.e. it is emphasized that the apparatus does

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not necessarily comprise any sensor element for measuring the signal indicative of cardiovascular motion.

An advantage of using the signal indicative of cardiovascular motion with respect to the ECG is that there is no need to provide electrical contact to the individual's skin and thus the skin irritation can be significantly minor especially in long lasting and/or repetitive use. Furthermore, the sensor element can be integrated to clothes and it can be provided with a radio transmitter which transmits the measured signal over a radio link. This facilitates long lasting and repetitive measurements.

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- 10 An apparatus according to an exemplifying embodiment of the invention comprises a low-pass filter for low-pass filtering a signal indicative of the cardiovascular motion and means, e.g. a processor, for detecting the AO-peaks from the low-pass filtered signal and/or a band-pass filter for band-pass filtering the signal indicative of the cardiovascular motion and means for detecting the AC-peaks from the
- 15 band-pass filtered signal.

In accordance with the invention, there is provided also a new computer program for determining information indicative of cardiac malfunctions and abnormalities. The computer program comprises computer executable instructions for controlling a programmable processor to:

- 20
- detect amplitude variation from a signal indicative of cardiovascular motion, the amplitude variation being variation of amplitude of a wave pattern repeating on the heart-beat rate on the signal, and
 - determine, at least partly on the basis of the detected amplitude variation, an indicator of cardiac malfunction and abnormality.

- 25 A computer program according to an exemplifying embodiment of the invention comprises computer executable instructions for controlling a programmable processor to low-pass filter a signal indicative of the cardiovascular motion and to detect the AO-peaks from the low-pass filtered signal and/or computer executable instructions for controlling the programmable processor to band-pass filter the sig-

nal indicative of the cardiovascular motion and to detect the AC-peaks from the band-pass filtered signal.

In accordance with the invention, there is provided also a new computer program product. The computer program product comprises a non-volatile computer readable medium, e.g. a compact disc "CD", encoded with a computer program according to the invention.

A number of exemplifying embodiments of the invention are described in accompanied dependent claims.

Various exemplifying embodiments of the invention both as to constructions and to methods of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific exemplifying embodiments when read in connection with the accompanying drawings.

The verbs "to comprise" and "to include" are used in this document as open limitations that neither exclude nor require the existence of also un-recited features. The features recited in depending claims are mutually freely combinable unless otherwise explicitly stated.

Brief description of the figures

The exemplifying embodiments of the invention and their advantages are explained in greater detail below with reference to the accompanying drawings, in which:

figure 1a illustrates an example of an ECG waveform and figure 1b illustrates a waveform of an exemplifying signal indicative of cardiovascular motion and measured with an accelerometer in the "head-to-foot"-direction that is typically referred to as the y-direction,

figure 2a illustrates a flow chart of a method according to an exemplifying embodiment of the invention for determining information indicative of cardiac malfunctions and abnormalities,

figure 2b illustrates a flow chart of a method according to an exemplifying embodiment of the invention for extracting AO data and/or AC data from a signal indicative of the cardiovascular motion,

figure 3a illustrates a waveform of an exemplifying signal indicative of cardiovascular motion over several heart-beat periods in a normal case when a person under consideration holds breath, figure 3b illustrates a waveform of an exemplifying signal indicative of cardiovascular motion over several heart-beat periods in a case of atrial fibrillation when a person under consideration holds breath, these waveforms have been measured with an accelerometer in the “through chest”-direction that is typically referred to as the z-direction,

figure 3c shows a part of the waveform shown in figure 3b,

figure 3d illustrates a waveform of an exemplifying signal indicative of cardiovascular motion over several heart-beat periods in a normal case when a person under consideration is breathing, figure 3e illustrates a waveform of an exemplifying signal indicative of cardiovascular motion over several heart-beat periods in a case of atrial fibrillation when a person under consideration is breathing, these waveforms have been measured with an accelerometer in the “through chest”-direction that is typically referred to as the z-direction,

figure 4 illustrates an exemplifying time variation in a normal case, solid line, and an exemplifying time variation in a case of atrial fibrillation, dashed line, and

figure 5 shows a schematic illustration of an apparatus according to an exemplifying embodiment of the invention for determining information indicative of cardiac malfunctions and abnormalities.

Figures 1a and 1b have already been explained when describing the background of the invention.

Description of the exemplifying embodiments

Figure 2a illustrates a flow chart of a method according to an exemplifying embodiment of the invention for determining information indicative of cardiac malfunction-

tions and abnormalities, e.g. atrial fibrillation. The method comprises in a phase 201 detecting amplitude variation from a signal indicative of cardiovascular motion, where the amplitude variation means variation of amplitude of a wave pattern repeating on the heart-beat rate on the signal. The method comprises in a phase 5 202 determining, at least partly on the basis of the detected amplitude variation, an indicator of cardiac malfunction and abnormality.

Figure 3a illustrates an exemplifying waveform of the above-mentioned signal over several heart-beat periods in an exemplifying normal case when a person under consideration holds breath, and figure 3b illustrates an exemplifying waveform of the signal over several heart-beat periods in an exemplifying case of atrial fibrillation when a person under consideration holds breath. The waveforms shown in 10 figures 3a and 3b have been measured with an accelerometer in the “through chest”-direction that is typically referred to as the z-direction. A coordinate system 550 shown in figure 5 illustrates the z-direction.

15 The amplitude variation in the normal case is illustrated by an envelope curve 311 shown in figure 3a, and the amplitude variation in the exemplifying case of atrial fibrillation is illustrated with an envelope curve 312 shown in figures 3b and 3c. As can be seen from figure 3b, the amplitude variation includes a plurality of increases of the amplitude and a plurality of decreases of the amplitude within about ten 20 successive heart-beat periods HB, and the increases and the decreases are interleaved with each other in a substantially stochastic way. As illustrated by figures 3a and 3b, the strength of the amplitude variation represents information indicative of cardiac malfunction and abnormality.

Figure 3d illustrates an exemplifying waveform of the above-mentioned signal over 25 several heart-beat periods in an exemplifying normal case when a person under consideration is breathing, and figure 3e illustrates an exemplifying waveform of the signal over several heart-beat periods in an exemplifying case of atrial fibrillation when a person under consideration is breathing. The waveforms shown in figures 3d and 3e have been measured with an accelerometer in the “through chest”-direction that is typically referred to as the z-direction. A coordinate system 30 550 shown in figure 5 illustrates the z-direction. The amplitude variation in the

normal case is illustrated by an envelope curve 321 shown in figure 3d, and the amplitude variation in the exemplifying case of atrial fibrillation is illustrated with an envelope curve 322 shown in figure 3e. As can be seen from figure 3d, the amplitude variation in the normal case has a clear signal component having the frequency of the breathing rhythm. As can be seen from figure 3e, there is no clear signal component having the frequency of the breathing rhythm in the case of atrial fibrillation.

In a method according to an exemplifying embodiment of the invention:

- 10 - the detection of the amplitude variation, i.e. the phase 201 shown in figure 2a, comprises computing the above-mentioned signal component of the amplitude variation having the frequency of the respiratory rhythm, and
- 15 - the determining of the indicator of cardiac malfunction and abnormality, i.e. the phase 202, comprises determining the indicator of cardiac malfunction and abnormality at least partly on the basis of the strength of the signal component of the amplitude variation having the frequency of the respiratory rhythm.

The signal component of the amplitude variation having the frequency of the respiratory rhythm can be computed, for example, in the same way as a Fourier component having a given frequency is computed, i.e. by correlating a time trend of the amplitude with sine and/or cosine functions having the frequency of the respiratory rhythm.

The above-mentioned signal component of the amplitude variation having the frequency of the respiratory rhythm is indicative of cardiac malfunction and abnormality, and it can be compared to a threshold in order to detect occurrence of cardiac malfunction and abnormality. The threshold can be determined on the basis of empirical data gathered from a group of patients and/or other persons. The threshold is not necessary a constant but the threshold can be changing according to the individual under consideration, according to time, and/or according to some other factors. It is also possible to construct a series of thresholds so that each

threshold represents a specific probability of atrial fibrillation or some other cardiac malfunction and/or abnormality.

Figure 3c shows a part of the waveform shown in figure 3b. The waveform comprises AO-peaks caused by openings of the aortic valve and downwards waves
 5 MA each of which takes place just after the respective AO-peak.

In a method according to an exemplifying embodiment of the invention:

- the detection of the amplitude variation, i.e. the phase 201 shown in figure 2a, comprises detecting peak-to-peak values related to wave complexes each of which being constituted by the AO-peak and the downward wave
 10 MA following the AO-peak, and
- the determining of the indicator of cardiac malfunction and abnormality, i.e. the phase 202, comprises computing an amplitude variation quantity indicative of the strength of the variation of the detected peak-to-peak values.

The amplitude variation quantity is indicative of cardiac malfunction and abnormali-
 15 ty and it can be compared to a threshold in order to detect occurrence of cardiac malfunction and abnormality. The threshold can be determined on the basis of empirical data gathered from a group of patients and/or other persons. The threshold is not necessary a constant but the threshold can be changing according to the individual under consideration, according to time, and/or according to some
 20 other factors. It is also possible to construct a series of thresholds so that each threshold represents a specific probability of atrial fibrillation or some other cardiac malfunction and/or abnormality.

The amplitude variation quantity can be, for example:

$$\text{RMS}_{p-p} - \text{AVE}_{p-p},$$

25 where RMS_{p-p} is the root-mean-square "RMS" of the detected peak-to-peak values and AVE_{p-p} is the arithmetic average of the detected peak-to-peak values. For another example, the strength of the amplitude variation can be expressed with the aid of the standard deviation of the detected peak-to-peak values, i.e. amplitude

variation quantity can be the standard deviation of the detected peak-to-peak values.

Furthermore, the amplitude variation quantity can be indicative of variation of a ratio $S1/S2$ or of a difference $S1 - S2$, where:

- 5 - $S1$ is a signal indicative of cardiovascular motion measured in the “through chest”-direction, i.e. the z-direction, and
- $S2$ is a signal indicative of cardiovascular motion measured in the “head-to-foot”-direction, i.e. the y-direction.

The coordinate system 550 shown in figure 5 illustrates the y- and z-directions.

- 10 Especially, the signal $S1$ can be the OA-peak shown in figure 3c and the signal $S2$ can be the J-peak shown in figure 1b.

- Each peak value, e.g. the height of a single AO-peak shown in figure 3c, can be taken as a single point by searching a local maximum. Alternatively, the peak value can be obtained so that many samples are taken first from a time-window covering the peak under consideration and then the peak value is computed as a mathematical function, e.g. an arithmetic mean, of the samples in order to mitigate the effect of noise. The time window can be e.g. 100 ms, and the number of samples within the time window can be e.g. ten or more. The method based on the time-window is an example of digital filtering. Generally, there are numerous digital and analogue signal processing methods that can be used for mitigating the effect of noise in the signals indicative of cardiovascular motion.
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It is to be noted that there are numerous ways to express the strength of the amplitude variation and the present invention is not limited to any particular ways of expressing the strength of the amplitude variation.

- 25 In a method according to another exemplifying embodiment of the invention:
 - the detection of the amplitude variation, i.e. the phase 201 shown in figure 2a, comprises detecting maximum signal values of the AO-peaks, and

- the determining of the indicator of cardiac malfunction and abnormality, i.e. the phase 202, comprises computing an amplitude variation quantity indicative of the strength of the variation of the detected maximum signal values.

A solid curve 401 in figure 4 illustrates variation of temporal lengths of successive heart-beat periods, i.e. the time variation, in an exemplifying normal case. The temporal length of a single heart-beat period is denoted with "HB" in figure 3b. A dashed curve 402 in figure 4 illustrates the time variation in an exemplifying case of atrial fibrillation. As illustrated by figure 4, also the strength of the time variation represents information indicative of cardiac malfunction and abnormality.

- 10 A method according to an exemplifying embodiment of the invention comprises, in addition to utilizing the amplitude variation, detecting the time variation from the signal indicative of cardiovascular motion. The indicator of cardiac malfunction and abnormality is advantageously determined on the basis of both the amplitude variation and the time variation in order to improve the reliability of the information indicative of cardiac malfunctions and abnormalities.

In a method according to an exemplifying embodiment of the invention, the detection of the time variation comprises detecting temporal lengths of time intervals between successive AO-peaks, and computing a time variation quantity that is indicative of the strength of the variation of the detected temporal lengths.

- 20 The indicator of cardiac malfunction and abnormality can be formed, for example, with the aid of a mathematical or logical operation from the amplitude variation quantity indicative of the strength of the amplitude variation and the time variation quantity indicative of the strength of the time variation. It is also possible that the amplitude variation quantity and the time variation quantity are used separately; e.g. each of them is compared to its own threshold.

- 25 A method according to an exemplifying embodiment of the invention comprises producing a signal expressing that atrial fibrillation is taking place in response to a situation in which at least one of the following takes place: the strength of the amplitude variation exceeds a first threshold, the strength of the time variation exceeds a second threshold. In this exemplifying embodiment, the risk that atrial fi-
- 30

brillation remains undetected is reduced by indicating the occurrence of the atrial fibrillation if at least one of the amplitude variation and the time variation indicates the occurrence.

5 A method according to another exemplifying embodiment of the invention comprises producing a signal expressing that atrial fibrillation is taking place if and only if the strength of the amplitude variation exceeds a first threshold and the strength of the time variation exceeds a second threshold. In this exemplifying embodiment, the risk of false alarms is reduced by indicating the occurrence of the atrial fibrillation if and only if both the amplitude variation and the time variation indicate the
10 occurrence.

Figure 2b illustrates a flow chart of a method according to an exemplifying embodiment of the invention for extracting AO data and/or AC data from a signal indicative of the cardiovascular motion. The signal indicative of the cardiovascular motion is advantageously measured with an accelerometer in the “through chest”-
15 direction that is typically referred to as the z-direction. The method comprises the following actions:

- action 211: low-pass filtering the signal indicative of the cardiovascular motion and/or band-pass filtering the signal indicative of the cardiovascular motion, and
- 20 - action 212: detecting the AO-peaks from the low-pass filtered signal and/or detecting the AC-peaks from the band-pass filtered signal.

The upper limit frequency of the low-pass filtering can be, for example but not necessarily, 30 Hz, and the pass-band of the band-pass filtering can be, for example but not necessarily, from 40 Hz up to 100 Hz. The low-pass filtering and/or the
25 pass-band filtering facilitate the detection of the AO- and/or AC-peaks. The detected AO- and/or AC-peaks can be utilized when detecting for example the above-mentioned amplitude variation and/or the above-mentioned time variation. The detected AO- and/or AC-peaks can be used for many other purposes too, e.g. for detecting the heart-beat rate, the systolic intervals, and/or the diastolic intervals.

A method according to an exemplifying embodiment of the invention comprises detecting temporal lengths of AC-AO intervals and computing a time variation quantity indicative of strength of variation of the detected temporal lengths of the AC-AO intervals, where each of the AC-AO intervals is a time interval from one of the AC-peaks to the following one of the AO-peaks and the time variation quantity is indicative of cardiac malfunction and abnormality.

A method according to an exemplifying embodiment of the invention comprises detecting temporal lengths of AC-AO intervals and temporal lengths of AO-AO intervals and computing a ratio quantity indicative of the ratio between the temporal length of the AC-AO interval and the temporal length of the AO-AO interval within a same heart-beat period. Each of the AC-AO intervals is a time interval from one of the AC-peaks to the following one of the AO-peaks, each of the AO-AO intervals is a time interval from one of the AO-peaks to the following one of the AO-peaks, and the ratio quantity is indicative of cardiac malfunction and abnormality.

A method according to an exemplifying embodiment of the invention comprises optionally measuring the signal indicative of cardiovascular motion with a sensor element from an individual's body. A method according to another exemplifying embodiment of the invention comprises reading this signal from a memory, in which case the signal has been measured earlier and recorded to the memory. A method according to an exemplifying embodiment of the invention comprises receiving the signal from an external data transfer system. Hence, the measuring is not an essential and necessary step of methods according to embodiments of the invention.

Figure 5 illustrates a schematic illustration of an apparatus according to an exemplifying embodiment of the invention for determining information indicative of cardiac malfunctions and abnormalities. The apparatus comprises a signal interface 501 for receiving a signal indicative of cardiovascular motion, and a processing device 502 coupled to the signal interface. The processing device is configured to:

- detect amplitude variation from the signal, the amplitude variation being variation of amplitude of a wave pattern repeating on the heart-beat rate on the signal, and

- determine, at least partly on the basis of the amplitude variation, an indicator of cardiac malfunction and abnormality.

The indicator can be, for example, a message shown on a display screen 506.

In an apparatus according to an exemplifying embodiment of the invention, the
5 signal interface 501 is further configured to receive information indicative of frequency of a respiratory rhythm and the processing device 502 is configured to:

- compute a signal component of the amplitude variation having the frequency of the respiratory rhythm, and
- determine the indicator of cardiac malfunction and abnormality at least part-
10 ly on the basis of the signal component of the amplitude variation having the frequency of the respiratory rhythm.

In an apparatus according to an exemplifying embodiment of the invention, the processing device 502 is configured to produce a signal expressing atrial fibrillation in response to a situation in which the signal component of the amplitude vari-
15 ation having the frequency of the respiratory rhythm is less than a pre-determined threshold.

An apparatus according to an exemplifying embodiment of the invention further comprises a sensor element 503 for measuring the signal indicative of cardiovascular motion from individual's body 510. The sensor element is connected to the
20 signal interface via a data transfer link that can be, for example, a radio link or a corded link. The data transfer from the sensor element 503 to the signal interface 501 may take place either directly or via a data transfer network 505 such as e.g. a telecommunications network. It is also possible that the apparatus comprising the processing device is integrated with the sensor element. In this case, the signal
25 interface is actually a simple wiring between the sensor element 503 and the processing device 502. In an apparatus according to an exemplifying embodiment of the invention, the sensor element 503 is also suitable for providing the information indicative of the frequency of the respiratory rhythm.

The sensor element 503 may comprise, for example, an accelerometer, a piezo-electronic sensor, an inclinometer, a pressure sensor, or any other element suitable for measuring force, acceleration, displacement, or any other physical quantity related to and indicative of cardiovascular motion. The sensor element may further
5 comprise, for example, an amplifier, a signal filter, and/or an analog-to-digital "AD" converter. An accelerometer can be, for example, a three-axis accelerometer which is capable of measuring movements independently in three mutually orthogonal directions x, y, and z of e.g. the coordinate system 550 shown in figure 5. In this case, the signal indicative of cardiovascular motion comprises three com-
10 ponents and the signal can be, for example, pre-processed by forming its Euclidian norm, i.e. the absolute value of the three component vector indicative of cardiovascular motion.

An apparatus according to an exemplifying embodiment of the invention is configured to record the signal within a time window having a fixed temporal start point
15 and a fixed temporal end point or within a sliding time window having a fixed temporal length and moving along with elapsing time. The apparatus may comprise an internal memory 507 for recording the signal or the apparatus may comprise a data port for connecting to an external memory.

In an apparatus according to an exemplifying embodiment of the invention, the
20 processing device 502 is configured to detect peak-to-peak values related to wave complexes each of which being constituted by the AO-peak caused by opening of the aortic valve and the downward wave following the AO-peak, and to compute an amplitude variation quantity indicative of the strength of the variation of the detected peak-to-peak values.

25 In an apparatus according to an exemplifying embodiment of the invention, the processing device 502 is configured to detect maximum signal values of the AO-peaks, and to compute an amplitude variation quantity indicative of the strength of the variation of the detected maximum signal values.

In an apparatus according to an exemplifying embodiment of the invention, the
30 processing device 502 is configured to detect time variation from the signal and to

determine the indicator of cardiac malfunction and abnormality on the basis of both the amplitude variation and the time variation.

In an apparatus according to an exemplifying embodiment of the invention, the processing device 502 is configured to detect temporal lengths of time intervals
5 between successive AO-peaks, and to compute a time variation quantity indicative of the strength of the variation of the detected temporal lengths.

In an apparatus according to an exemplifying embodiment of the invention, the processing device 502 is configured to produce a signal expressing atrial fibrillation in response to a situation in which at least one of the following takes place: the
10 strength of the amplitude variation exceeds a first threshold, the strength of the time variation exceeds a second threshold, the signal component of the amplitude variation having the frequency of the respiratory rhythm is less than a third threshold.

In an apparatus according to an exemplifying embodiment of the invention, the
15 processing device 502 is configured to low-pass filter the signal indicative of the cardiovascular motion and to detect the above-mentioned AO-peaks from the low-pass filtered signal. A functional block 520 shown in figure 5 represents of the low-pass filtering, and a functional block 522 represents the detection of the AO-peaks.

In an apparatus according to an exemplifying embodiment of the invention, the
20 processing device 502 is configured to band-pass filter the signal indicative of the cardiovascular motion and to detect AC-peaks from the band-pass filtered signal, the AC-peaks being caused by the closures of the aortic valve. A functional block 521 shown in figure 5 represents of the band-pass filtering, and the functional block 522 represents the detecting the AC-peaks. In the exemplifying case illustrated in figure 5, there are both the low-pass filtering and the band-pass filtering
25 and the functional block 522 represents the detection of both the AO- and AC-peaks. The upper limit frequency of the low-pass filtering can be, for example but not necessarily, 30 Hz, and the pass-band of the band-pass filtering can be, for example but not necessarily, from 40 Hz up to 100 Hz. The low-pass filtering
30 and/or the pass-band filtering facilitate the detection of the AO- and/or AC-peaks. The detected AO- and/or AC-peaks can be utilized when detecting for example the

above-mentioned amplitude variation and/or the above-mentioned time variation. The detected AO- and/or AC-peaks can be used for many other purposes too, e.g. for detecting the heart-beat rate, the systolic intervals, and/or the diastolic intervals.

- 5 In an apparatus according to an exemplifying embodiment of the invention, the processing device 502 is configured to detect temporal lengths of AC-AO intervals and to compute a time variation quantity indicative of strength of variation of the detected temporal lengths of the AC-AO intervals. Each of the AC-AO intervals is a time interval from one of the AC-peaks to the following one of the AO-peaks and
10 the time variation quantity is indicative of cardiac malfunction and abnormality.

In an apparatus according to an exemplifying embodiment of the invention, the processing device 502 is configured to detect temporal lengths of AC-AO intervals and temporal lengths of AO-AO intervals and to compute a ratio quantity indicative of the ratio between the temporal length of the AC-AO interval and the temporal
15 length of the AO-AO interval within a same heart-beat period. Each of the AC-AO intervals is a time interval from one of the AC-peaks to the following one of the AO-peaks, each of the AO-AO intervals is a time interval from one of the AO-peaks to the following one of the AO-peaks, and the ratio quantity is indicative of cardiac malfunction and abnormality.

- 20 The processing device 502 can be, for example, implemented with one or more processor circuits, each of which can be a programmable processor circuit provided with appropriate software, a dedicated hardware processor such as, for example, an application specific integrated circuit "ASIC", or a configurable hardware processor such as, for example, a field programmable gate array "FPGA".

- 25 An apparatus according to an exemplifying embodiment of the invention comprises means for pre-processing the signal indicative of cardiovascular motion prior to the detection of the amplitude variation. The pre-processing may comprise, for example, cancellation of noise caused by e.g. breathing, non-cardiovascular movements of the individual, tremble caused by external reasons, etc. The means for
30 the pre-processing can be, for example, implemented with the processing device

502 or there can be one or more separate processing devices for the pre-processing.

A computer program according to an exemplifying embodiment of the invention comprises software modules for determining information indicative of cardiac mal-
5 functions and abnormalities. The software modules comprise computer executable instructions for controlling a programmable processor to:

- detect amplitude variation from a signal indicative of cardiovascular motion, the amplitude variation being variation of amplitude of a wave pattern repeating on the heart-beat rate on the signal, and
- 10 - determine, at least partly on the basis of the amplitude variation, an indicator of cardiac malfunction and abnormality.

In a computer program according to an exemplifying embodiment of the invention, the software modules further comprise computer executable instructions for controlling the programmable processor to:

- 15 - compute a signal component of the amplitude variation having a frequency of a respiratory rhythm, and
- determine the indicator of cardiac malfunction and abnormality at least partly on the basis of the signal component of the amplitude variation having the frequency of the respiratory rhythm.

20 The software modules can be e.g. subroutines or functions implemented with a suitable programming language and with a compiler suitable for the programming language and the programmable processor.

In a computer program according to an exemplifying embodiment of the invention, the software modules comprise at least one of the following:

- 25 - computer executable instructions for controlling a programmable processor to low-pass filter a signal indicative of the cardiovascular motion and to detect the AO-peaks from the low-pass filtered signal, and/or

- computer executable instructions for controlling a programmable processor to band-pass filter the signal indicative of the cardiovascular motion and to detect the AC-peaks from the band-pass filtered signal.

A computer program product according to an exemplifying embodiment of the invention comprises a computer readable medium, e.g. a compact disc ("CD"), encoded with a computer program according to an embodiment of invention.

A signal according to an exemplifying embodiment of the invention is encoded to carry information defining a computer program according to an embodiment of invention.

Certain exemplifying new technologies for determining information indicative of cardiac malfunctions and abnormalities are based on the autocorrelation and/or the frequency spectrum of a signal indicative of cardiovascular motion.

The autocorrelation, as a general concept, has the property that, when irregularity of the waveform of a signal under consideration increases, the autocorrelation gets more and more concentrated to a point that corresponds to zero time-shift between signal samples whose mutual correlation is expressed by the autocorrelation. The autocorrelation R_e of an example signal $S_e(t)$ can be defined, for example, as:

$$R_e(\tau) = E\{ (S_e(t) - \mu) \times (S_e(t - \tau) - \mu) \} / \sigma^2,$$

where E is the expected value operator, i.e. $E\{\text{signal}\}$ is the expected value of the signal, t is time, τ is a time-shift between signal samples whose mutual correlation is expressed by $R_e(\tau)$, and μ and σ^2 are the mean and the variance of the example signal $S_e(t)$. For example, if the example signal $S_e(t)$ were ideal white noise "IWN" which has extremely irregular waveform, there would be zero correlation between any signal samples separated by a non-zero time-shift, and thus the autocorrelation $R_e(\tau)$ of the example signal would be only a single peak at the point $\tau = 0$.

Such cardiac malfunctions and abnormalities, e.g. atrial fibrillation, which may be sometimes challenging to diagnose, may however cause irregularities on the waveform of the signal indicative of cardiovascular motion. These irregularities

may be difficult to detect from waveforms of one or two heart-beat periods but they manifest themselves in longer time periods covering several successive heart-beat periods so that the autocorrelation is more concentrated on the point that corresponds to zero time-shift than normally. Therefore, a quantity that indicates the degree of concentration of the autocorrelation to the point that corresponds to the zero time-shift represents information indicative of cardiac malfunctions and abnormalities, e.g. atrial fibrillation.

The obtaining the quantity indicating the degree of concentration of the autocorrelation can be based on computing an estimate of the autocorrelation or on computing an estimate of the frequency spectrum of the signal. The frequency spectrum is closely related to the autocorrelation because the power spectral density "PSD" $\sim F(f) \times F^*(f)$ is the Fourier transformation of the autocorrelation, where $F(f)$ and $F^*(f)$ are the frequency spectrum and its complex conjugate. The frequency spectrum, as a general concept, has the property that, when irregularity of the waveform of a signal under consideration increases, the frequency spectrum gets more and more evenly distributed. For example, if an example signal were ideal white noise "IWN" which has extremely irregular waveform, the frequency spectrum of the example signal would be totally flat. This property of the frequency spectrum can be used for obtaining the quantity indicating the degree of concentration of the autocorrelation.

Certain exemplifying new apparatuses for determining information indicative of cardiac malfunctions and abnormalities are described below with the aid of numbered Clauses 1-6:

Clause 1. An apparatus comprising:

- a signal interface for receiving a signal indicative of cardiovascular motion, and
- a processing device coupled to the signal interface and configured to:
 - a) form an estimate of at least one of the following: the autocorrelation of the signal, the frequency spectrum of the signal, and

- b) form an indicator quantity that indicates the degree of concentration of the autocorrelation of the signal to a point that corresponds to zero time-shift between signal samples whose mutual correlation is expressed by the autocorrelation, the indicator quantity being indicative of cardiac malfunction and abnormality.

Clause 2. An apparatus according to Clause 1, wherein the apparatus further comprises a sensor element for measuring the signal, the sensor element being connected to the signal interface via a data transfer link.

Clause 3. An apparatus according to Clause 2, wherein the sensor element comprises one of the following: an accelerometer, a piezo-electronic sensor, an inclinometer, a microphone, a pressure sensor.

Clause 4. An apparatus according to any of Clauses 1-3, wherein the processing device is configured to produce an indicator of atrial fibrillation in response to a situation in which the ratio $P_{\max} / B_R$ is at least 1.3, where $P_{\max}$ is a value of the highest peak of the estimate of the autocorrelation and B_R is an average of values of one or more next highest peaks of the estimate of the autocorrelation, the ratio $P_{\max} / B_R$ representing the indicator quantity.

Clause 5. An apparatus according to any of Clauses 1-3, wherein the processing device is configured to produce an indicator of atrial fibrillation in response to a situation in which the ratio $P_{\max} / B_R$ is at least 1.4, where $P_{\max}$ is a value of the highest peak of the estimate of the autocorrelation and B_R is an average of values of one or more next highest peaks of the estimate of the autocorrelation, the ratio $P_{\max} / B_R$ representing the indicator quantity.

Clause 6. An apparatus according to any of Clauses 1-3, wherein the processing device is configured to produce an indicator of atrial fibrillation in response to a situation in which the ratio $P_{\max} / B_R$ is at least 1.4, where $P_{\max}$ is a value of the highest peak of the estimate of the autocorrelation and B_R is an average of values of one or more next highest peaks of the estimate of the autocorrelation, the ratio $P_{\max} / B_R$ representing the indicator quantity.

Certain exemplifying new methods for determining information indicative of cardiac malfunctions and abnormalities are described below with the aid of numbered Clauses 7-10:

Clause 7. A method comprising:

- 5 - forming an estimate of at least one of the following: the autocorrelation of a signal indicative of cardiovascular motion, the frequency spectrum of the signal, and
- 10 - forming an indicator quantity that indicates the degree of concentration of the autocorrelation of the signal to a point that corresponds to zero time-shift between signal samples whose mutual correlation is expressed by the autocorrelation, the indicator quantity being indicative of cardiac malfunction and abnormality.

Clause 8. A method according to Clause 7, wherein the method comprises producing an indicator of atrial fibrillation in response to a situation in which the ratio
15 $P_{\max} / B_R$ is at least 1.3, where $P_{\max}$ is a value of the highest peak of the estimate of the autocorrelation and B_R is an average of values of one or more next highest peaks of the estimate of the autocorrelation, the ratio $P_{\max} / B_R$ representing the indicator quantity.

Clause 9. A method according to Clause 7, wherein the method comprises producing an indicator of atrial fibrillation in response to a situation in which the ratio
20 $P_{\max} / B_R$ is at least 1.4, where $P_{\max}$ is a value of the highest peak of the estimate of the autocorrelation and B_R is an average of values of one or more next highest peaks of the estimate of the autocorrelation, the ratio $P_{\max} / B_R$ representing the indicator quantity.

25 Clause 10. A method according to Clause 7, wherein the method comprises producing an indicator of atrial fibrillation in response to a situation in which the ratio $P_{\max} / B_R$ is at least 1.4, where $P_{\max}$ is a value of the highest peak of the estimate of the autocorrelation and B_R is an average of values of one or more next highest

peaks of the estimate of the autocorrelation, the ratio $P_{\max} / B_R$ representing the indicator quantity.

A new computer program for determining information indicative of cardiac malfunctions and abnormalities is described below with the aid of a numbered Clause 11.

5 Clause 11. A computer program comprising computer executable instructions for controlling a programmable processor to:

- form an estimate of at least one of the following: the autocorrelation of a signal indicative of cardiovascular motion, the frequency spectrum of the signal, and

10 - form an indicator quantity that indicates the degree of concentration of the autocorrelation of the signal to a point that corresponds to zero time-shift between signal samples whose mutual correlation is expressed by the autocorrelation, the indicator quantity being indicative of cardiac malfunction and abnormality.

15 A new computer program product for determining information indicative of cardiac malfunctions and abnormalities is described below with the aid of a numbered Clause 12.

Clause 12. A computer program product comprising a non-transitory computer readable medium encoded with a computer program according to Clause 11.

20 The specific examples provided in the description given above should not be construed as limiting the scope and/or the applicability of the appended claims. Furthermore, it is also to be noted that, in many cases, the present invention can be used together with other techniques for detecting cardiac malfunctions and abnormalities.

What is claimed is:

1. An apparatus comprising:

- a signal interface (501) for receiving a signal indicative of cardiovascular motion, and
- 5 - a processing device (502) coupled to the signal interface,

characterized in that the processing device is configured to:

- detect amplitude variation from the signal, the amplitude variation being variation of amplitude of a wave pattern repeating on a heart-beat rate on the signal so that the amplitude variation includes a plurality of increases of the amplitude and a plurality of decreases of the amplitude, and
- 10 - determine, at least partly on the basis of the amplitude variation, an indicator of cardiac malfunction and abnormality.

2. An apparatus according to claim 1, wherein the signal interface is further configured to receive information indicative of frequency of a respiratory rhythm and the processing device is configured to:

15

- compute a signal component of the amplitude variation having the frequency of the respiratory rhythm, and
- determine the indicator of cardiac malfunction and abnormality at least partly on the basis of the signal component of the amplitude variation having the frequency of the respiratory rhythm.
- 20

3. An apparatus according to claim 1, wherein the apparatus further comprises a sensor element (503) for measuring said signal, the sensor element being connected to the signal interface.

4. An apparatus according to claim 3, wherein the sensor element is suitable for providing the information indicative of the frequency of the respiratory rhythm.

25

5. An apparatus according to claim 3 or 4, wherein the sensor element comprises one of the following: an accelerometer, a piezo-electronic sensor, an inclinometer, a pressure sensor.
6. An apparatus according to any of claims 1-5, wherein the processing device
5 is configured to detect peak-to-peak values related to wave complexes each of which being constituted by the AO-peak caused by opening of the aortic valve and the downward wave following the AO-peak, and to compute an amplitude variation quantity indicative of strength of variation of the peak-to-peak values, the amplitude variation quantity being indicative of cardiac malfunction and abnormality.
- 10 7. An apparatus according to any of claims 1-5, wherein the processing device is configured to detect maximum signal values of the AO-peaks caused by openings of the aortic valve, and to compute an amplitude variation quantity indicative of strength of variation of the maximum signal values, the amplitude variation quantity being indicative of cardiac malfunction and abnormality.
- 15 8. An apparatus according to any of claims 1-7, wherein the processing device is configured to detect time variation from the signal and to determine, on the basis of both the amplitude variation and the time variation, the indicator of cardiac malfunction and abnormality, the time variation being the variation of temporal lengths of heart-beat periods.
- 20 9. An apparatus according to claim 8, wherein the processing device is configured to detect temporal lengths of time intervals between successive AO-peaks caused by openings of the aortic valve, and to compute a first time variation quantity indicative of strength of variation of the detected temporal lengths, the first time variation quantity being indicative of cardiac malfunction and abnormality.
- 25 10. An apparatus according to claim 8 or 9, wherein the processing device is configured to produce a signal expressing atrial fibrillation in response to a situation in which at least one of the following takes place: strength of the amplitude variation exceeds a first threshold, strength of the time variation exceeds a second threshold.

11. An apparatus according to claim 2 or 10, wherein the processing device is configured to produce a signal expressing atrial fibrillation in response to a situation in which the signal component of the amplitude variation having the frequency of the respiratory rhythm is less than a third threshold.
- 5 12. An apparatus according to any of claims 6-11, wherein the processing device is configured to low-pass filter the signal indicative of the cardiovascular motion and to detect the AO-peaks from the low-pass filtered signal.
13. An apparatus according to claim 12, wherein an upper limit frequency of the low-pass filtering is 30 Hz.
- 10 14. An apparatus according to any of claims 6-13, wherein the processing device is configured to band-pass filter the signal indicative of the cardiovascular motion and to detect AC-peaks from the band-pass filtered signal, the AC-peaks being caused by closures of the aortic valve.
- 15 15. An apparatus according to claim 14, wherein a pass-band of the band-pass filtering is from 40 Hz to 100 Hz.
16. An apparatus according to claim 14 or 15, wherein the processing device is configured to detect temporal lengths of AC-AO intervals and to compute a second time variation quantity indicative of strength of variation of the detected temporal lengths of the AC-AO intervals, each of the AC-AO intervals being a time interval
20 from one of the AC-peaks to the following one of the AO-peaks and the second time variation quantity being indicative of cardiac malfunction and abnormality.
17. An apparatus according to claim 14 or 15, wherein the processing device is configured to detect temporal lengths of AC-AO intervals and temporal lengths of AO-AO intervals and to compute a ratio quantity indicative of a ratio between the
25 temporal length of the AC-AO interval and the temporal length of the AO-AO interval within a same heart-beat period, each of the AC-AO intervals being a time interval from one of the AC-peaks to the following one of the AO-peaks, each of the AO-AO intervals being a time interval from one of the AO-peaks to the following

one of the AO-peaks, and the ratio quantity being indicative of cardiac malfunction and abnormality.

18. A method **characterized** in that the method comprises:

- 5 - detecting (201) amplitude variation from a signal indicative of cardiovascular motion, the amplitude variation being variation of amplitude of a wave pattern repeating on a heart-beat rate on the signal so that the amplitude variation includes a plurality of increases of the amplitude and a plurality of decreases of the amplitude, and
- 10 - determining (202), at least partly on the basis of the amplitude variation, an indicator of cardiac malfunction and abnormality.

19. A method according to claim 18, wherein the method further comprises:

- computing a signal component of the amplitude variation having a frequency of a respiratory rhythm, and
- 15 - determining the indicator of cardiac malfunction and abnormality at least partly on the basis of the signal component of the amplitude variation having the frequency of the respiratory rhythm.

20. A method according to claim 18 or 19, wherein the detecting (201) of the amplitude variation comprises detecting peak-to-peak values related to wave complexes each of which being constituted by the AO-peak caused by opening of the aortic valve and the downward wave following the AO-peak, and the determining (202) of the indicator of cardiac malfunction and abnormality comprises computing an amplitude variation quantity indicative of strength of variation of the peak-to-peak values, the amplitude variation quantity being indicative of cardiac malfunction and abnormality.

25 21. A method according to claim 18 or 19, wherein the detecting (201) of the amplitude variation comprises detecting maximum signal values of the AO-peaks caused by openings of the aortic valve, and the determining (202) of the indicator of cardiac malfunction and abnormality comprises computing an amplitude varia-

tion quantity indicative of strength of variation of the maximum signal values, the amplitude variation quantity being indicative of cardiac malfunction and abnormality.

22. A method according to any of claims 18-21, wherein the method further comprises detecting time variation from the signal and determining, on the basis of both the amplitude variation and the time variation, the indicator of cardiac malfunction and abnormality, the time variation being the variation of temporal lengths of heart-beat periods.

23. A method according to claim 22, wherein the detecting of the time variation comprises detecting temporal lengths of time intervals between successive AO-peaks caused by openings of the aortic valve, and the determining (202) of the indicator of cardiac malfunction and abnormality comprises computing a time variation quantity indicative of strength of variation of the detected temporal lengths, the time variation quantity being indicative of cardiac malfunction and abnormality.

24. A method according to claim 22 or 23, wherein the method comprises producing a signal expressing atrial fibrillation in response to a situation in which at least one of the following takes place: strength of the amplitude variation exceeds a first threshold, strength of the time variation exceeds a second threshold.

25. A method according to claim 19 or 24, wherein the method comprises producing a signal expressing atrial fibrillation in response to a situation in which the signal component of the amplitude variation having the frequency of the respiratory rhythm is less than a third threshold.

26. A method according to any of claims 20-25, wherein the method comprises low-pass filtering (211) the signal indicative of the cardiovascular motion and detecting (212) the AO-peaks from the low-pass filtered signal.

27. A method according to claim 26, wherein an upper limit frequency of the low-pass filtering is 30 Hz.

28. A method according to any of claims 20-27, wherein the method comprises band-pass filtering (211) the signal indicative of the cardiovascular motion and de-

detecting (212) AC-peaks from the band-pass filtered signal, the AC-peaks being caused by closures of the aortic valve.

29. A method according to claim 28, wherein a pass-band of the band-pass filtering is from 40 Hz to 100 Hz.

5 30. A method according to claim 28 or 29, wherein the method comprises detecting temporal lengths of AC-AO intervals and computing a second time variation quantity indicative of strength of variation of the detected temporal lengths of the AC-AO intervals, each of the AC-AO intervals being a time interval from one of the AC-peaks to the following one of the AO-peaks and the second time variation
10 quantity being indicative of cardiac malfunction and abnormality.

31. A method according to claim 28 or 29, wherein the method comprises detecting temporal lengths of AC-AO intervals and temporal lengths of AO-AO intervals and computing a ratio quantity indicative of a ratio between the temporal length of the AC-AO interval and the temporal length of the AO-AO interval within a same
15 heart-beat period, each of the AC-AO intervals being a time interval from one of the AC-peaks to the following one of the AO-peaks, each of the AO-AO intervals being a time interval from one of the AO-peaks to the following one of the AO-peaks, and the ratio quantity being indicative of cardiac malfunction and abnormality.

20 32. A computer program **characterized** in that the computer program comprises computer executable instructions for controlling a programmable processor to:

- detect amplitude variation from a signal indicative of cardiovascular motion, the amplitude variation being variation of amplitude of a wave pattern repeating on a heart-beat rate on the signal so that the amplitude variation includes a plurality of increases of the amplitude and a plurality of decreases of the amplitude, and
25
- determine, at least partly on the basis of the amplitude variation, an indicator of cardiac malfunction and abnormality.

33. A computer program according to claim 32, wherein the computer program further comprises computer executable instructions for controlling the programmable processor to:

- 5 - compute a signal component of the amplitude variation having a frequency of a respiratory rhythm, and
- determine the indicator of cardiac malfunction and abnormality at least partly on the basis of the signal component of the amplitude variation having the frequency of the respiratory rhythm.

34. A computer program product comprising a non-transitory computer readable
10 medium encoded with a computer program according to claim 32 or 33.

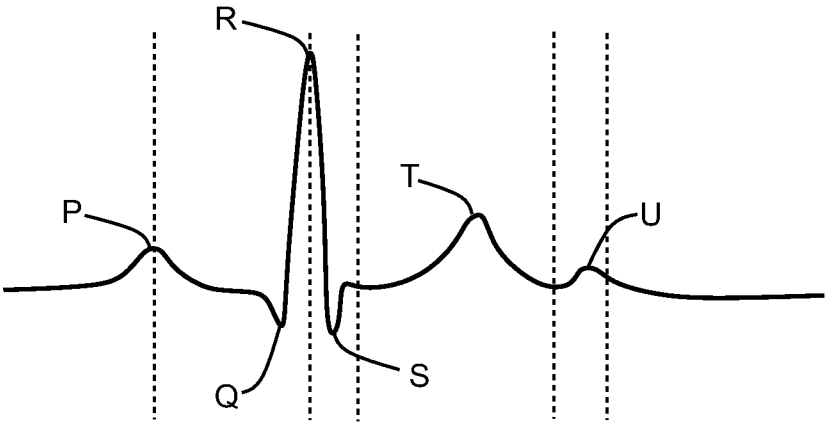


Figure 1a

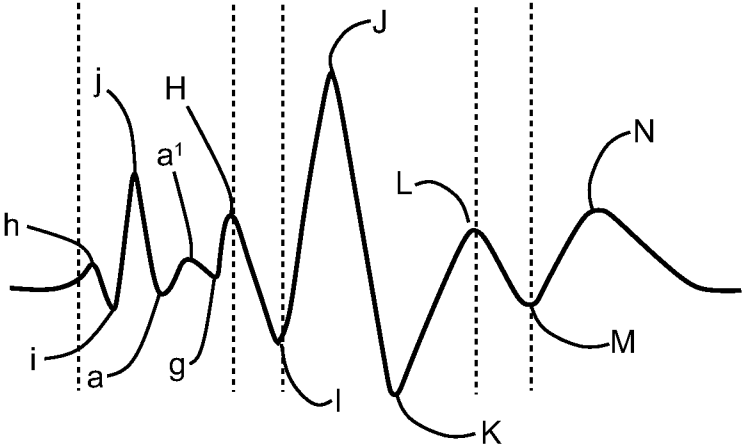


Figure 1b

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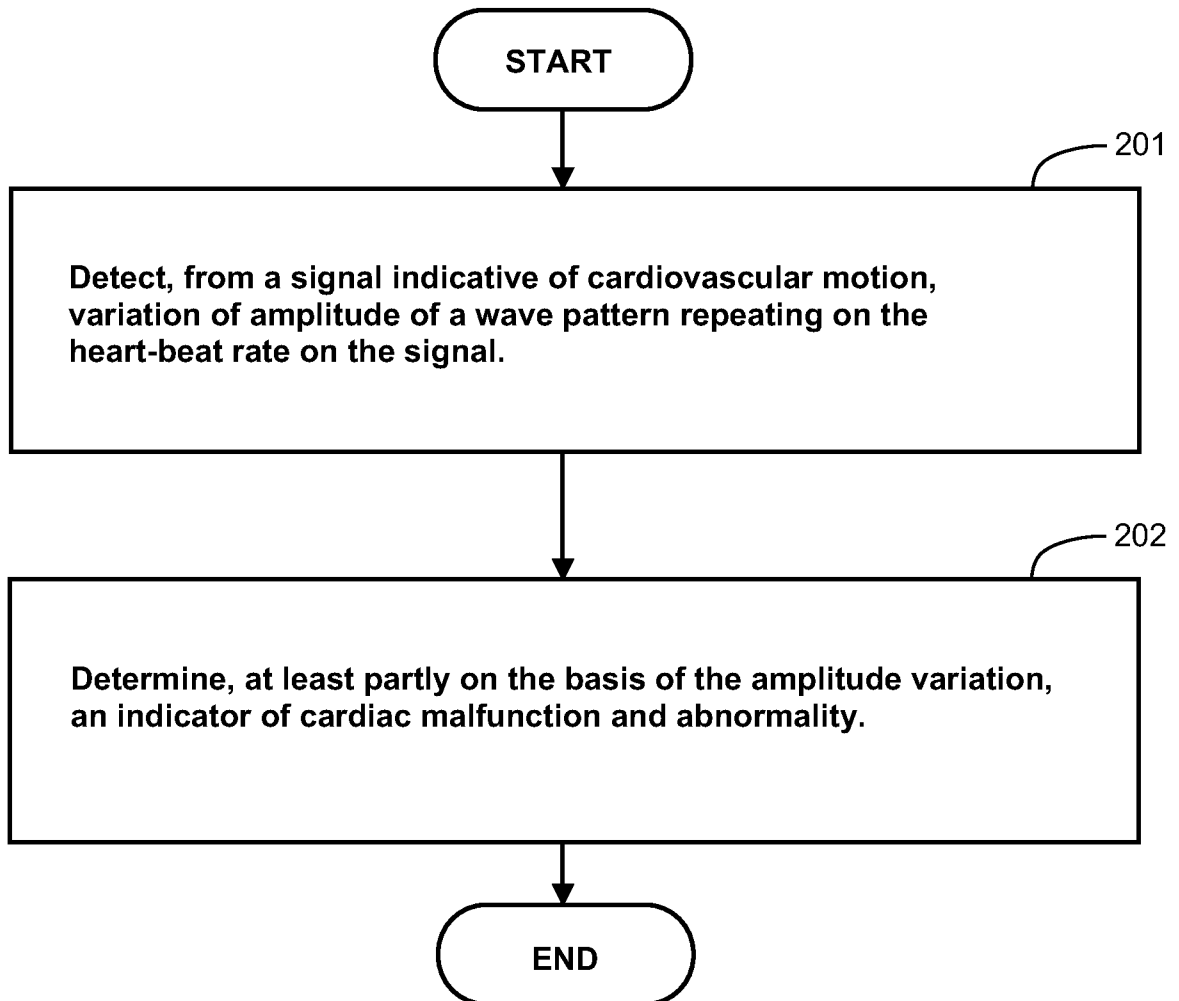


Figure 2a

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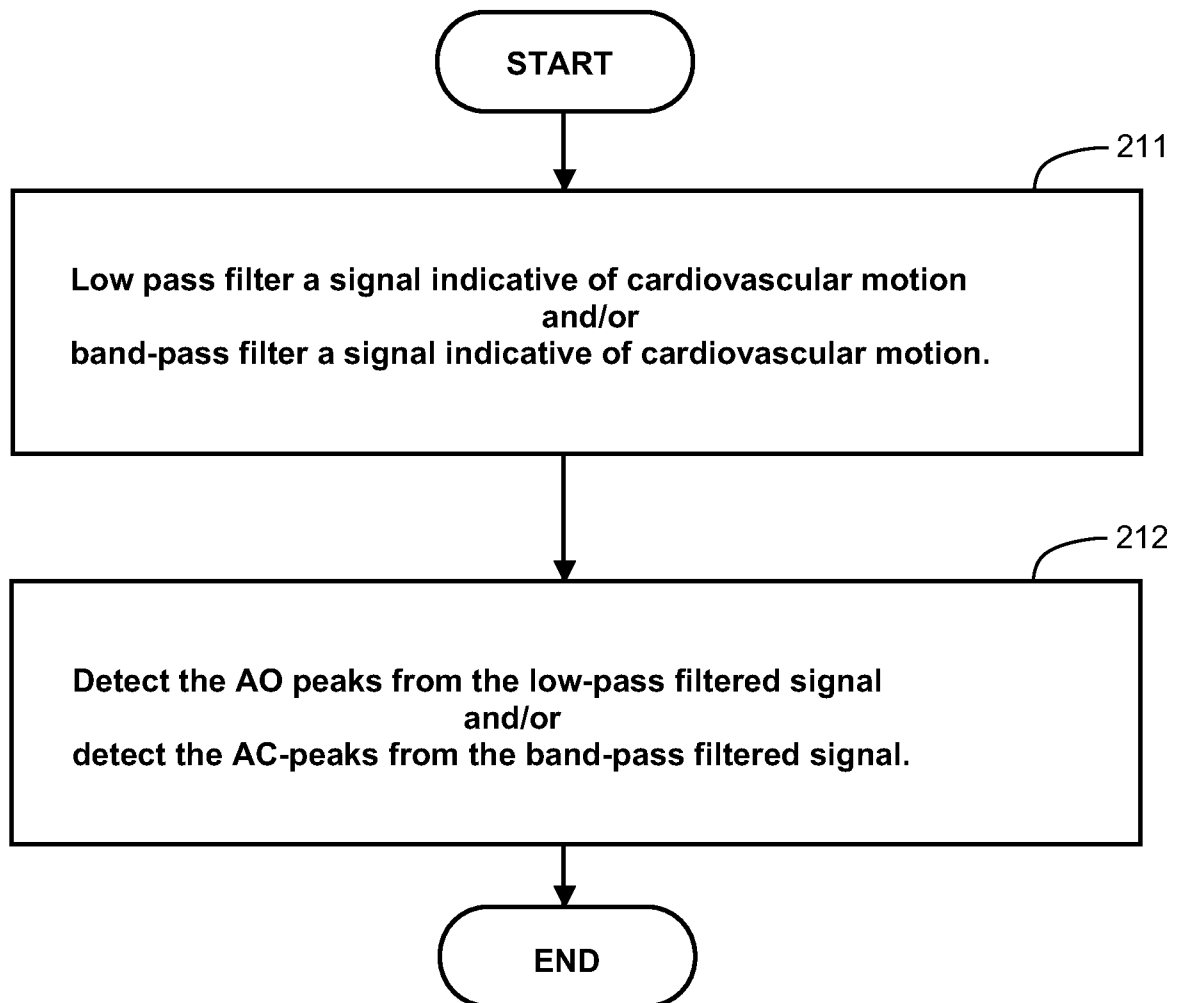


Figure 2b

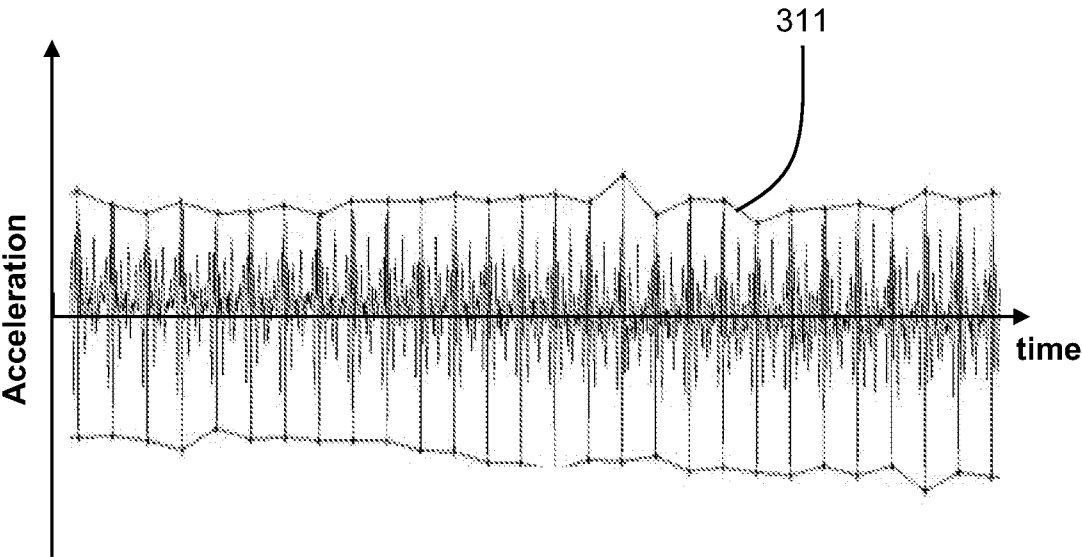


Figure 3a

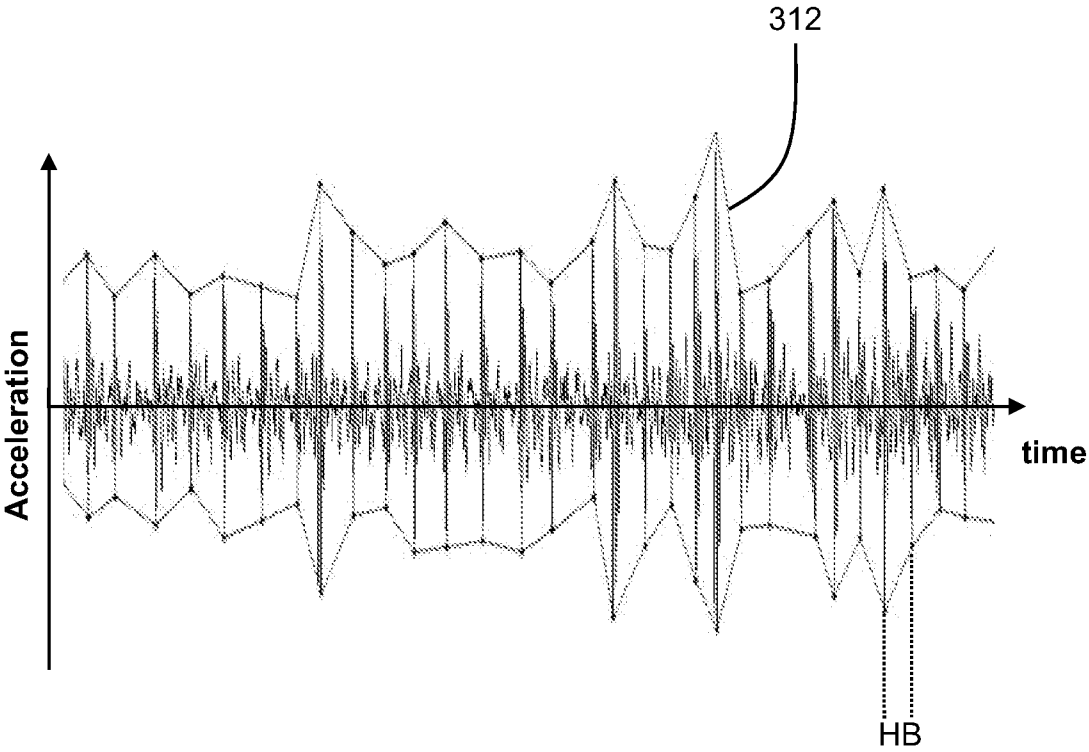


Figure 3b

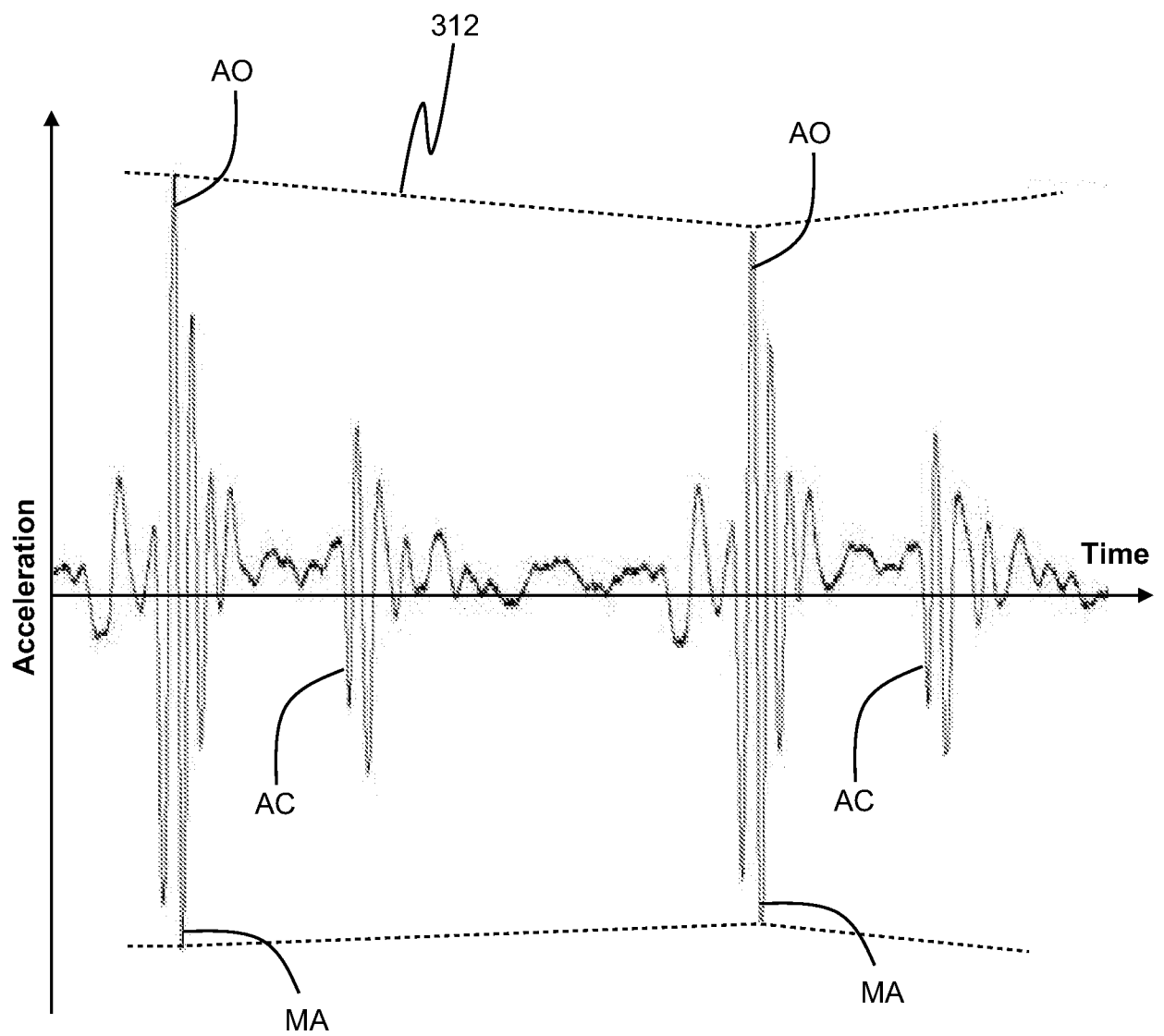


Figure 3c

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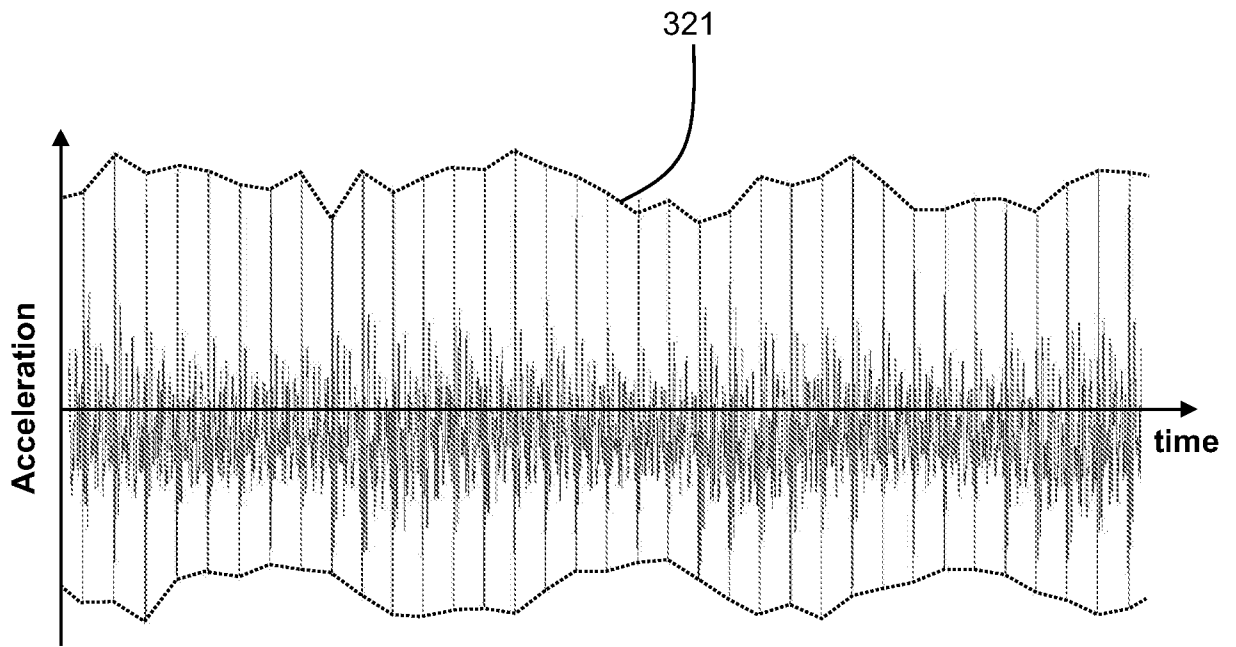


Figure 3d

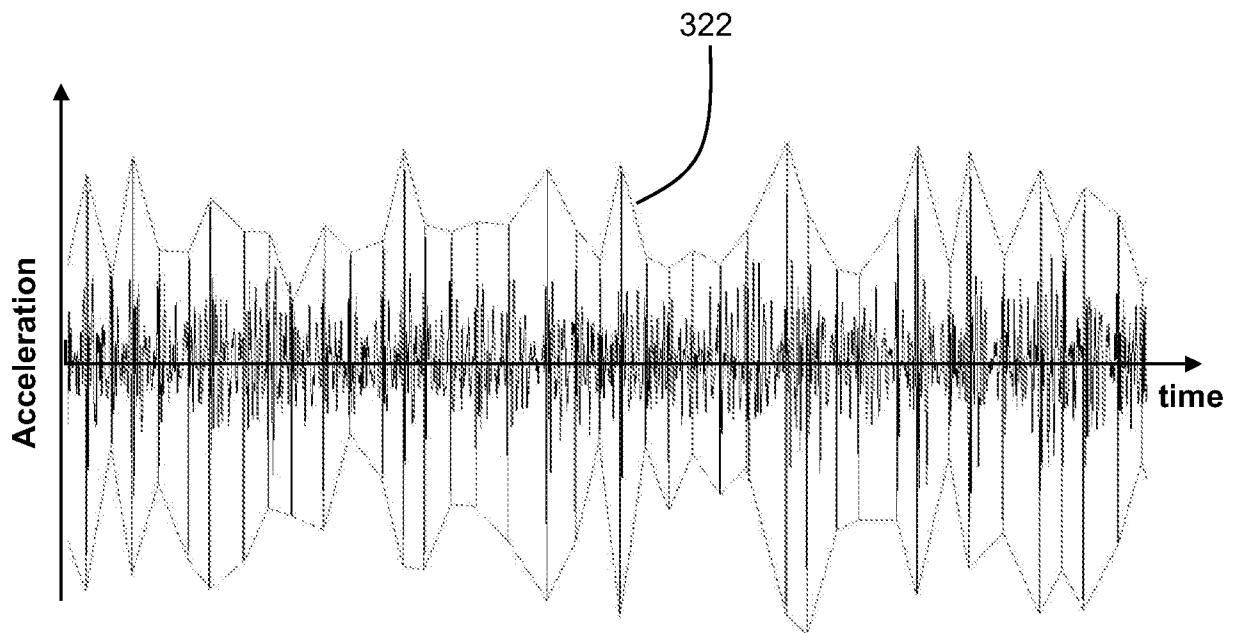
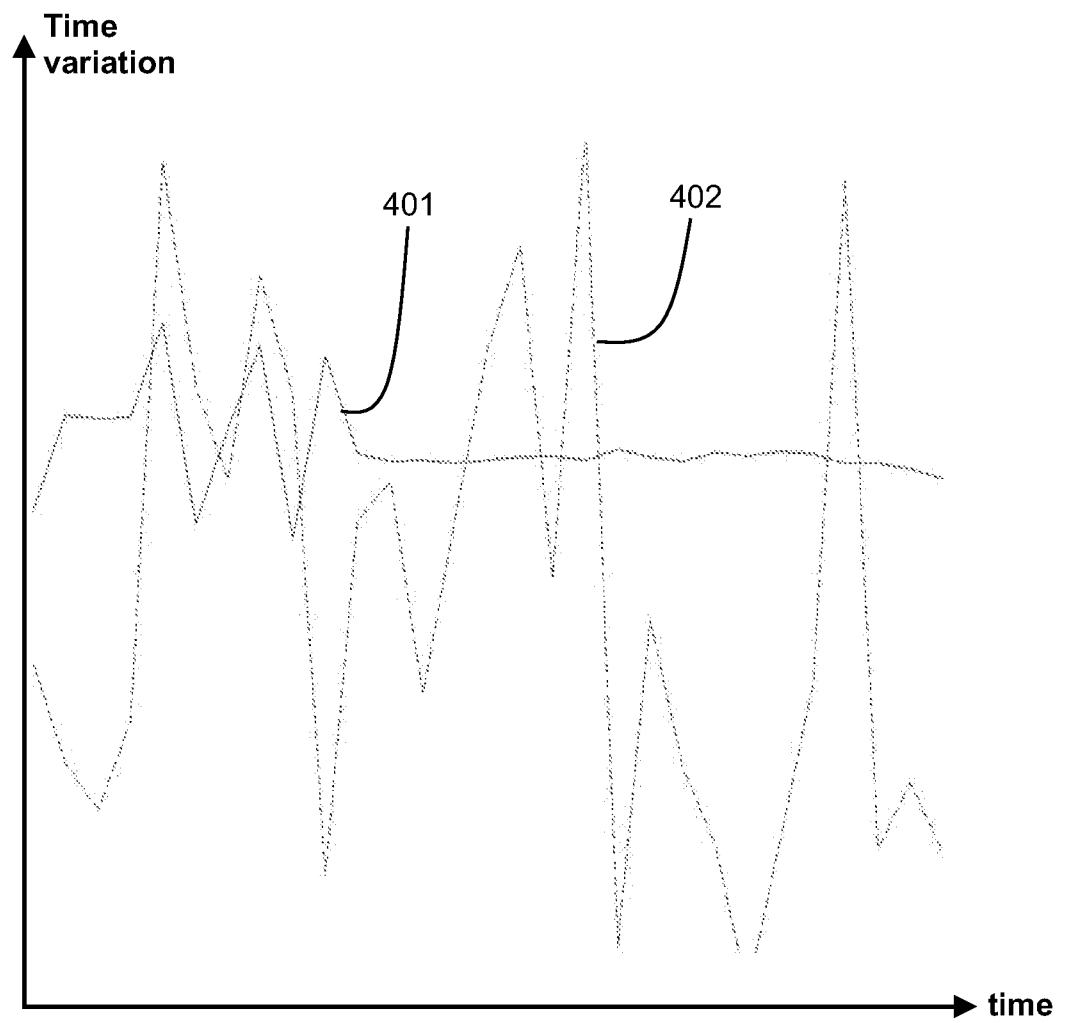


Figure 3e

**Figure 4**

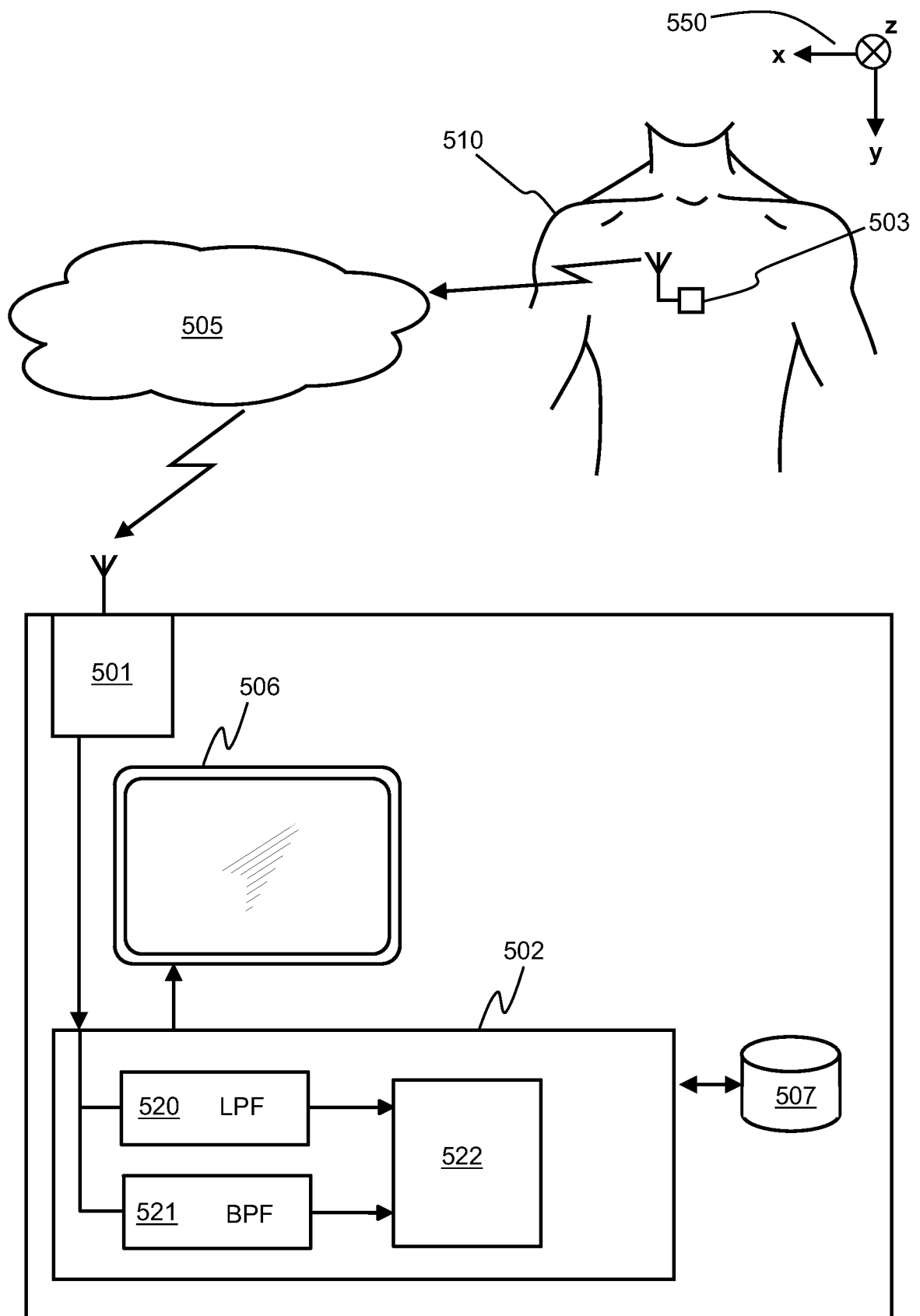


Figure 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2013/050422

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B5/0205 A61B5/08 A61B5/11 G01R19/04
ADD. A61B5/046

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61B G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/233034 A1 (VARRI ALPO [FI] ET AL) 18 December 2003 (2003-12-18) paragraph [0016] paragraph [0035] - paragraph [0038] paragraph [0046] - paragraph [0047] paragraph [0052] - paragraph [0053] ----- -/-	1-34

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

16 July 2013

Date of mailing of the international search report

22/07/2013

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Kowalczyk, Szczepan

INTERNATIONAL SEARCH REPORT

International application No

PCT/FI2013/050422

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	INAN O T ET AL: "Robust ballistocardiogram acquisition for home monitoring", PHYSIOLOGICAL MEASUREMENT, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 30, no. 2, 1 February 2009 (2009-02-01), pages 169-185, XP020153654, ISSN: 0967-3334, DOI: 10.1088/0967-3334/30/2/005 page 172, line 1 - page 173, line 22 page 179, line 1 - page 181, line 21 table 1 figures 4,5	1,3-5, 8-10, 16-18, 22-24, 30-32
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