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(54) HEART RATE DETECTION METHOD AND DEVICE USING HEART SOUND ACQUIRED FROM AUSCULATION POSITIONS

(57) A heart rate detection method for calculating heart rate uses heart sound acquired from auscultation positions. The heart rate detection method comprises a down-sampling step, a band pass filtering step, time sequence defined filtering step, simple moving average filtering step, a peak locating step to acquire samples of heart sound from auscultation positions. The heart rate measured from the auscultation positions allows fast and precise heart rate detection.

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Description

FIELD

[0001] The present invention relates to a heart rate detection method and a heart rate detection device.

BACKGROUND

[0002] Heart rate is one of the vital signs used to measure the body's basic function and is essential to clinicians' access to patient treatment and evaluation of patient's status. Electrocardiogram (ECG) and phonocardiogram (PCG) can both used to measure heart rate. ECG differs from PCG in that ECG records the electrical activities of the heart while PCG records the sounds the heart produces. Compared to ECG, PCG diagnosis is much easier by placing the stethoscope against one of the auscultation positions.

[0003] When experiencing a critical condition, such as pulseless electronic activity (PEA) that is a clinical condition characterized by unresponsiveness and lack of palpable pulse in the presence of cardiac rhythm while can be observed on ECG, the phenomenon of ECG oftentimes leads to misjudgment in diagnosing the critical condition.

[0004] In the event of a cardiac emergency caused by cardiovascular diseases, the patient or the wounded person may lose the best chance of saving their lives due to misjudgment, inappropriate first aid measures or long judgment time. How to quickly prepare equipment and position a probe on the patient to collect sufficient data for calculating the heart rate within a short period of time is always one of the top concerns on the list. Currently, a common way of measuring heart rate of a patient or a wounded person is to apply a pulse oximeter to a fingertip of the patient or the wounded person to measure oxygen concentration and transform the oxygen concentration into heart rate, which is very unstable and can be influenced by injured limb or nail decoration, such as nail polish, nail art, and the like.

[0005] To cope with the infeasibility or inconvenience upon measuring heart rate at fingertip, an approach of measuring heart rate at other body locations instead of fingertip, which has good performance and acceptable correlation when benchmarking with the measurements of heart rate done by physiological monitors through the means of electrocardiogram (ECG), should be provided.

SUMMARY

[0006] An objective of the present invention is to provide a heart rate detection method using heart sound acquired from auscultation positions, which reduces samples required for heart rate detection and identifies auscultation positions that generates heart sound required for fast calculation and high correlation relative to heart rate calculated through electrocardiography.

[0007] To achieve the foregoing objective, the heart rate detection method using heart sounds acquired from auscultation positions, wherein the heart rate detection method is performed at a heart rate detection device and is performed by a processor of the heart rate detection device, the heart rate detection method has steps of:

[0008] acquiring and processing samples of heart sound at a first sampling frequency from the auscultation positions of a testee using a heart rate detection process to identify a first heart sound occurring at beginning of each systole and a second heart sound occurring at beginning of a diastole paired to the systole from the samples acquired at a second sampling frequency, wherein the auscultation positions may be an auscultation position for mitral valve, an auscultation position for pulmonary valve, a first auscultation position for aortic valve, a second auscultation position for aortic valve, and an auscultation position for tricuspid valve;

[0009] calculating a target heart rate for each auscultation position of each testee according to each pair of the first heart sound and the second heart sound, and recording a target heart rate detection time for the auscultation position of the testee when calculation of the target heart rate for the auscultation position of the testee is completed for the first time; and

[0010] recording a reference heart rate for each auscultation position of each testee and a reference heart rate detection time for the auscultation position of the testee when calculation of the reference heart rate for the auscultation position is completed by a reference electrocardiogram (ECG) heart rate detector for the first time.

[0011] The target heart rate detection time, the reference heart rate detection time, the target heart rate and the reference heart rate for each auscultation position are analyzed by a statistical process to obtain an analysis result that the target heart rate detection time measured from the auscultation position for tricuspid valve, the auscultation position for pulmonary valve and the auscultation position for mitral valve is faster than the target heart rate measured from any other auscultation positions, the target heart rate detection time measured from the auscultation position for mitral valve and the auscultation position for tricuspid valve has higher degree of stability than the target heart rate detection time measured from any other auscultation positions, and the target heart rate measured from the tricuspid position and the mitral position is more accurate than the target heart rate measured from any other auscultation positions.

[0012] Given the foregoing heart rate detection method, samples of heart sound can be lowered from the first sampling frequency to the second sampling frequency, the statistical approach incorporating the use of mean error, standard deviation error, the Bland-Altman difference plot, the coefficient of determination and the Pearson's correlation coefficient to identify the auscultation positions ensuring generation of heart sound for faster calculation of precise heart rate with high degree of consistency and correlation.

[0013] Other objectives, advantages and novel features of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 is a graph illustrating curves for identifying pulse through ECG and PCG;

FIG. 2 is a schematic diagram illustrating auscultation positions of heart sound;

FIG. 3 is a flow diagram of a heart rate detection method in accordance with the present invention;

FIG. 4 is a curve diagram of original heart sound signals acquired by the original heart sound signals acquisition step in the heart rate detection method in FIG. 3;

FIG. 5 is a curve diagram of heart sound signals done by a down-sampling step of the heart rate detection method in FIG. 3;

FIG. 6 is a timing diagram illustrating to overlap down-sampled heart sound signals for computation of heart rate;

FIG. 7 is a curve diagram of heart sound signals done by a bandpass filtering step in FIG. 3;

FIG. 8 is a curve diagram of heart sound signals done by a TT defined filtering step in FIG. 3;

FIG. 9 is a curve diagram of heart sound signals done by a TT SMA filtering process in FIG. 3;

FIG. 10A is a chart illustrating coefficient of determination between heart rate at the mitral position calculated by MP70 and that calculated by 3M detector;

FIG. 10B is a chart illustrating coefficient of determination between heart rate at the mitral position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 11A is a chart illustrating Bland-Altman difference plot between heart rate at the mitral position calculated by MP70 and that calculated by 3M detector;

FIG. 11B is a chart illustrating Bland-Altman difference plot between heart rate at the mitral position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 12A is a chart illustrating coefficient of determination between heart rate at the pulmonary position calculated by MP70 and that calculated by 3M detector;

FIG. 12B is a chart illustrating coefficient of determination between heart rate at the pulmonary position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 13A is a chart illustrating Bland-Altman difference plot between heart rate at the pulmonary position calculated by MP70 and that calculated by 3M detector;

FIG. 13B is a chart illustrating Bland-Altman difference plot between heart rate at the pulmonary position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 14A is a chart illustrating coefficient of determination between heart rate at the right aortic position calculated by MP70 and that calculated by 3M detector;

FIG. 14B is a chart illustrating coefficient of determination between heart rate at the right aortic position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 15A is a chart illustrating coefficient of determination plot between heart rate at the right aortic position calculated by MP70 and that calculated by 3M detector;

FIG. 15B is a chart illustrating Bland-Altman difference plot between heart rate at the right aortic position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 16A is a chart illustrating coefficient of determination between heart rate at the left aortic position calculated by MP70 and that calculated by 3M detector;

FIG. 16B is a chart illustrating coefficient of determination between heart rate at the left aortic position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 17A is a chart illustrating Bland-Altman difference plot between heart rate at the left aortic position calculated by MP70 and that calculated by 3M detector;

FIG. 17B is a chart illustrating Bland-Altman difference plot between heart rate at the left aortic position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 18A is a chart illustrating coefficient of determination between heart rate at the tricuspid position calculated by MP70 and that calculated by 3M detector;

FIG. 18B is a chart illustrating coefficient of determination between heart rate at the tricuspid position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 19A is a chart illustrating Bland-Altman difference plot between heart rate at the tricuspid position calculated by MP70 and that calculated by 3M detector;

FIG. 19B is a chart illustrating Bland-Altman difference plot between heart rate at the tricuspid position calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 20A is a chart illustrating coefficient of determination between heart rate at all the five auscultation positions calculated by MP70 and that calculated by 3M detector;

FIG. 20B is a chart illustrating coefficient of determination between heart rate at all the five auscultation positions calculated by MP70 and that calculated by the method in FIG. 3;

FIG. 21A is a chart illustrating Bland-Altman difference plot between heart rate at all the five auscultation positions calculated by MP70 and that calculated by 3M detector; and

FIG. 21B is a chart illustrating Bland-Altman difference plot between heart rate at all the five auscultation positions calculated by MP70 and that calculated by the method in FIG. 3.

FIG. 22 illustrates a system block diagram according to one example of the present invention.

FIG. 23 illustrates a system block diagram according to one example of the present invention.

FIG. 24 shows one example of the present invention applied to an electronic stethoscope.

FIG. 25 illustrates a system block diagram according to one example of the present invention.

FIG. 26 shows one example of the present invention applied to an electronic stethoscope with an auscultation patch.

DETAILED DESCRIPTION

[0015] Basically, heart rate indicates the frequency of heart beat, which is the frequency of a cardiac cycle including a systole phase and a diastole phase, and heart sound is the sound uttered when heart is beating. With reference to FIG. 1, heart rate can be found and calculated by two approaches, namely, electrocardiogram (ECG) and phonocardiogram (PCG). A curve in the bottom representing the PCG approach shows the first heart sound (S1), which occurs at the beginning of each systole, and the second heart sound (S2), which occurs at the beginning of each diastole. According to ECG, the first heart sound (S1) can be interpreted as the timing when the mitral valve closes, and the second heart sound (S2) can be interpreted as the timing when the aortic valve closes. As can be seen from FIG. 1, a time duration between a first heart sound (S1) and a subsequent first heart sound (S1') in the PCG and a time duration between two successive pulses abruptly rising in a curve represented by ventricular pressure in the ECG correspond to each other and can be used to calculate the heart rate. This also explains why ECG and PCG can both be used to determine heart rate.

[0016] To perform adequate auscultation for the first heart sound (S1) and the second heart sound (S2), with reference to FIG. 2, the auscultation positions are preferred to correspond to the heart valves and are marked by 'M', 'P', 'A', 'T', and 'E'. The auscultation position 'M' represents the auscultation position for the mitral valve situated in the left fifth intercostals space (ICS) close to the midclavicular line (MCL). The auscultation position 'P' represents the auscultation position for the pulmonary valve situated in the left second ICS close to the parasternal line (PSL). The auscultation position 'A' represents the first auscultation position for aortic valve situated in the right second ICS close to the PSL. The auscultation position 'T' represents the auscultation position for tricuspid valve situated in the left fourth ICS close to the PSL. The auscultation position 'E' represents the auscultation position for Erb's point serving as the second auscultation position for aortic valve and situated in the left third ICS close to the PSL.

[0017] With reference to FIG. 3, a heart rate detection method using heart sound acquired from auscultation positions in accordance with the present invention has the following steps.

[0018] Step S301: Original heart sound signal acquisition step. Specifically, sample heart sound signals from auscultation positions of a person at a first sampling frequency. The initial samples of heart sound signal are acquired by a sound pickup device. The first sampling frequency is 48 kHz. With reference to FIG. 4, a curve represents the initial samples of heart sound signals acquired at the first sampling frequency.

[0019] Step S302: Down-sampling step. Specifically, perform a down sampling processing on the initial samples of heart sound signal. The down sampling processing serves to extend a time interval between each adjacent two of the initial samples of heart sound signal and the effect is to reduce the number of the initial samples, so as to speed up computation for heart rate using less samples. With reference to FIG. 5, after the down sampling processing, the first sampling frequency 48 kHz is dropped to a second sampling frequency 375 Hz, which is 1/128 of the first sampling frequency. When the number of the initial samples sampled per second is 51,200 samples, with reference to FIG. 5, this number can be greatly reduced to the 400 samples, which corresponds to half of the samples in a two-second period. After the down-sampling step is done, the heart rate detection method calculates heart rate every second on a real-time basis using the samples in each second and the samples in a previous second. With reference to FIG. 6, when calculating heart rate at each second, there is no sufficient samples available for calculation of heart rate at the initial two seconds because of the number of minimum samples required for calculation of heart rate at each second is 1,200 while the number of samples acquired at each second is 400. Therefore, the first heart rate calculated is available at the third second because the number of accumulated samples for the first three seconds reaches 1,200. The heart rate at and after the fourth second can be repeatedly calculated by using the 400 samples at the instant second and the 800 samples at the two seconds right before the instant second. Heart rate at each second as shown in FIGs. 7-9 is calculated with 1,200 samples, such that the calculated heart can range from 20 to 220 beat per second.

[0020] Step S303 (Bandpass filtering step): Apply a bandpass filter and configure two frequency thresholds to filter out noises falling out of frequency ranges of the first heart sound and the second heart sound, namely, frequency ranges blow 20 Hz and above 100 Hz, from the samples in the two-second period. As noticed from FIG. 7, after the bandpass filtering step is done, samples in corrugated portions other than peak portions are not as dense as those before the bandpass filtering step.

[0021] Step S304 (Time sequence, TT, defined filtering step): Acquire absolute values of energy of the samples in the two-second period processed by the bandpass filtering step, take an average energy value for all the samples in the two-second period, configure an energy threshold λ from the average energy value, and set energy of the samples below the energy threshold λ to be zero. With reference to FIG. 8, the energy threshold λ is set to be 0.91e where e is the average energy value of all the samples. Thus, samples with primary energy of heart sound signal and regularity can be found while relatively low-energy noises can be screened out.

[0022] Step S305 (TT SMA filtering step): Apply a simple moving average (SMA) filter to continuously redraw each 31 continuous samples identified in the TT defined filtering step with an average energy value of the 31 continuous samples to smoothen or filter out the samples having rough edges, complicated peak energy values and high frequency in FIG. 8, so as to generate the samples in the form of continuous peaks with and smooth contour as shown in FIG. 9. Then, computer algorithm can easily discriminate true peaks from false peaks having rough edges or complicated peak energy values, and identify the true peaks for computation of heart rate.

[0023] Step S306 (Peak-locating step): Search peaks with maximal energy value in every fixed time duration, apply a heart rate requirement for peak grouping and analysis of a peak-to-peak cycle, and repeatedly identify the peaks corresponding to the first heart sound (S1) and the second heart sound (S2) to calculate the corresponding heart rate.

[0024] Step S307 (heart rate standard deviation step): calculate average and standard deviation continuously according to the continuous peaks with non-zero peak value. Occasionally, noises may be recognized as peaks in the preceding steps or other interference may lead to unreasonable heart rate deviated far from normal range. During the heart rate standard deviation step, the standard deviation of the heart rates is calculated and evaluate whether the standard deviation is larger than the expected standard deviation. A certain number of the most deviated heart rates leading to unreasonable standard deviation are removed. The standard deviation is calculated repeatedly and most deviated peaks is again removed until the standard deviation is smaller than the expected standard deviation. As a result, a relatively steady heat rate with small variance is generated during the heart rate standard deviation step.

[0025] Step S308 (time sequence (TT) algorithm output step): evaluate the data output from the heart rate standard deviation step by TT algorithm. TT algorithm evaluates and restricts the important parameters from the heart rate standard deviation step. For example, the last estimated heart rate is updated and shown on the display module if the mean of the heart rates within four seconds is three beats/min (BPM) different from the last estimated heart rate. Also, the last estimated heart rate may not be updated if the mean of the heart rates is smaller than 20 BPM or greater than 200 BPM. The TT algorithm step may reduce the fluctuation of the estimated value of the heart rate and may reduce the computation errors from the ambient noises.

[0026] To benchmark performance associated with the measurements of heart rate done by the foregoing heart rate detection method with that done by another PCG-type heart rate detector and compare correlation between measurements of heart rate done by the foregoing heart rate detection method and a typical ECG-type physiological monitor with correlation between measurements of heart rate done by the PCG-type heart rate detector and the typical ECG-type a typical ECG-type physiological monitor, an experiment is set up as follows.

[0027] A prototype heart sound acquisition device DS301 built in with the foregoing heart rate detection method and a processor of DS301 performs the heart rate detection method, another PCG-type heart rate detector from 3M® and the physiological monitor Philips® IntelliVue MP70 are used to determine the respective time to successfully determine heart rate for the first time (speed - sec) at five different auscultation positions, that is, the auscultation position for the mitral valve, the auscultation position for the pulmonary valve, the first auscultation position for aortic valve (right aortic position), the second auscultation position for aortic valve (left aortic position), and the auscultation position for tricuspid valve, of a same testee and the heart rate calculated by DS301, 3M® detector and MP70 are recorded and a stopwatch is used to record the time for calculating heart rate for the first time determined by each of DS301, 3M® detector and MP70. Totally, there are 19 testees and 150 test records. Among the 19 testees, 12 testees are repeatedly sampled.

[0028] To ascertain whether data collected from the experiment are meaningful and convincible, the heart rate detection method further includes a statistical approach as follows.

[0029] Add up the time for calculating heart rate for the first time measured by each of MP70, DS301 and 3M® detector repeatedly from each of the five auscultation positions to take an arithmetic average value of the accumulated time. According to the comparison of the arithmetic average values, which one of DS301 and 3M® detector is quicker in calculating heart rate from each of the five auscultation positions has better performance in terms of the speed of calculating heart rate. Add up a difference between the time for calculating heart rate from each auscultation position for the first time measured by DS301 and MP70 and a difference between the time for calculating heart rate from each auscultation position for the first time measured by MP70 and 3M® detector to take an arithmetic average of each of the accumulated differences in generation of a mean error, which represents a mean error of the time measurements for the auscultation position done by DS301 or 3M® detector. Furthermore, apply standard deviation to the mean error to obtain a standard deviation error representing the degree of stability of the time measurements at the auscultation position done by DS301 or 3M® detector. The arithmetic values and standard deviation errors of DS301 and 3M® detector can be compared to give respective performance indication about heart rate detection at each auscultation position.

[0030] Data associated with heart rate calculated by MP70, DS301 and 3M® detector from entire auscultation positions and each auscultation position are used to plot and obtain a coefficient of determination R^2 for understanding correlation or similarity between heart rate calculated by DS301 and MP70 and between heart rate calculated by 3M® detector and MP70. Higher coefficient of determination R^2 means higher correlation.

[0031] Apply a Bland-Altman difference plot serving to assess the consistency between two types of data to be analyzed, and a coefficient of determination and a Pearson's correlation coefficient to determine correlation between heart rate calculated by DS301 and MP70 and between heart rate calculated by 3M® detector and MP70. As high correlation does not necessarily lead to high consistency, the Bland-Altman difference plot is performed first to observe distribution of the residual, which is effective in determining the degree of consistency. Then, the coefficient of determination and the Pearson's correlation coefficient are used to determine the degree of correlation.

[0032] The experiment results acquired according to the five auscultation positions are given as follows.

[0033] The following table shows experiment results measured at mitral valve for performance comparison between

DS301 and 3M® detector, and FIGs. 10A, 10B respectively employs the coefficient of determination R^2 and the Bland-Altman difference plot to respectively compare correlation of heart rate calculated by DS301 and MP70 and correlation of heart rate calculated by 3M® detector and MP70 at mitral valve.

Table 1 - Mitral Position

3M® detector			DS301		
STDEV ERROR	MEAN ERROR	SPEED (sec)	STDEV ERROR	MEAN ERROR	SPEED (sec)
4.394354	2.103448	8.55517241	5.756983	3.571429	6.9

[0034] The following table shows expe riment results measured at pulmonary valve for performance comparison between DS301 and 3M® detector, and FIGs. 11A, 11B respectively employ the coefficient of determination R^2 and the Bland-Altman difference plot to respectively compare correlation of heart rate calculated by DS301 and MP70 and correlation of heart rate calculated by 3M® detector and MP70 at pulmonary valve.

Table 2 - Pulmonary Position

3M® detector			DS301		
STDEV ERROR	MEAN ERROR	SPEED (sec)	STDEV ERROR	MEAN ERROR	SPEED (sec)
5.664904	5.664904	5.66490362	8.217037	1.655172	6.63103448

[0035] The following table shows experiment results measured at aortic valve I for performance comparison between DS301 and 3M® detector, and FIGs. 13A, 13B respectively employ the coefficient of determination R^2 and the Bland-Altman difference plot to respectively compare correlation of heart rate calculated by DS301 and MP70 and correlation of heart rate calculated by 3M® detector and MP70 at aortic valve I.

Table 3 - Right Aortic Position

3M® detector			DS301		
STDEV ERROR	MEAN ERROR	SPEED (sec)	STDEV ERROR	MEAN ERROR	SPEED (sec)
10.16292	2.851852	11.5925926	7.04371	0.423077	8.04230769

[0036] The following table shows experiment results measured at aortic valve II for performance comparison between DS301 and 3M® detector, and FIGs. 15A, 15B respectively employ the coefficient of determination R^2 and the Bland-Altman difference plot to respectively compare correlation of heart rate calculated by DS301 and MP70 and correlation of heart rate calculated by 3M® detector and MP70 at aortic valve II.

Table 4 - Left Aortic Position

3M® detector			DS301		
STDEV ERROR	MEAN ERROR	SPEED (sec)	STDEV ERROR	MEAN ERROR	SPEED (sec)
4.284832	0.714286	7.90714286	6.827997	4.692308	7.18076923

[0037] The following table shows experiment results measured at tricuspid valve for performance comparison between DS301 and 3M® detector, and FIGs. 17A, 17B respectively employ the coefficient of determination R^2 and the Bland-Altman difference plot to respectively compare correlation of heart rate calculated by DS301 and MP70 and correlation of heart rate calculated by 3M® detector and MP70 at tricuspid valve.

Table 5 - Tricuspid Position

3M® detector			DS301		
STDEV ERROR	MEAN ERROR	SPEED (sec)	STDEV ERROR	MEAN ERROR	SPEED (sec)
4.100342	0.793103	9.57931034	4.740209	2.107143	6.46785714

[0038] The following table shows performance comparison of the total samples calculated by DS301 and the total samples calculated by 3M® detector, and FIGs. 19A, 19B respectively employ the coefficient of determination R^2 and the Bland-Altman difference plot to compare correlation of the total samples of heart rate calculated by DS301 and MP70 and correlation of the total samples of heart rate calculated by 3M® detector and MP70.

Table 6 - Total Samples

3M® detector			DS301		
STDEV ERROR	MEAN ERROR	SPEED (sec)	STDEV ERROR	MEAN ERROR	SPEED (sec)
10.16292	2.851852	11.5925926	7.04371	0.423077	8.04230769

Table 7 - Detection Rate

3M® detector			DS301		
Total Sample	Valid Sample	Detection Rate	Total Sample	Valid Sample	Detection Rate
150	142	94.67%	150	137	91.33%

[0039] To sum up and analyze the foregoing information collected from the five auscultation positions, the heart rate measuring speed calculated from any auscultation position by DS301 of the present invention is faster than that calculated by 3M® detector and is 7.025 seconds in average. Among the five auscultation positions, DS301 has the fastest heart rate measuring speed from the tricuspid position (Table 5), which is 6.47 seconds in average while the most stable heart sound signals are from the aortic valve II (Table 4) as the standard deviation error for the left aortic position is approximately 6.83. The mitral position has the second most stable heart sound signals whose standard deviation error is 5.76, and also has a satisfactory heart rate measuring speed at approximately 6.9 seconds. Although the mean error for the right aortic position and the pulmonary position are both low, the standard deviation error for the right aortic position and the pulmonary position are high, meaning that the heart sound signals measured from the right aortic position and the pulmonary position are not stable enough.

[0040] With further reference to FIGs. 11B, 13B, 15B, 17B and 19B, a Bland-Altman difference plot is created by taking the average heart beat of MP70 and DS301 as X-axis coordinate, the difference in heart beat between MP70 and DS301 as Y-axis coordinate, the mean error as a reference line parallel to the X axis, and ± two folds of standard deviation error as the 95% confidence interval. As can be seen from FIGs. 11B, 13B, 15B, 17B and 19B, almost all points plotted based on samples of heart rate from all the five auscultation positions fall within the 95% confidence interval, proving that the heart rate values calculated by the DS301 and MP70 have high-degree of consistency.

[0041] With further reference to FIGs. 10B, 12B, 14B, 16B and 18B, the values of the coefficient of determination R^2 are 0.8275, 0.7118, 0.7773, 0.7276, and 0.875 for the mitral position, pulmonary position, right aortic position, left aortic position, and tricuspid position respectively. According to all the values of the coefficient of determination R^2, the correlation between the heart rate calculated by DS301 from the tricuspid position and the mitral position and the reference heart rate calculated by MP70 is higher than that between the heart rate calculated by DS301 from other auscultation positions and the reference heart rate calculated by MP70. Such result can also explain the relatively low standard deviation error of the two auscultation positions.

Table 8 - Pearson Correlation for five auscultation positions

Mitral position	Correlation coefficient	0.91**
	Significant (2-tailed)	0.000
	N	28
Pulmonary position	Correlation coefficient	0.844**
	Significant (2-tailed)	0.000
	N	29
Right aortic position	Correlation coefficient	0.879**
	Significant (2-tailed)	0.000
	N	27

(continued)

Left aortic position	Correlation coefficient	0.853**
	Significant (2-tailed)	0.000
	N	26
Tricuspid position	Correlation coefficient	0.941**
	Significant (2-tailed)	0.000
	N	27
** Correlation is significant at the 0.01 level (2-tailed)		

[0042] Table 7 is used to determine Pearson Correlation, which is a measure of the strength of the linear relationship between the heart rate calculated by DS301 at the five auscultation positions and that calculated by MP70. As can be seen from Table 7, the correlation coefficient in the five auscultation positions falls in a range of 0.7~0.99 with a p value less than 0.001. Accordingly, the heart rate calculated by DS301 at the five auscultation positions and that calculated by MP70 are high are highly correlated. In particular, the correlation coefficient for the relationship between heart rate calculated by DS301 from the tricuspid position and that calculated by MP70 reaches a high value 0.941, representing that the readings of heart beat at the tricuspid position calculated by DS301 are more accurate than those at other auscultation positions.

[0043] The heart rate detection method in accordance with the present invention can be applied to diagnosis of loss of pulse, ventricular arrhythmia, ventricular tachycardia and ventricular fibrillation.

[0044] With reference to FIG. 22, a heart rate detection device using heart sounds 10 in accordance with the present invention comprises an analog-to-digital (A/D) converter 20, a processor 30, a memory module 40 and a heart rate detection module 50. The heart rate detection device 10 is coupled to an analog input unit 70. The analog input unit receives heart sounds in the form of analog signal measured from one of the auscultation positions.

[0045] The A/D converter 20 is connected to the analog input unit 70 and converts the heart sounds into digital data. The processor 30 is connected to the A/D converter 20, receives the digital data transmitted from the A/D converter 20. The memory module 40 is connected to the processor 30 and stores the digital signals. The heart rate detection module 50 is connected to the processor 30, receives the digital data transmitted from the processor 30, and performs the down-sampling process, the band-pass filtering process, the TT defined filtering process, the TT SMA filtering process and the peak-locating process as mentioned in the foregoing heart rate detection method to acquire heart rate of each auscultation position. It is contemplated that the heart rate detection module may be integrated with the processor.

[0046] As shown in FIG. 23, the heart rate detection device further comprises a display module 100, an analog output unit 80, a communication module 90, and a power supply 120. The analog input unit 70 may be a microphone configured to receive heart sound and deliver to the A/D converter 20. The A/D converter processes the received heart sound into digital data and the digital data is delivered to the processor 30. The heart rate detection module may be integrated in the processor 30. The heart rate detection method is performed at the processor to obtain a heart rate value and the heart rate detection method may comprise a bandpass filtering step, a TT defined filtering step, a TT SMA filtering step, a peak-locating step, a heart rate standard deviation step, and a TT algorithm output step. The heart rate value may be consequent numerical sequences per minute or the mean of heart rate during a certain period. The heart rate value may be delivered to the display module to visualize in digits and may be stored at the memory module. The memory module may be an internal memory or a memory card, so a user may retrieve the information of heart rate value at a time point or within a period of time. The heart rate value may be delivered to the communication module as a data output. For example, the communication module may be a Bluetooth module, WiFi module, or a Zigbee module. The communication module may be a wired connection port, such as a USB port, so a user may transmit the information of heart rate value to a corresponding hardware device or a software platform. The analog input unit 70 may also deliver the heart sound acquired from the auscultation positions to the analog output unit 80. The analog output may be an earphone set.

[0047] As shown in FIG. 24, the heart rate detection device may be an electronic stethoscope. The electronic stethoscope comprises an analog input unit 70, a A/D converter, a processor, a heart rate detection module, a communication module, a memory module, a display module 100, an analog output unit and a power supply.

[0048] As shown in FIG. 25, the heart rate detection device is a mobile electronic device further comprising a communication module, a memory module, a display module 100, an analog output unit and a power supply. The analog output unit 70 may be accommodated in an auscultation patch 200.

[0049] As shown in FIG. 26, the heart rate detection device is a mobile electronic device. The analog input unit 70 may be a microphone accommodated in an auscultation patch. The auscultation patch may be attached to auscultation positions of a testee. The analog input unit of the auscultation patch receives heart sound and delivers the heart sound to the communication module. The communication module may be a wireless communication module, such as a Bluetooth module, WiFi module, or a Zigbee module. The analog input unit 70 is coupled to the A/D converter 20 via the communication module 91. The auscultation patch may be attached to auscultation positions of a testee so that the analog input unit 70 of the auscultation patch receives heart sound and delivers the heart sound to the A/D converter via the communication module.

[0050] In sum, the heart rate detection method in accordance with the present invention lowers the quantity of samples of heart sound collected from the five auscultation positions, including the mitral position, the pulmonary position, the right aortic position, the left aortic position, and the tricuspid position, of multiple testees through the down-sampling step, bandpass filtering step, TT defined filtering step, TT SMA filtering step, peak-locating step conducted in an experiment and repeatedly identify the first heart sound and the second heart sound for heart rate detection. The heart rate detection method also effectively lowers the possibility of error in calculating heart rate arising from noises in the surrounding environment. Heart rate data calculated by the heart rate detection method at the five auscultation positions are statistically analyzed by using the standard deviation error, the coefficient of determination, the Bland-Altman difference plot and the Pearson's correlation coefficient to find out that the heart rate detection method has s faster average speed at 7.025 seconds in calculating heart rate than the PCG-type 3M® detector, a detection rate of the heart rate detection method is 91.33%, and the heart rate calculated at the tricuspid position and the mitral position has higher heart rate measuring speed in contrast to the PCG-type 3M® detector and higher degree of correlation with the ECG-type physiological monitor MP70, rendering the heart rate detection method and any heart sound acquisition device built in with the heart rate detection method with competitive edge in field of heart rate detection using heart sound.

[0051] Even though numerous characteristics and advantages of the present invention have been set forth in the foregoing description, together with details of the structure and function of the invention, the disclosure is illustrative only. Changes may be made in detail, especially in matters of shape, size, and arrangement of parts within the principles of the invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed.

Claims

1. A heart rate detection method using heart sounds acquired from an auscultation position, wherein the heart rate detection method is performed at a processor of a heart rate detection device, the heart rate detection method comprising steps of:

   an original heart sound signal acquisition step; a bandpass filtering step; a TT defined filtering step; a TT SMA filtering step; and a peak-locating step.

2. The heart rate detection method as claimed in claim 1, further comprising a down-sampling step for reducing a first sampling frequency of the heart sound signal acquired from the original heart sound signal acquisition step into a second sampling frequency.

3. The heart rate detection method as claimed in claim 2, wherein the first sampling frequency is substantially 48kHz and the second sampling frequency is substantially 375Hz.

4. The heart rate detection method as claimed in claim 2, wherein the samples at each second is accumulated with the samples at the two seconds right before the instant second for the band pass filtering step.

5. The heart rate detection method as claimed in claim 1, further comprising a heart rate standard deviation step.

6. The heart rate detection method as claimed in claim 5, further comprising the TT algorithm output step.

7. The heart rate detection method as claimed in claim 5, used for detecting heart rate abnormality selected from the group consisting of loss of pulse, ventricular arrhythmia, ventricular tachycardia and ventricular fibrillation.

8. The heart rate detection method as claimed in claim 1, the auscultation position is selected from the group consisting of an auscultation position for mitral valve, an auscultation position for pulmonary valve, a first auscultation position for aortic valve, a second auscultation position for aortic valve, and an auscultation position for tricuspid valve.

9. The heart rate detection method as claimed in claim 1, wherein the two frequency thresholds are 20Hz and 100Hz.

10. The heart rate detection method as claimed in claim 1, used for detecting heart rate abnormality selected from the group consisting of loss of pulse, ventricular arrhythmia, ventricular tachycardia and ventricular fibrillation.

11. A heart rate detection device comprising:

an analog-to-digital (A/D) converter coupled to an analog input module and converting the heart sounds into digital data;
a processor coupled to the A/D converter, and receiving the digital data transmitted from the A/D converter;
a memory module coupled to the processor and storing the digital signals; and
a heart rate detection module coupled to the processor, receiving the digital data transmitted from the processor, and performing a down-sampling process, a band-pass filtering process, a time sequence (TT) defined filtering process, a TT SMA filtering process and a peak-locating process to acquire heart rate of an auscultation position.

12. The heart rate detection device as claimed in claim 11, wherein the heart rate detection module is integrated in the processor.

13. The heart rate detection device as claimed in claim 11, further comprising a display module, an analog output unit, a communication module and a power supply.

14. The heart rate detection device as claimed in claim 11, wherein the heart rate detection device is an electronic stethoscope further comprising the analog input unit, a communication module, a memory module, a display module, an analog module and a power supply.

15. The heart rate detection device as claimed in claim 11, wherein the heart rate detection device is a mobile electronic device further comprising a communication module, a memory module, a display module, an analog module and a power supply; and the analog input unit is accommodated in an auscultation patch.

16. The heart rate detection device as claimed in claim 14, used for detecting heart rate abnormality selected from the group consisting of loss of pulse, ventricular arrhythmia, ventricular tachycardia and ventricular fibrillation.

17. The heart rate detection device as claimed in claim 15, used for detecting heart rate abnormality selected from the group consisting of loss of pulse, ventricular arrhythmia, ventricular tachycardia and ventricular fibrillation.

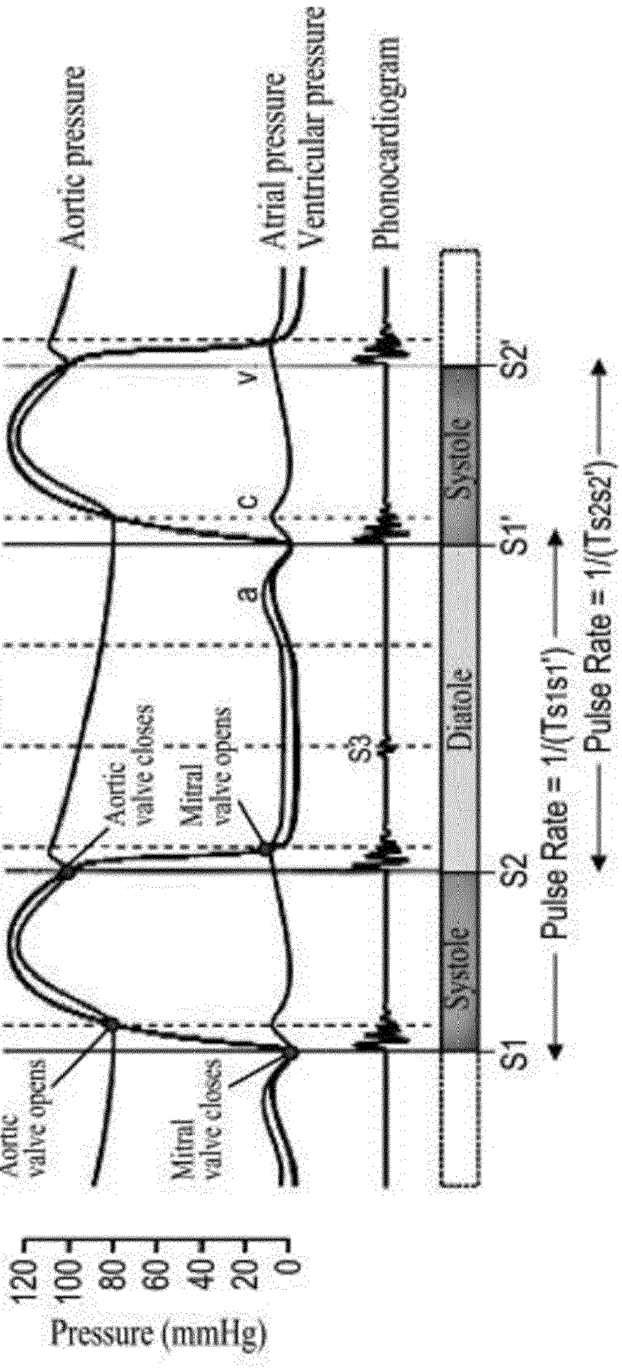
Electrocardiogram
Aortic pressure
Atrial pressure
Ventricular pressure
Phonocardiogram
P
R
Q
S
T
R'
Heart Rate = 1/(T_RR')
Aortic valve opens
Aortic valve closes
Mitral valve closes
Mitral valve opens
a
c
v
S3
Systole
Diatole
Systole
S1
S2
S1'
S2'
Pulse Rate = 1/(Ts1s1')
Pulse Rate = 1/(Ts2s2')
Pressure (mmHg)
120
100
80
60
40
20
0

FIG. 1

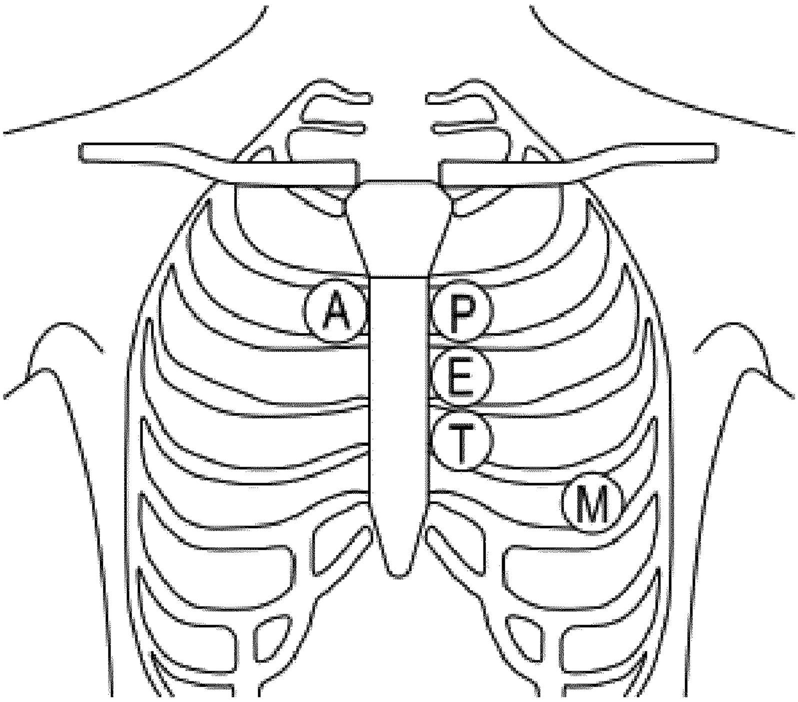

FIG. 2

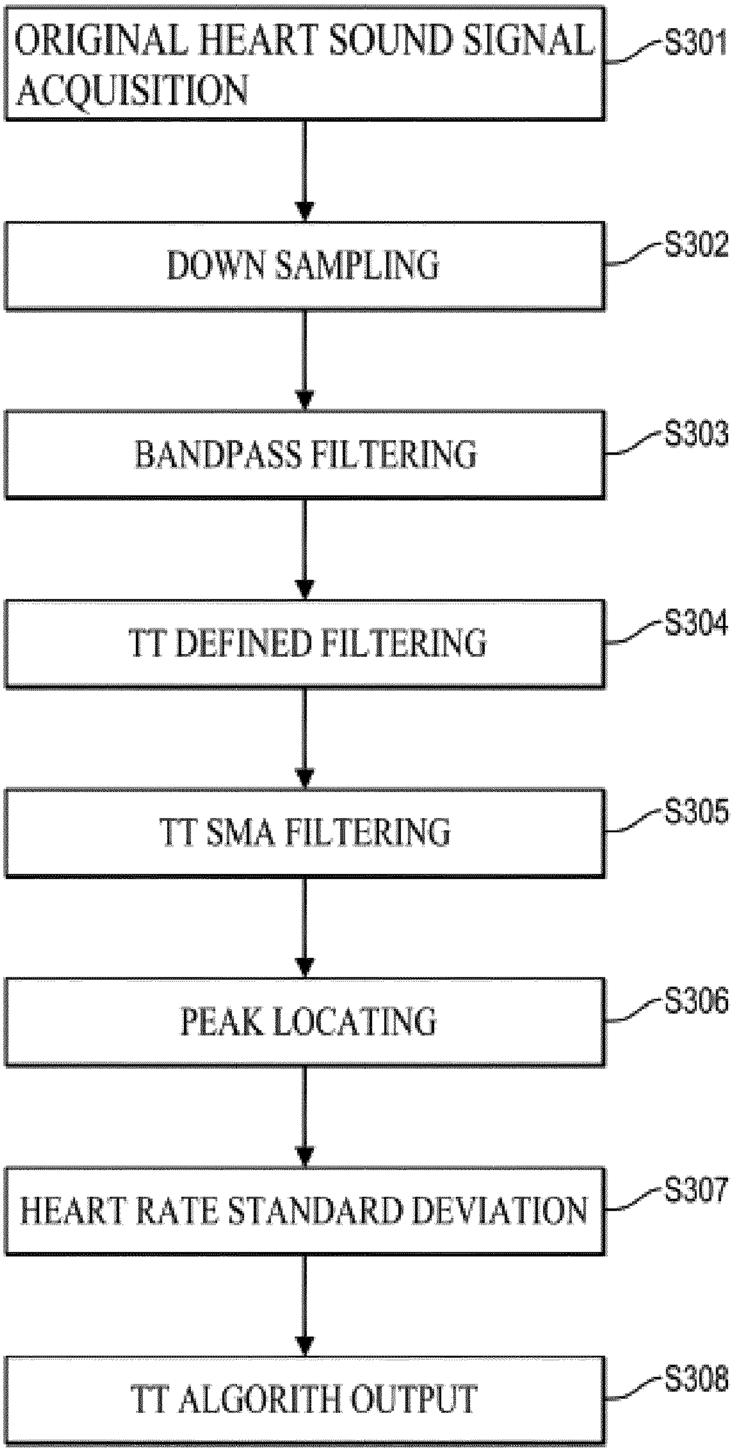
ORIGINAL HEART SOUND SIGNAL ACQUISITION
S301
DOWN SAMPLING
S302
BANDPASS FILTERING
S303
TT DEFINED FILTERING
S304
TT SMA FILTERING
S305
PEAK LOCATING
S306
HEART RATE STANDARD DEVIATION
S307
TT ALGORITH OUTPUT
S308

FIG. 3

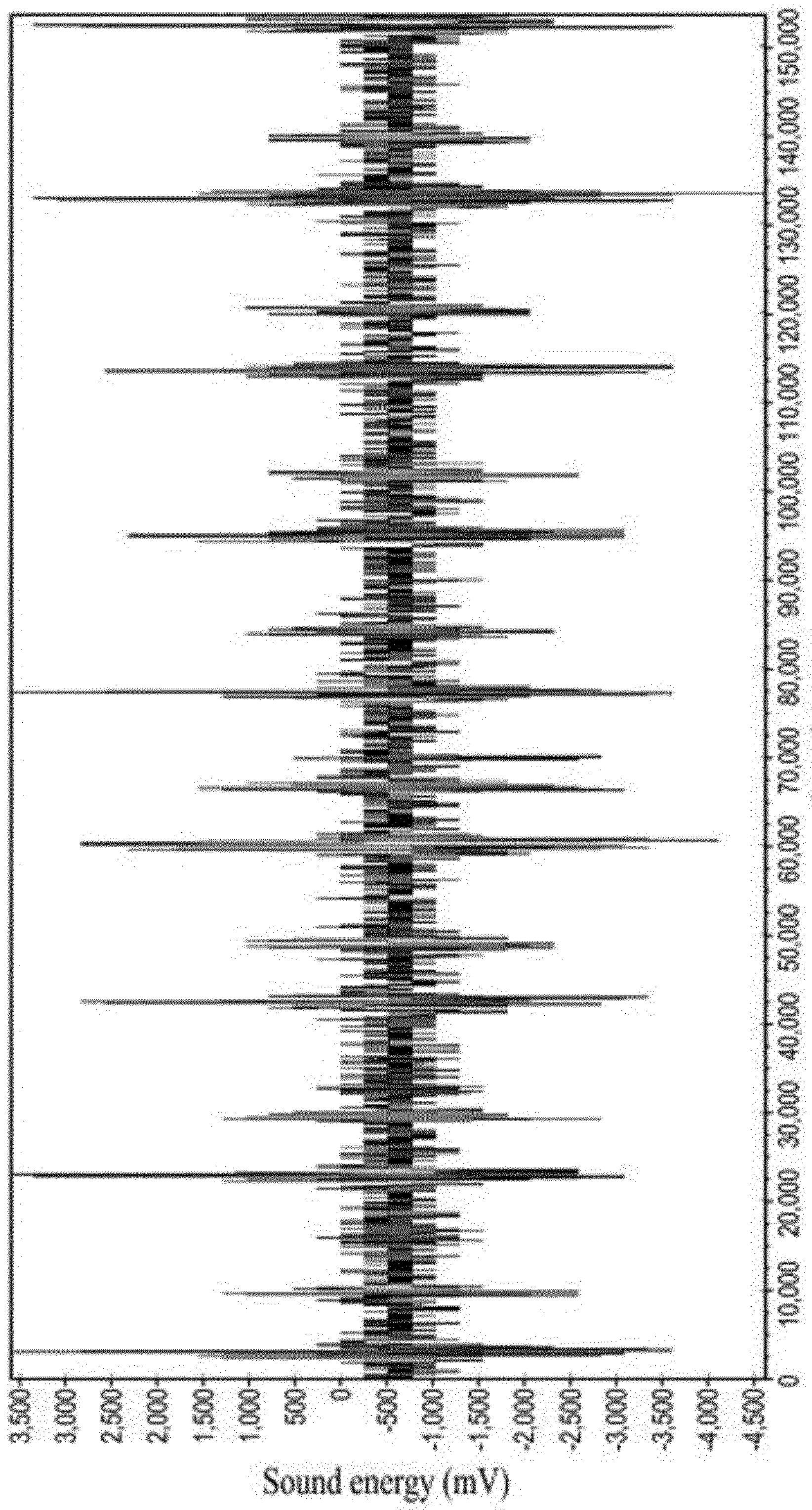
Sound energy (mV)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
-2,500
-3,000
-3,500
-4,000
-4,500
Sample count
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
110,000
120,000
130,000
140,000
150,000

FIG. 4

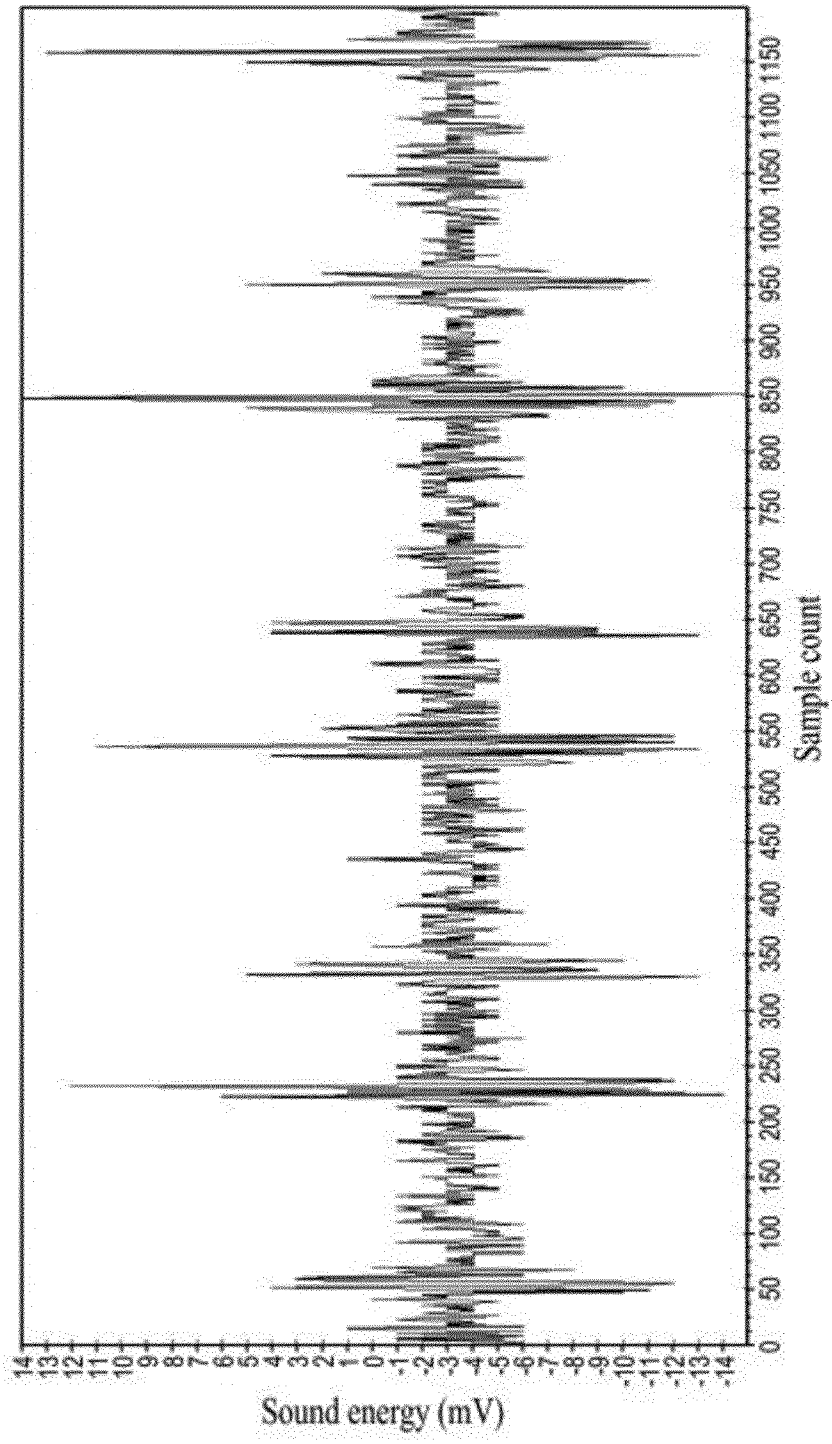

FIG. 5

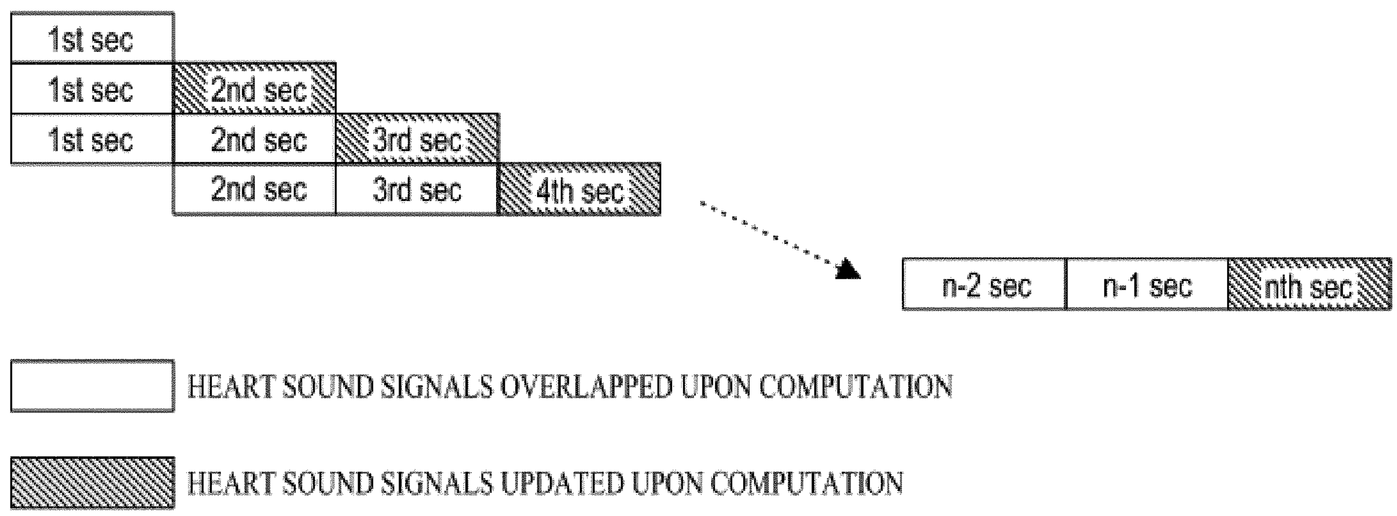
1st sec
1st sec
2nd sec
1st sec
2nd sec
3rd sec
2nd sec
3rd sec
4th sec
n-2 sec
n-1 sec
nth sec
HEART SOUND SIGNALS OVERLAPPED UPON COMPUTATION
HEART SOUND SIGNALS UPDATED UPON COMPUTATION

FIG. 6

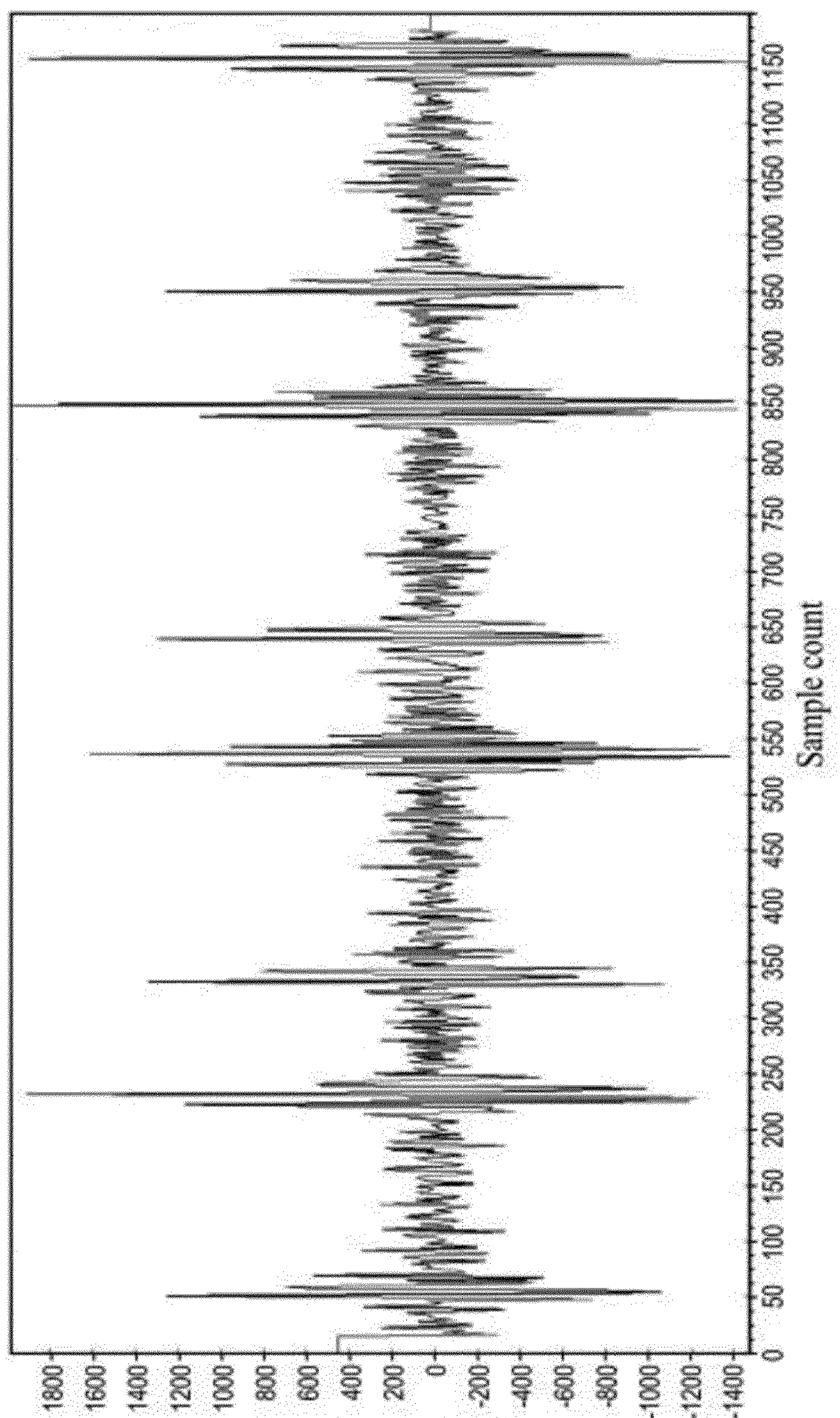
Sound energy (mV)
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
Sample count
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150

FIG. 7

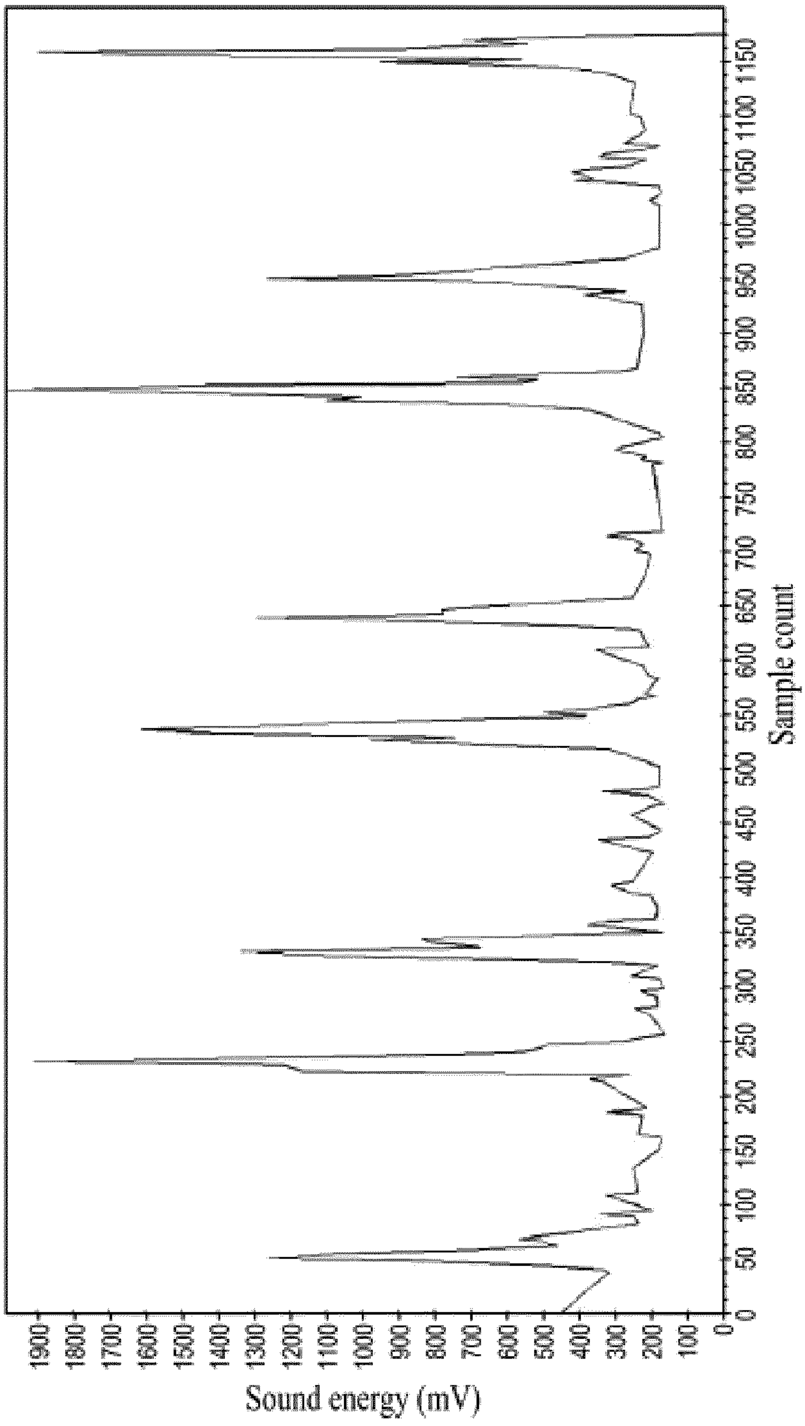

FIG. 8

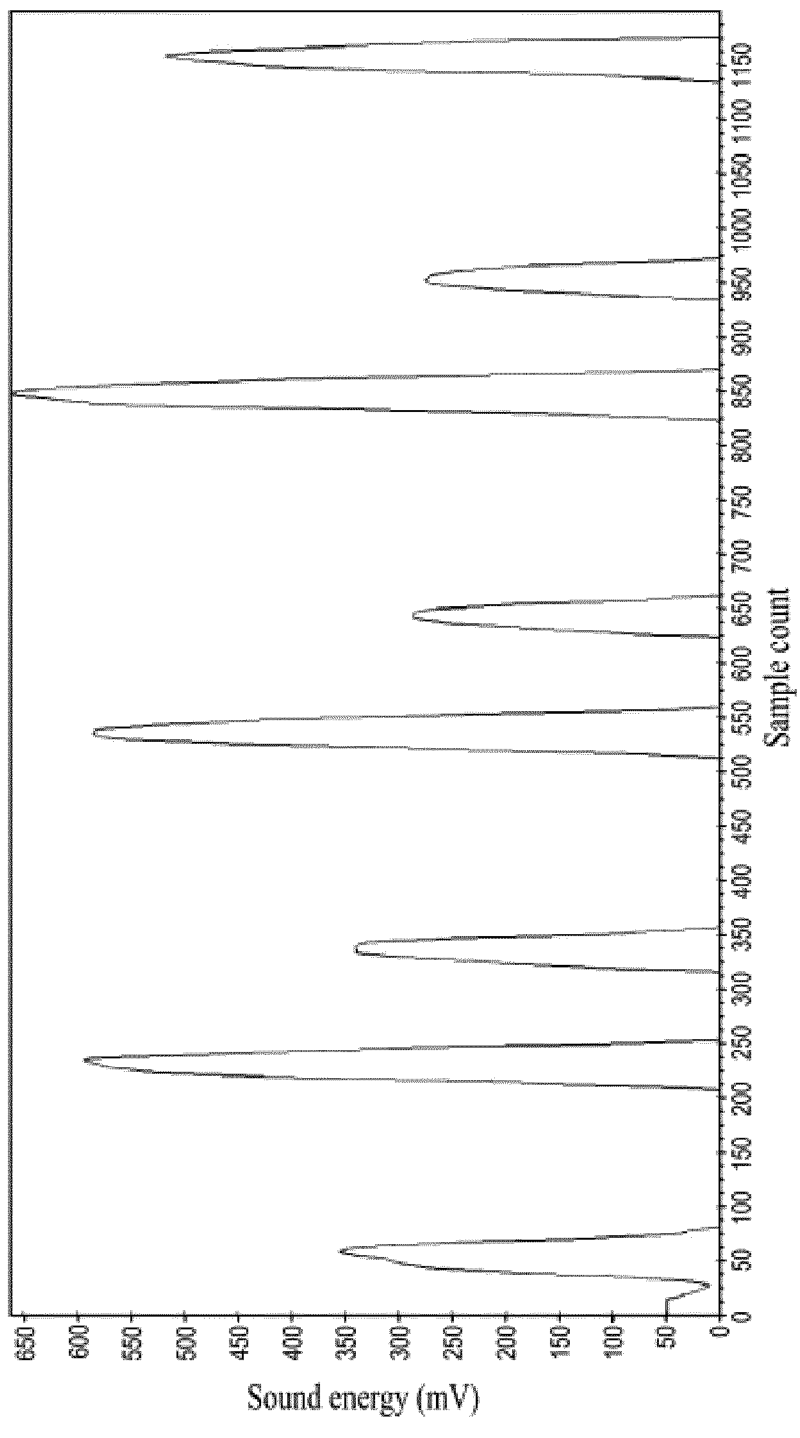
Sound energy (mV)
650 600 550 500 450 400 350 300 250 200 150 100 50 0
Sample count
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150

FIG. 9

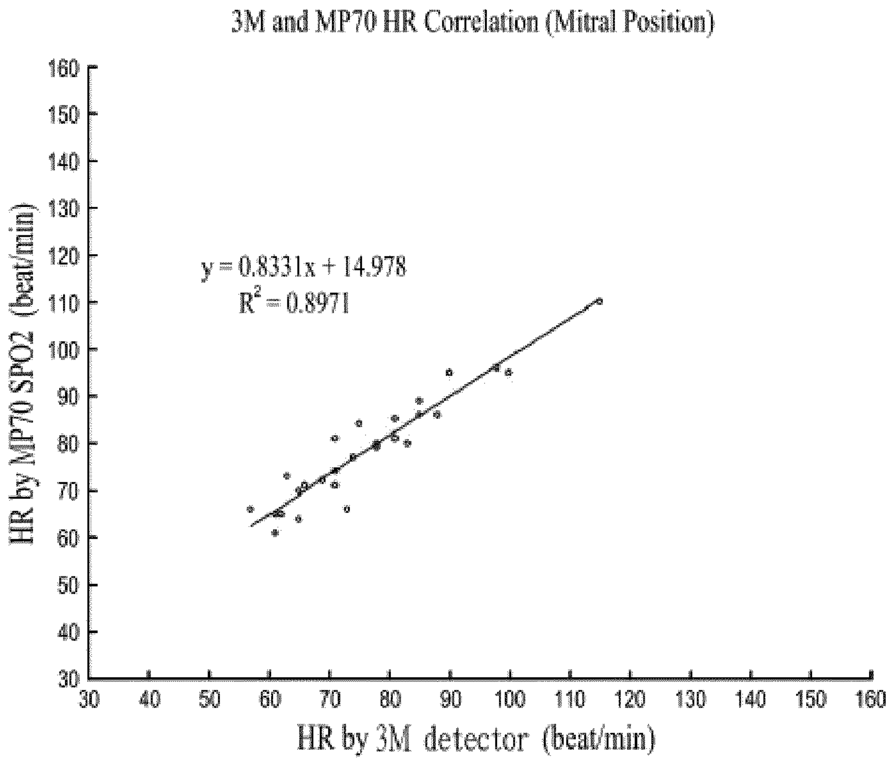

FIG. 10A

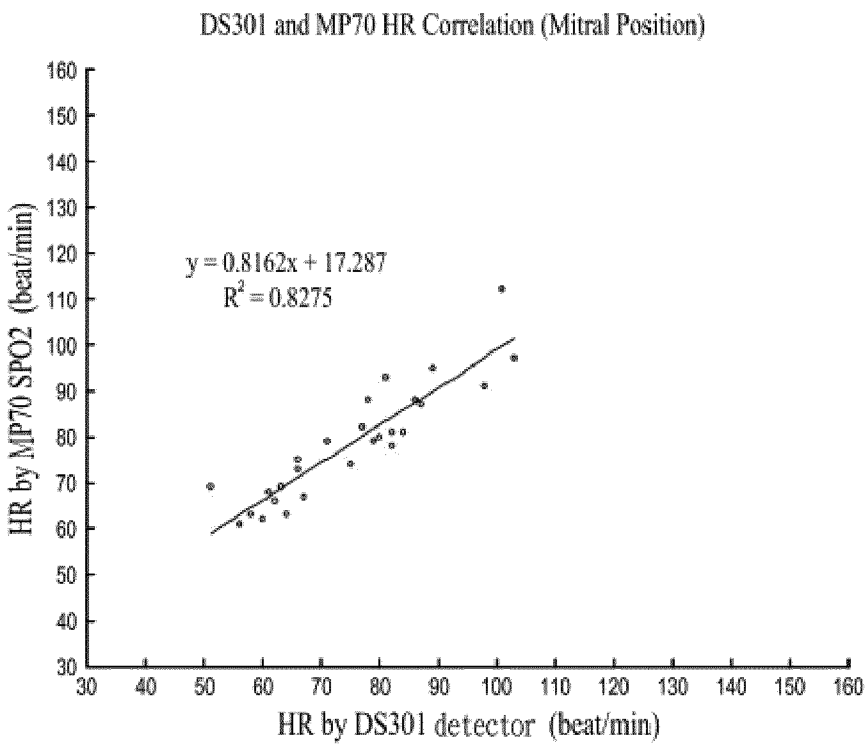

FIG. 10B

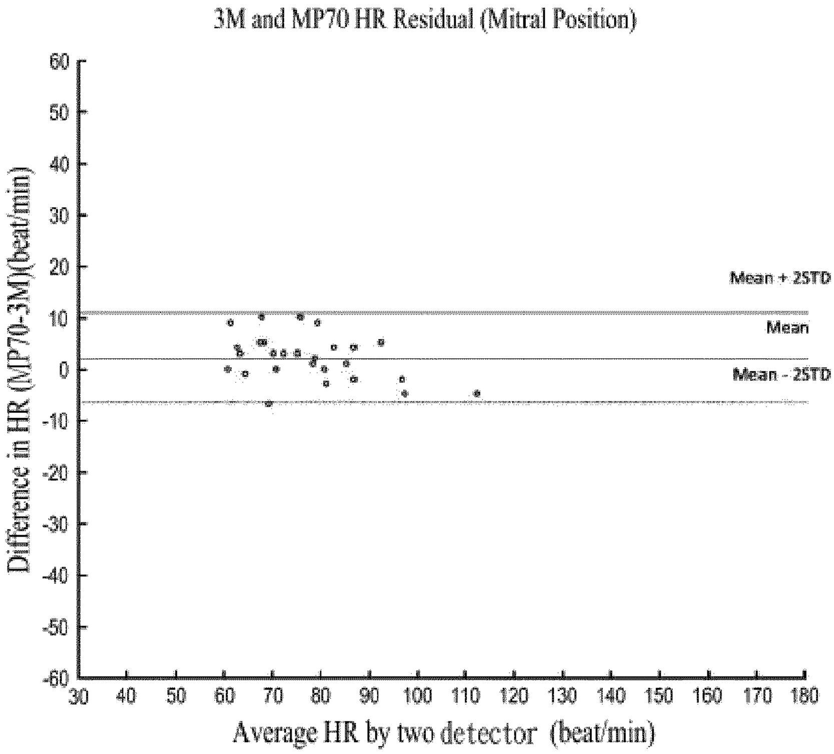

FIG. 11A

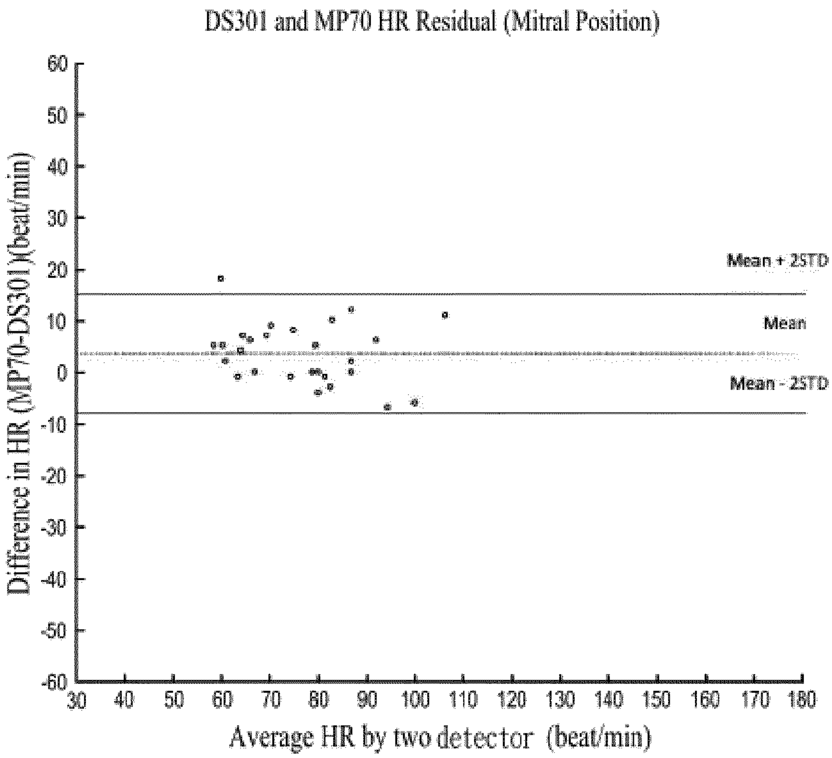

FIG. 11B

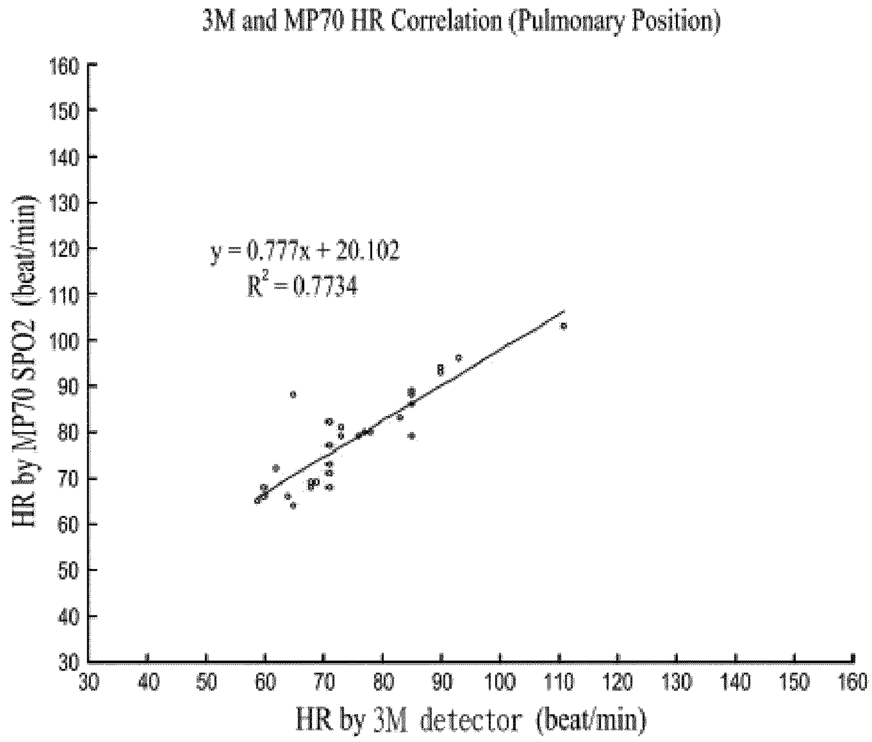

FIG. 12A

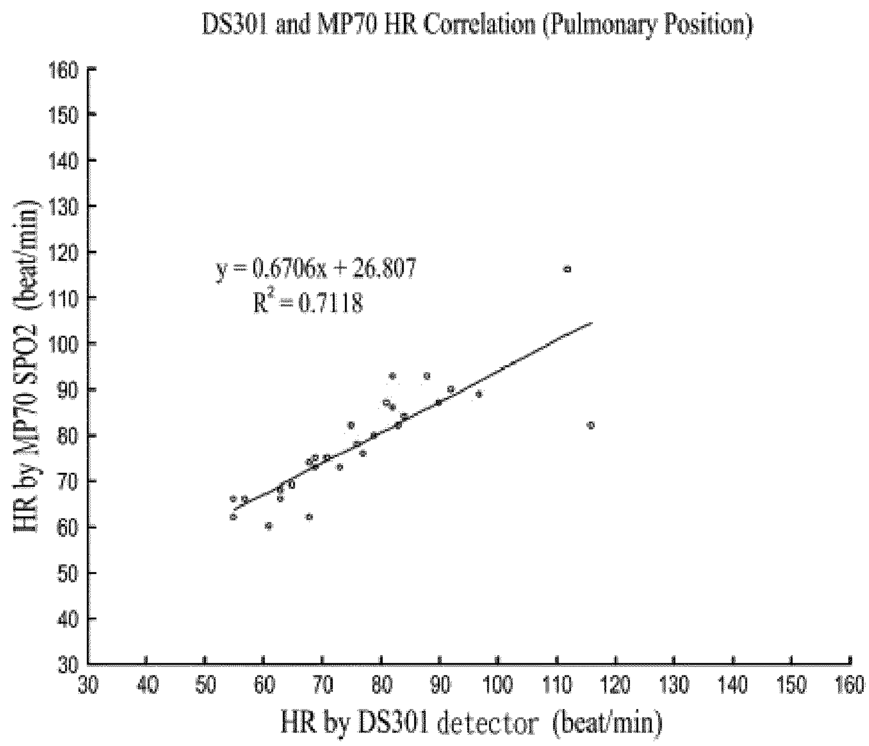

FIG. 12B

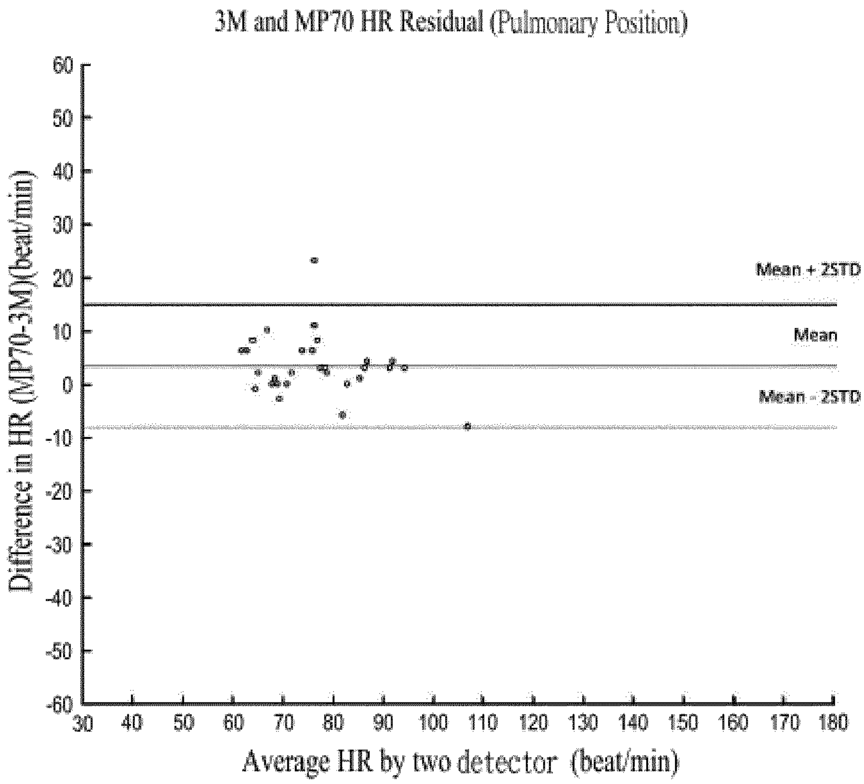

FIG. 13A

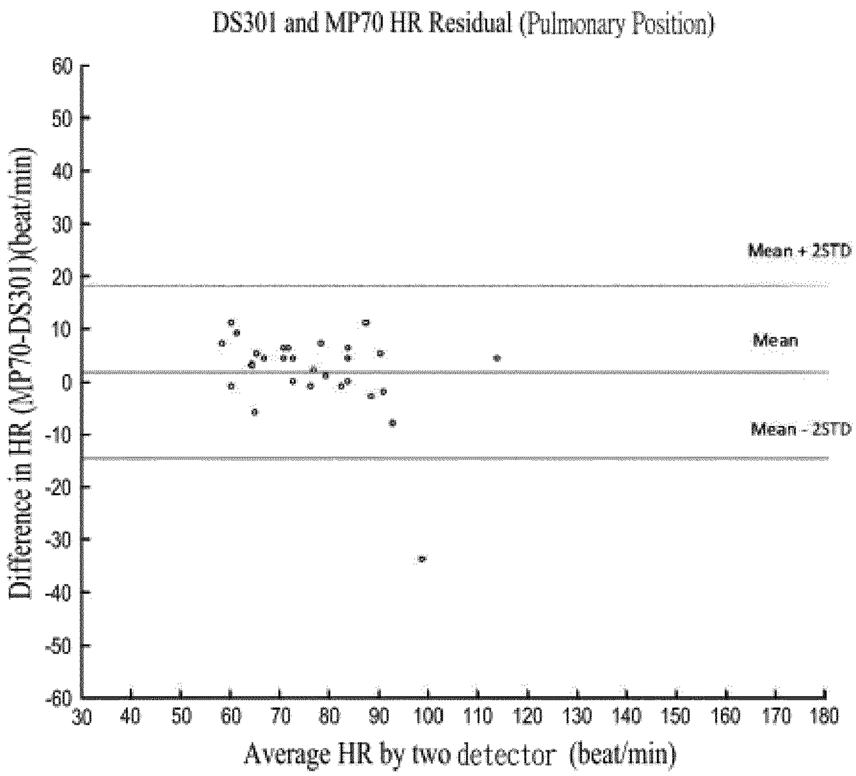

FIG. 13B

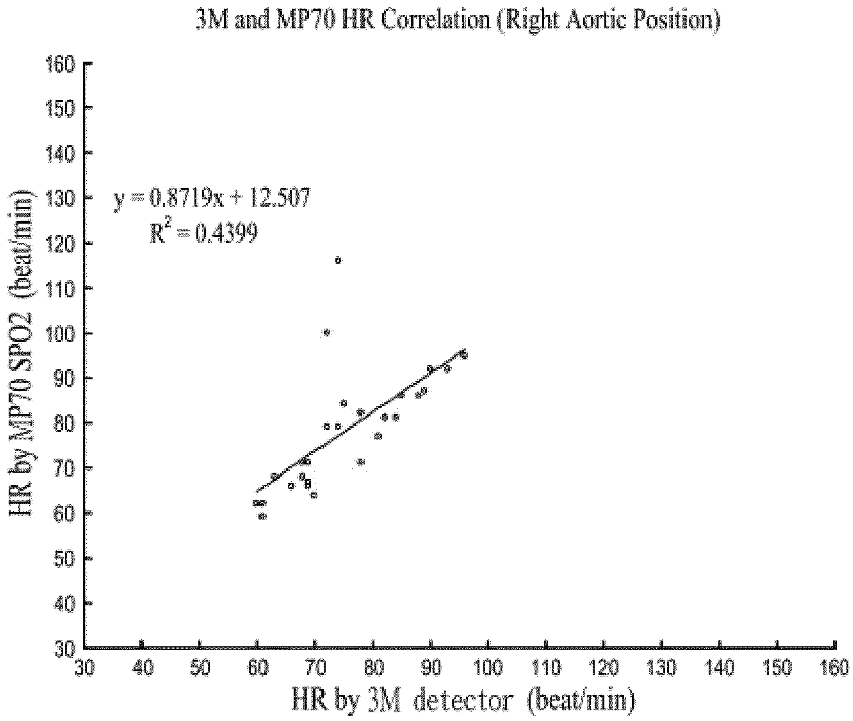

FIG. 14A

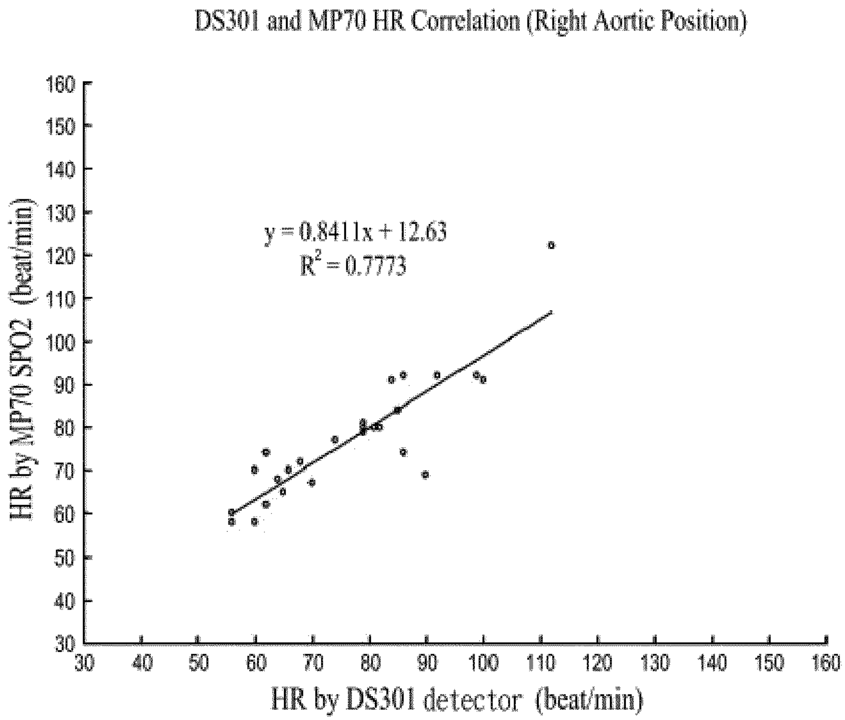

FIG. 14B

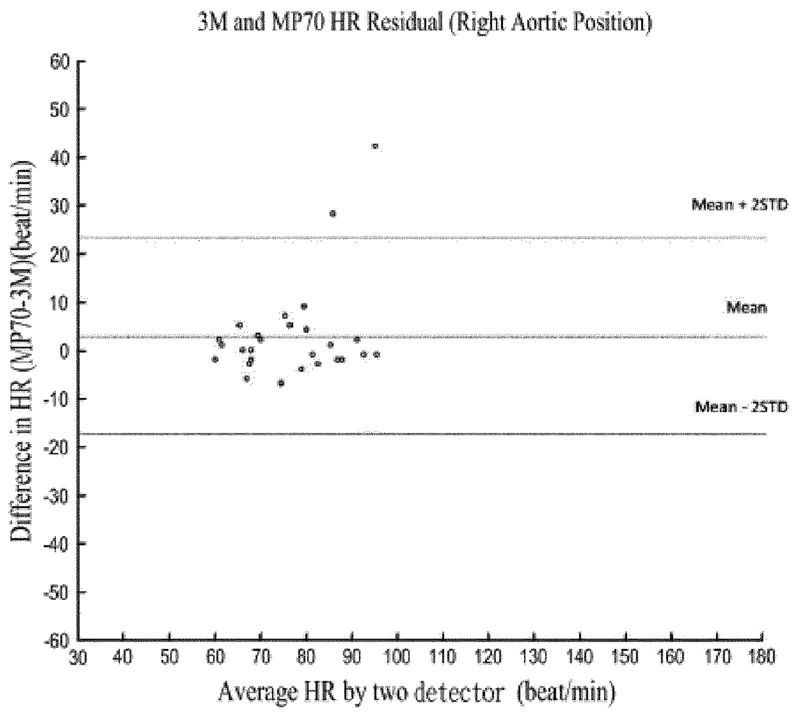

FIG. 15A

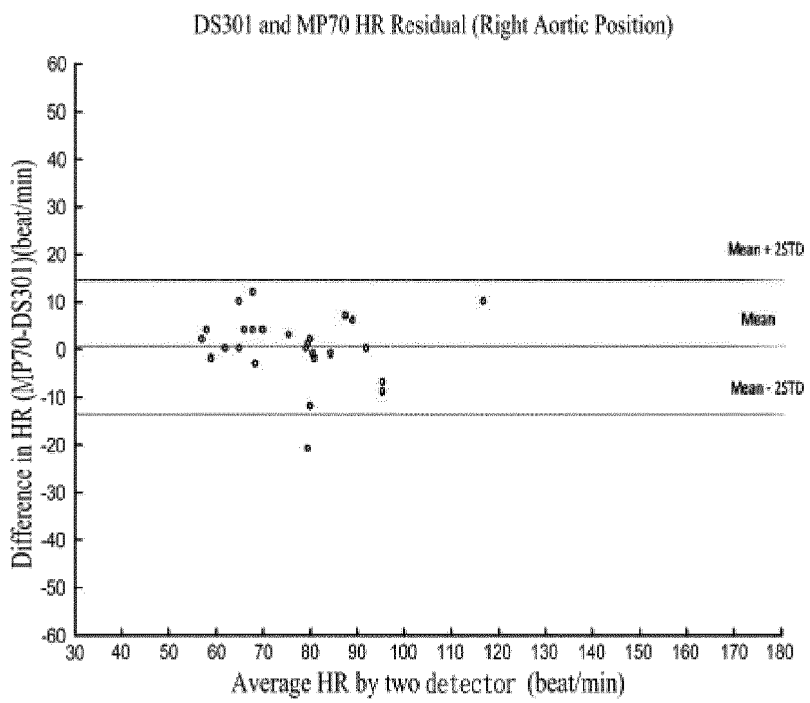

FIG. 15B

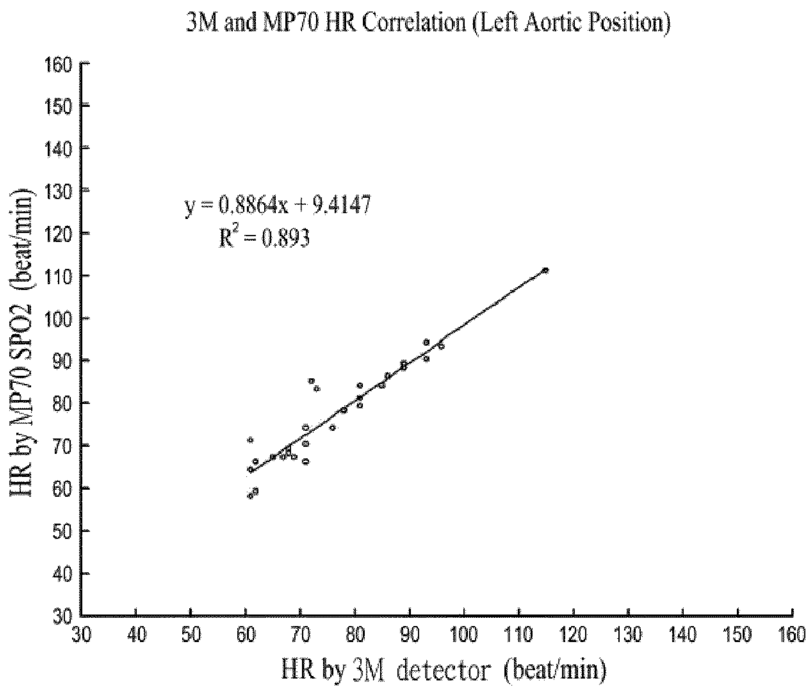

FIG. 16A

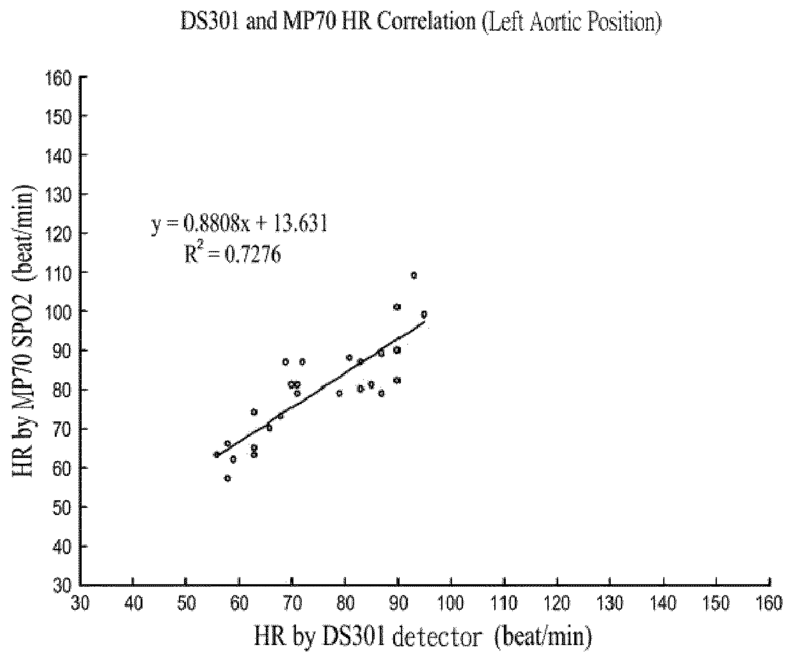

FIG. 16B

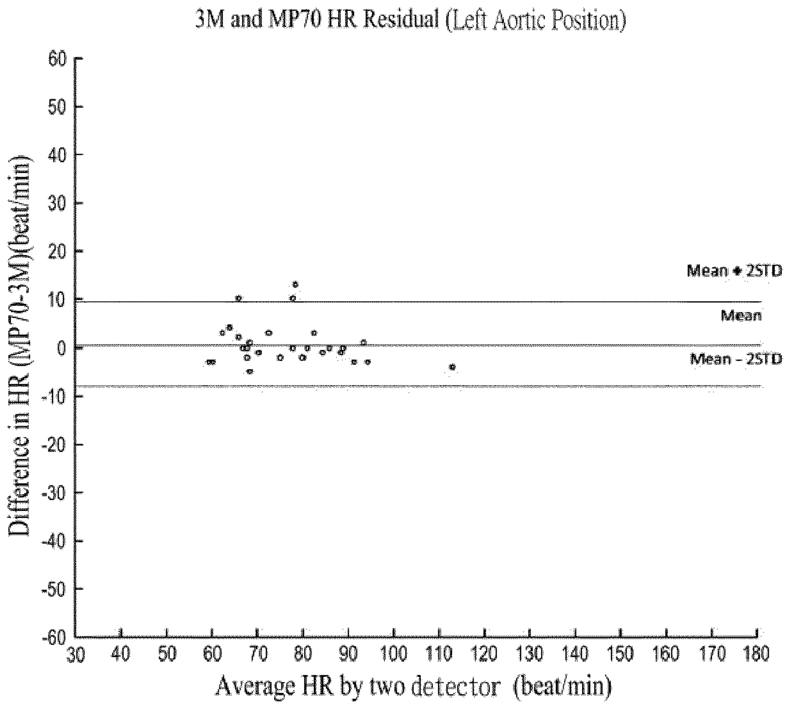

FIG. 17A

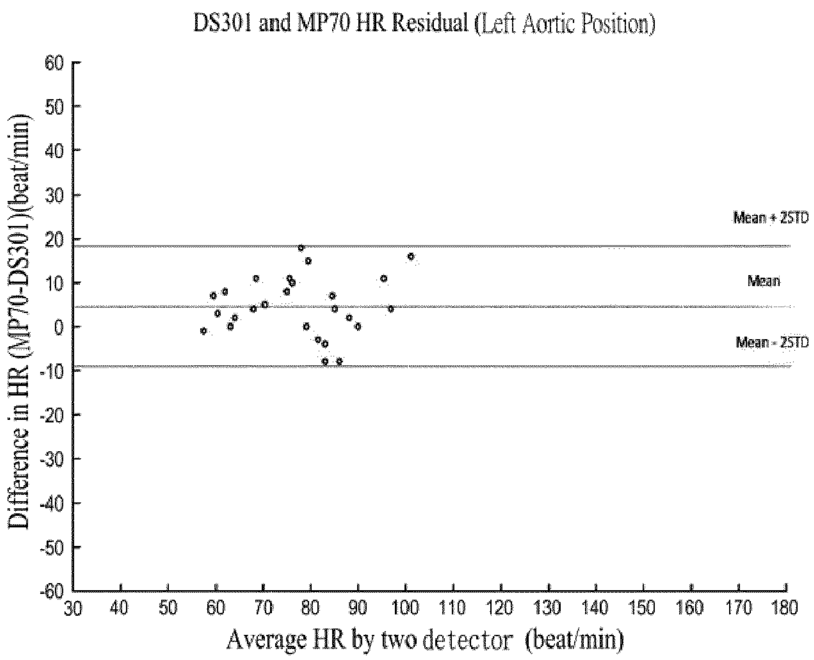

FIG. 17B

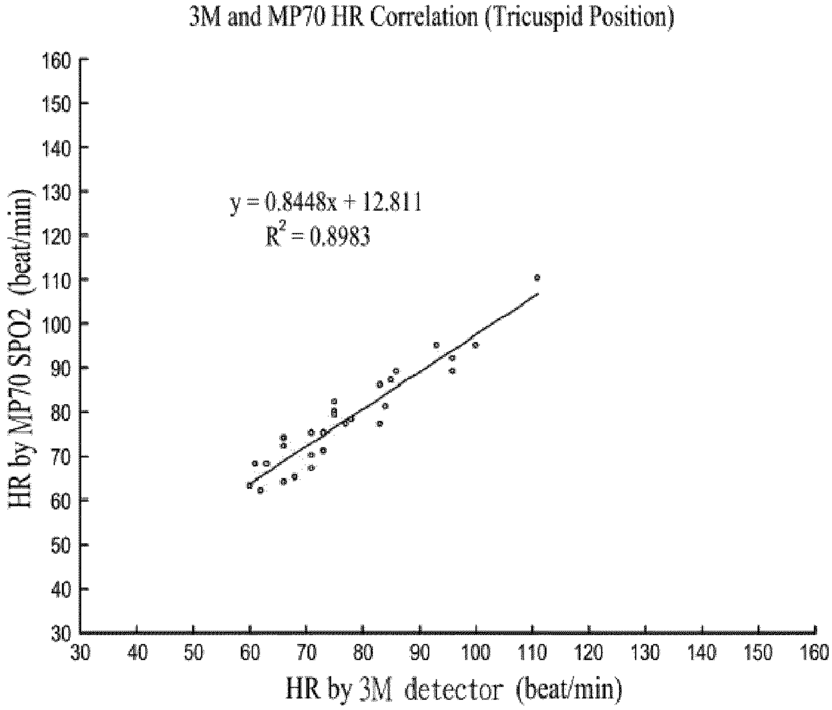

FIG. 18A

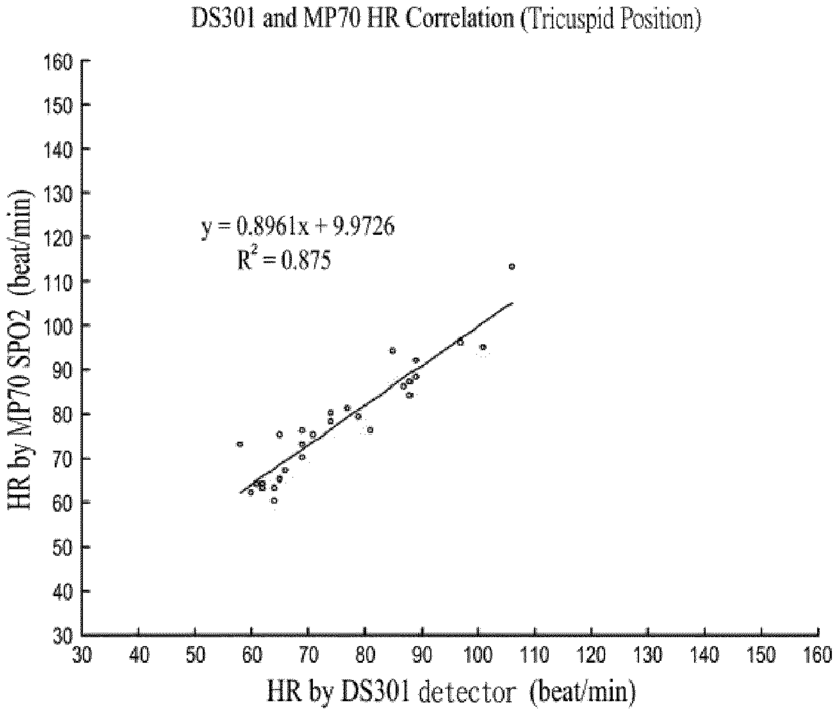

FIG. 18B

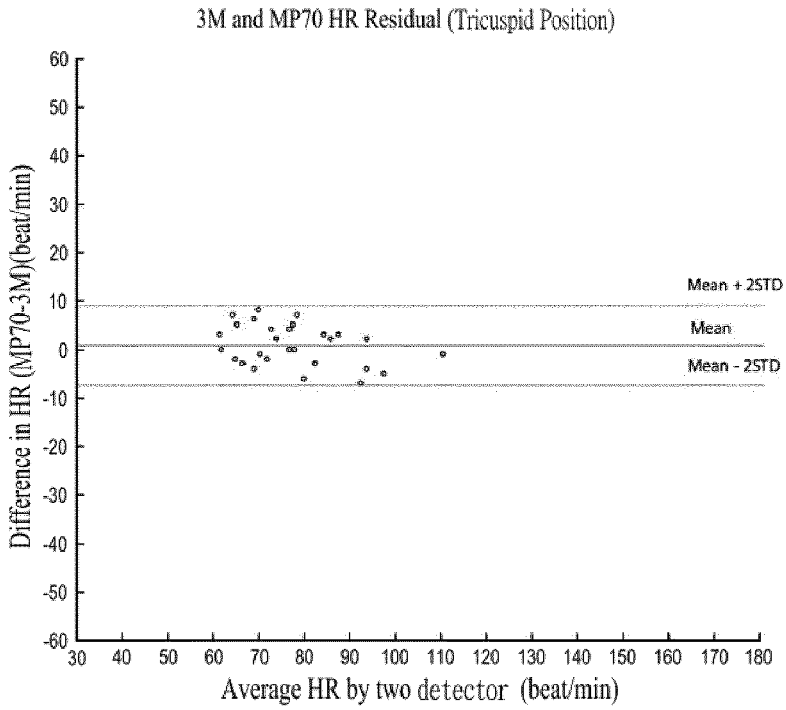

FIG. 19A

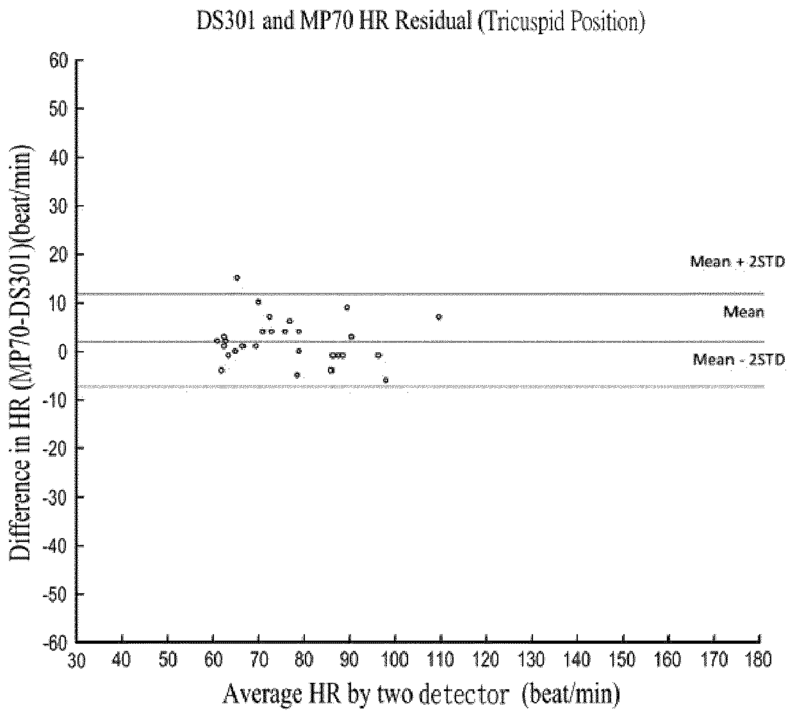

FIG. 19B

3M and MP70 HR Correlation (Total Position)

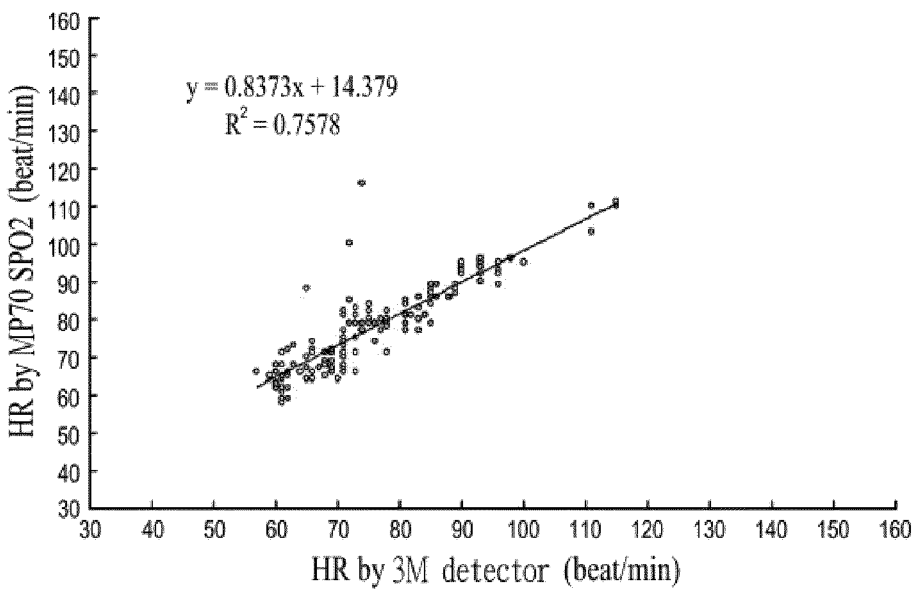

FIG. 20A

DS301 and MP70 HR Correlation (Total Position)

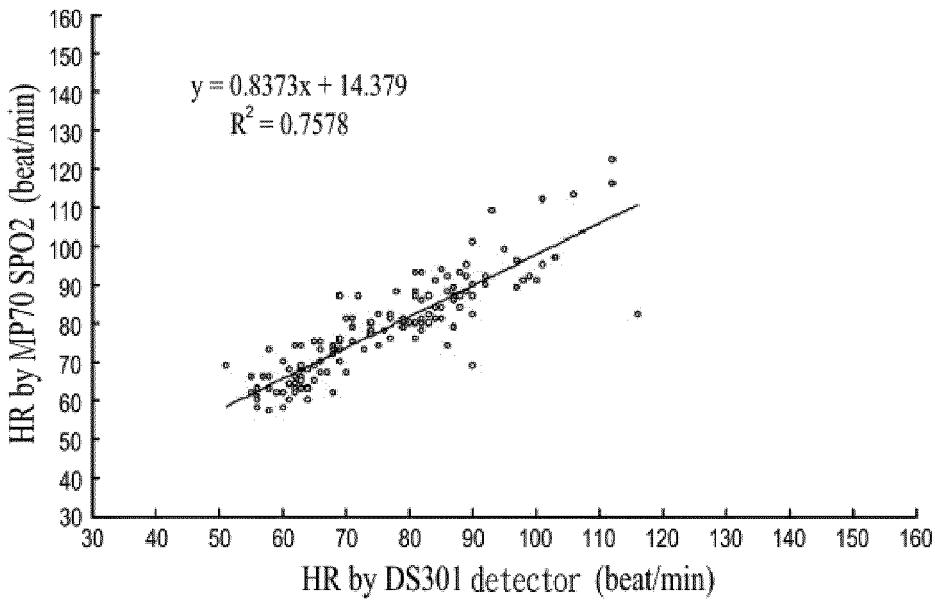

FIG. 20B

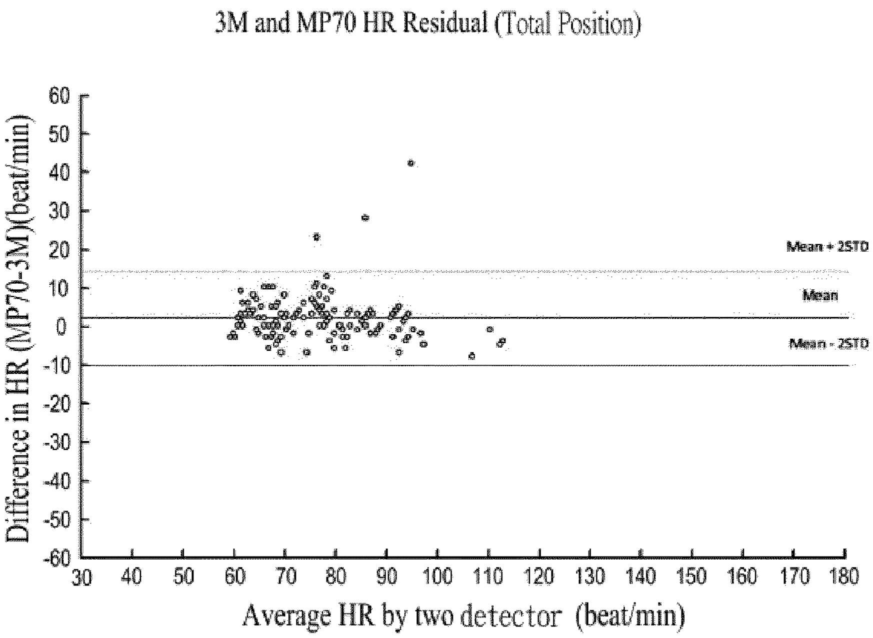

FIG. 21A

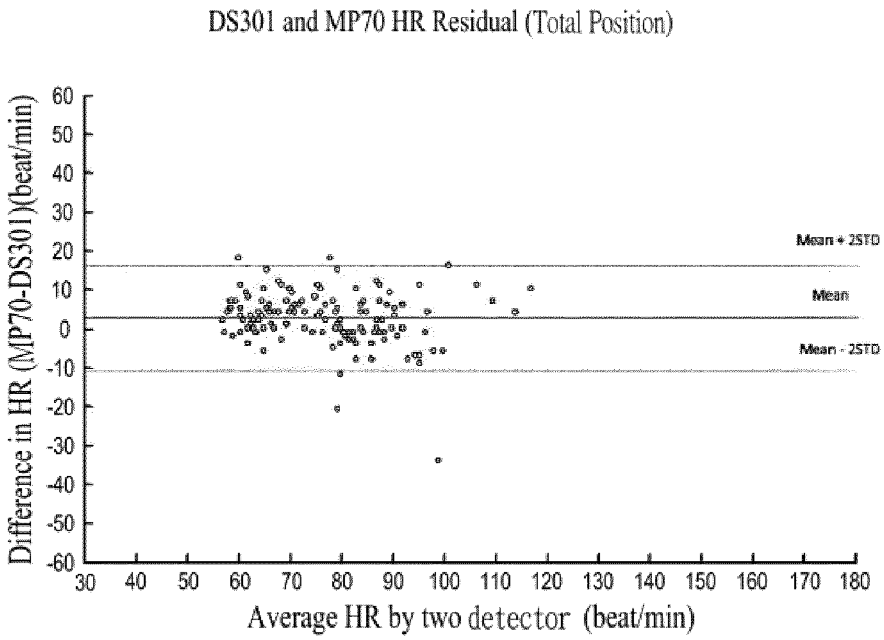

FIG. 21B

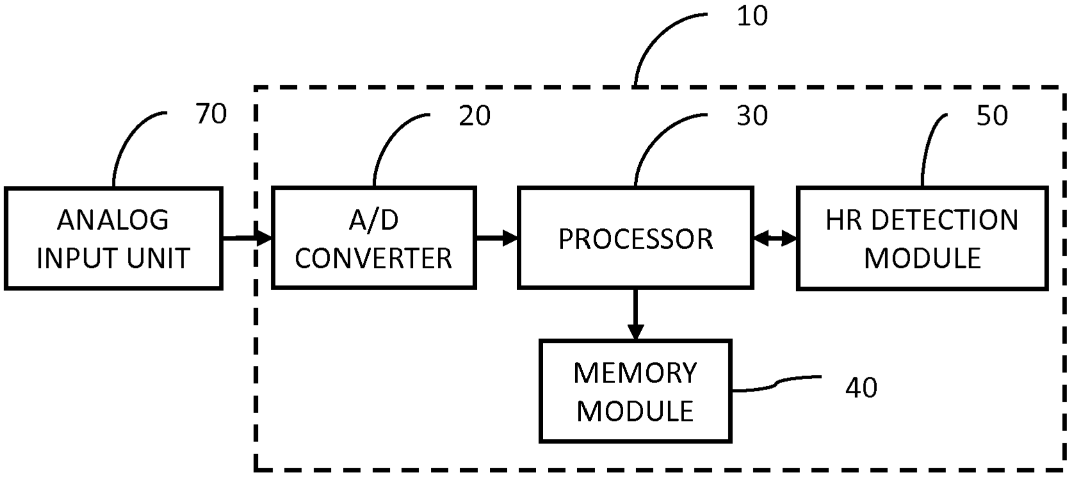
10
70
20
30
50
ANALOG
INPUT UNIT
A/D
CONVERTER
PROCESSOR
HR DETECTION
MODULE
MEMORY
MODULE
40

FIG. 22

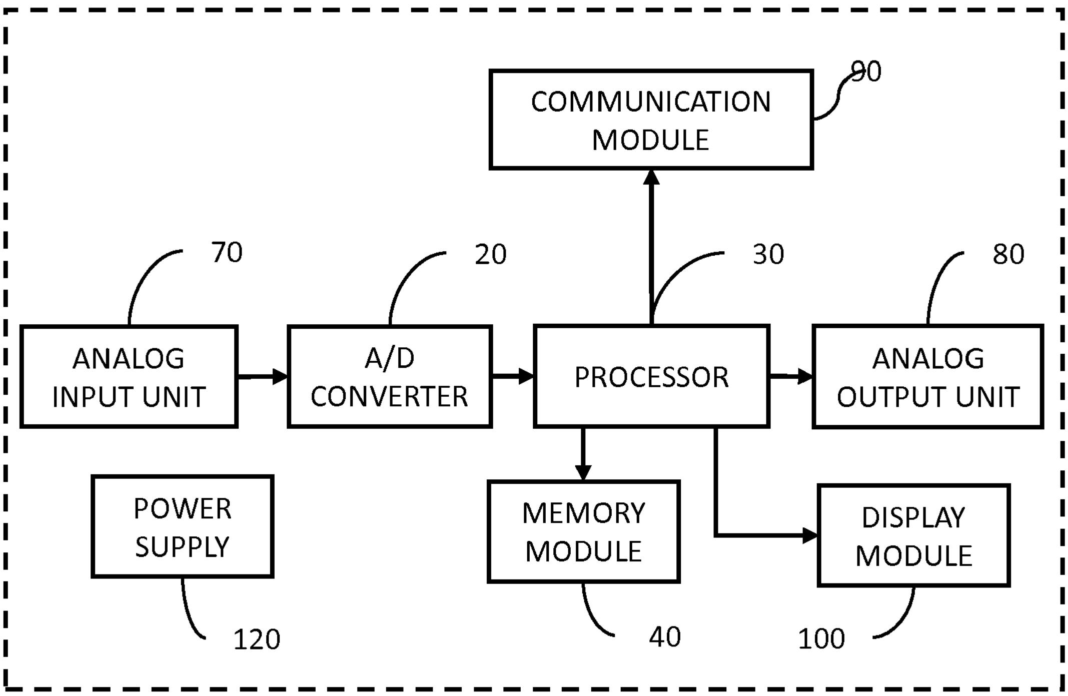
COMMUNICATION
MODULE
90
70
20
30
80
ANALOG
INPUT UNIT
A/D
CONVERTER
PROCESSOR
ANALOG
OUTPUT UNIT
POWER
SUPPLY
MEMORY
MODULE
DISPLAY
MODULE
120
40
100

FIG. 23

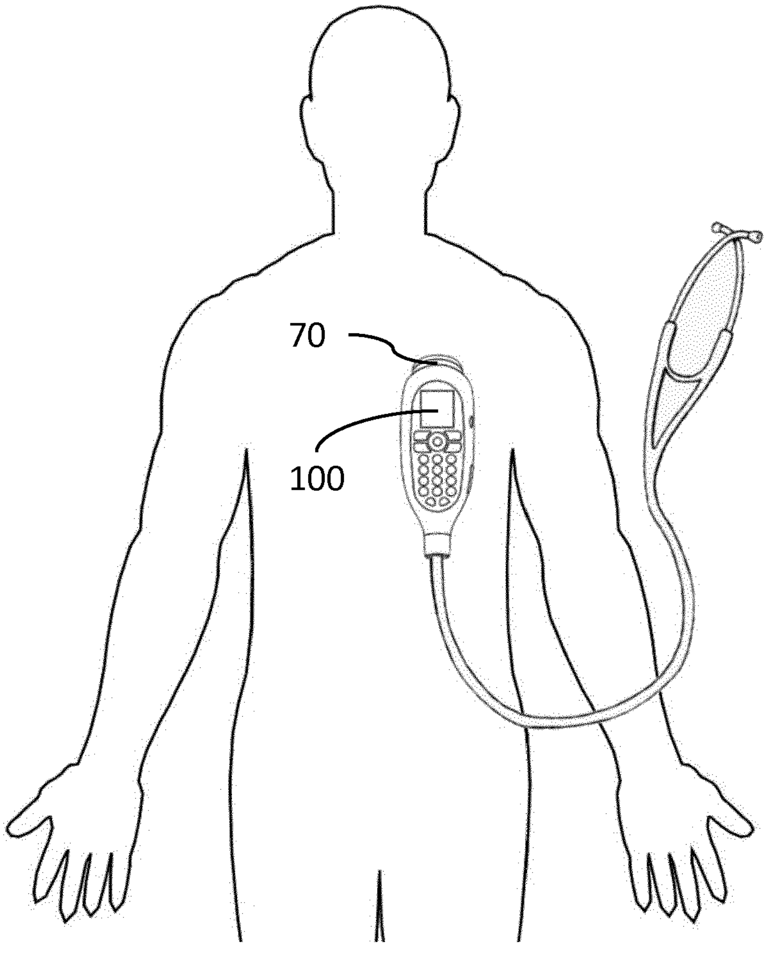

FIG. 24

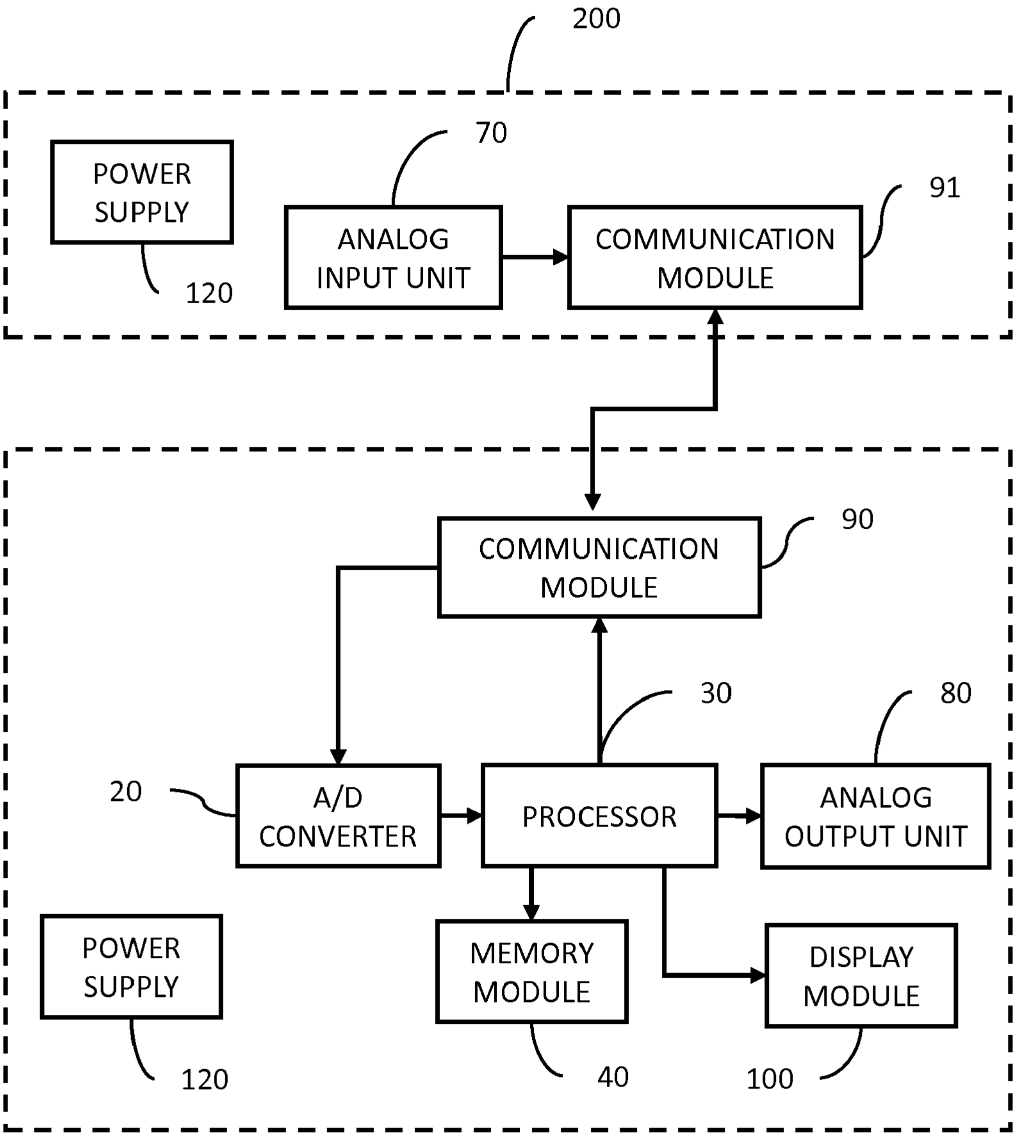
200
POWER SUPPLY
120
70
ANALOG INPUT UNIT
COMMUNICATION MODULE
91
COMMUNICATION MODULE
90
30
80
20
A/D CONVERTER
PROCESSOR
ANALOG OUTPUT UNIT
POWER SUPPLY
MEMORY MODULE
DISPLAY MODULE
120
40
100

FIG. 25

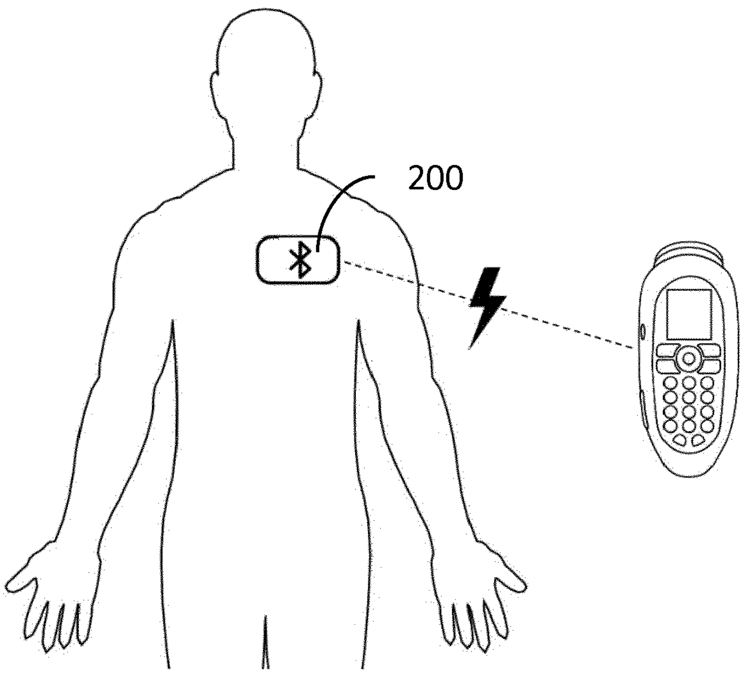

FIG. 26

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 16 17 8795

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2006/247550 A1 (THIAGARAJAN ARVIND [IN] ET AL) 2 November 2006 (2006-11-02) * paragraphs [0016], [0057], [0063], [0065], [0073], [0074], [0081], [0085], [0091] * * paragraphs [0118], [0124], [0127], [0155] * * figure 2, * -----	1-17	INV. A61B7/04 A61B5/00 A61B5/024 A61B5/0245 A61B5/0255
A	US 2011/295127 A1 (SANDLER RICHARD H [US] ET AL) 1 December 2011 (2011-12-01) * paragraphs [0014], [0051], [0053], [0079] * * figures 1,2 * -----	3,8,14, 15	
A	WO 2004/035137 A1 (GAVRIELY NOAM [IL]; INTRATOR NATHAN [US]) 29 April 2004 (2004-04-29) * page 1, line 21 * * page 13, line 1 * * page 15, lines 4, 7, 8 * -----	5-7,10, 16,17	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2010/331903 A1 (ZHANG XUSHENG [US] ET AL) 30 December 2010 (2010-12-30) * the whole document * -----	1-17	A61B
A	US 2013/237872 A1 (ZHANG XUSHENG [US] ET AL) 12 September 2013 (2013-09-12) * the whole document * ----- -/--	1-17	

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	9 February 2017	Meyer, Wolfgang

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 16 17 8795

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	CHEN GUANGWEI ET AL: "Algorithm for heart rate extraction in a novel wearable acoustic sensor", HEALTHCARE TECHNOLOGY LETTERS, THE INSTITUTION OF ENGINEERING AND TECHNOLOGY, MICHAEL FARADAY HOUSE, SIX HILLS WAY, STEVENAGE, HERTS. SG1 2AY, UK, vol. 2, no. 1, 1 February 2015 (2015-02-01), pages 28-33, XP006051322, DOI: 10.1049/HTL.2014.0095 * the whole document * -----	1-17	
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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	9 February 2017	Meyer, Wolfgang

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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L : document cited for other reasons

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专利名称(译)	使用从奥氏体位置获得的心音的心率检测方法和装置
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[标]申请(专利权)人(译)	创心医电股份有限公司
申请(专利权)人(译)	伊梅季PLUS INC.
当前申请(专利权)人(译)	伊梅季PLUS INC.
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发明人	TSAI, KUN-HSI YANG, SHIH-I KU, SHIH-HSUAN LIANG, TZU-CHEN WAN, LEI CHEN, CHUNG-LUN LIAO, WEN-LING CHEN, YU-HSUAN
IPC分类号	A61B7/04 A61B5/00 A61B5/024 A61B5/0245 A61B5/0255
CPC分类号	A61B5/024 A61B5/02438 A61B5/0245 A61B5/0255 A61B5/725 A61B7/00 A61B2505/01 A61B5/0205 A61B5/04017 A61B5/0402 A61B5/0432 A61B5/046 A61B5/0464 A61B7/04
审查员(译)	MEYER，WOLFGANG
优先权	14/849619 2015-09-10 US
外部链接	Espacenet

摘要(译)

用于计算心率的心率检测方法使用从听诊位置获取的心音。心率检测方法包括下采样步骤，带通滤波步骤，时序定义滤波步骤，简单移动平均滤波步骤，峰值定位步骤，以从听诊位置获取心音样本。从听诊位置测量的心率允许快速且精确的心率检测。

Table 3 - Right Aortic Position

3M® detector			DS301		
STDEV ERROR	MEAN ERROR	SPEED (sec)	STDEV ERROR	MEAN ERROR	SPEED (sec)
10.16292	2.851852	11.5925926	7.04371	0.423077	8.04230769