

of the plurality of smoothed cepstra at each reception time (i.e., each lag time index) of the plurality of digitized signals

[0036] Referring to FIG. 6, an illustration 600 depicts cepstrograms of twelve individual channels, and an illustration 700 (FIG. 7) depicts the fused cepstrogram. In general, the fused cepstrum would provide better indication of a heart beat interval than any individual channel.

[0037] Referring back to FIG. 2, a cepstral peak is detected 210 within each of the plurality of cepstra 204 and the fused cepstrum 208 in an interested lag time range, if the peak reaches a predetermined maximal value (i.e., a maximal cepstral energy value) during the lag time range. The lag time range is typically specified by the heart rate range of human being and the cepstral peak is defined by the lag time index and the cepstral energy value. The peak detection 210 is performed in all the channels as well as the fused cepstrum 208.

[0038] For heart rate estimation, a longer time window (say fifteen seconds) is used to calculate within the time window 212 an average heart rate 214. The cepstral peaks are checked for continuity within the time window. If the percentage of cepstrum with continuous peaks is above a predetermined threshold, the average heart rate 214 is derived by the mean lag time between the peaks. Thus, the average heart rate 214 can be calculated by Equation (2):

$$HR=60/T_lag \quad (2)$$

where T_lag is the mean lag time of the cepstral peaks. If the percentage is below the predetermined threshold, the average heart rate 214 for the time window is not estimated (i.e., is set to null).

[0039] The heart rate 216 estimated from the fused cepstrum 208 is checked for compliance with the heart rate 214 estimated from each of the individual channels.

CLAIMS

What is claimed is:

1. A method for ballistocardiography comprising:
digitizing a plurality of signals received from a corresponding plurality of sensors;
applying a frequency domain Hanning window with a frequency range of -128 to +128 Hz or narrower to a logarithm power spectrum that is transformed by inverse Fourier transform in order to estimate a plurality of smoothed cepstra corresponding to each of the plurality of digitized signals in response to a smoothed cepstrum analysis of a digital signal at a reception time of each of the plurality of digitized signals;
estimating a fused cepstrum for the plurality of digitized signals in response to the plurality of smoothed cepstra; and
determining a heart rate in response to the plurality of smoothed cepstra and the fused cepstrum.
2. The method in accordance with Claim 1 wherein the step of estimating the plurality of smoothed cepstra comprises for each of the plurality of digitized signals:
sampling the digitized signal in a plurality of time shifted predefined time windows to obtain a plurality of time domain samples;
estimating a power spectrum of the plurality of time domain samples by logarithmic smoothing a discrete Fourier transform of the plurality of time domain samples; and
estimating the smoothed cepstrum corresponding to the digitized signal by applying a frequency domain window function to the estimated power spectrum before inverse Fourier transforming the windowed estimated power spectrum of the plurality of time domain samples.

3. The method in accordance with Claim 1 wherein the frequency range of the frequency domain Hanning window is -64 to +64 Hz.

4. The method in accordance with Claim 1 wherein the frequency range of the frequency domain Hanning window is -32 to +32 Hz.

5. The method in accordance with Claim 1 wherein determining the heart rate step comprises detecting cepstral peaks within each of the plurality of smoothed cepstra and the fused cepstrum by detecting a highest value within a predetermined time range for each of the plurality of smoothed cepstra.

6. The method in accordance with Claim 1 wherein the determining the heart rate step further comprises determining the heart rate in response to a plurality of average heart rates, the plurality of average heart rates calculated for each of the plurality of smoothed cepstra and for the fused cepstrum.

7. The method in accordance with Claim 6 wherein the step of calculating the plurality of average heart rates comprises for each of the plurality of smoothed cepstra:

determining a percentage of the smoothed cepstrum comprising detected cepstral peaks;

if the percentage is determined to be greater than or equal to a predetermined percentage of the smoothed cepstrum, calculating the average heart rate by a mean

time of a difference between an end of one of the detected cepstral peaks and a start of a next one of the detected cepstral peaks; and

if the percentage is determined to be less than the predetermined percentage of the smoothed cepstrum, setting the average heart rate equal to null.

8. The method in accordance with Claim 6 wherein the step of determining the heart rate comprises determining whether the average heart rate of the fused cepstrum is within a predefined error margin of the average heart rates of each of n cepstra, wherein n is greater than a predetermined number.

9. The method in accordance with Claim 8 further comprising the step of dynamically selecting one of the plurality of digitized signals received from the corresponding plurality of sensors for monitoring heart beats in response to the average heart rate of one of the plurality of smoothed cepstra corresponding to the one of the plurality of digitized signals having a highest value average heart beat that corresponds to the average heart rate of the fused cepstrum.

10. A ballistocardiography (BCG) system for heart beat determination comprising:
a plurality of BCG sensors for generating a corresponding plurality of BCG signals in response to a subject's movement at a location of each of the plurality of BCG sensors;
a BCG analyzer for determining a heart rate of the subject in response to the plurality of BCG signals; and

a plurality of communication channels coupled to each of the plurality of BCG sensors and the BCG analyzer for providing the plurality of BCG signals from each of the plurality of BCG sensors to the BCG analyzer, wherein the BCG analyzer is configured to determine the heart rate of the subject by:

digitizing the plurality of BCG signals;

applying a frequency domain Hanning window with a frequency range of -128 to +128 Hz or narrower to a logarithm power spectrum that is transformed by inverse Fourier transform in order to estimate a plurality of smoothed cepstra corresponding to each of the plurality of digitized BCG signals in response to a smoothed cepstrum analysis of a digital signal magnitude at a reception time of each of the plurality of digitized BCG signals;

estimating a fused cepstrum for the plurality of digitized BCG signals in response to the plurality of smoothed cepstra; and

determining the heart rate of the subject in response to the plurality of smoothed cepstra and the fused cepstrum.

11. The BCG system in accordance with Claim 10 wherein the step of the BCG analyzer estimates the plurality of smoothed cepstra by for each of the plurality of digitized signals:

sampling the digitized signal in a plurality of time shifted predefined time windows to obtain a plurality of time domain samples;

estimating a power spectrum of the plurality of time domain samples by logarithmic smoothing a discrete Fourier transform of the plurality of time domain samples; and

estimating the smoothed cepstrum corresponding to the digitized signal by applying a frequency domain window function to the estimated power spectrum

before inverse Fourier transforming the windowed estimated power spectrum of the plurality of time domain samples.

12. The BCG system in accordance with Claim 10 wherein the frequency range of the frequency domain Hanning window is -64 to +64 Hz.

13. The BCG system in accordance with Claim 10 wherein the frequency range of the frequency domain Hanning window is -32 to +32 Hz.

14. The BCG system in accordance with Claim 10 wherein the BCG analyzer detects cepstral peaks by detecting a highest value within a predetermined time range for each of the plurality of smoothed cepstra.

15. The BCG system in accordance with Claim 10 wherein the BCG analyzer further determines the heart rate in response to a plurality of average heart rates, the plurality of average heart rates calculated for each of the plurality of smoothed cepstra and for the fused cepstrum.

16. The BCG system in accordance with Claim 15 wherein the BCG analyzer calculates the plurality of average heart rates for each of the plurality of smoothed cepstra by:

determining a percentage of the smoothed cepstrum comprising detected cepstral peaks;

if the percentage is determined to be greater than or equal to a predetermined percentage of the smoothed cepstrum, calculating the average heart rate by a mean time of a difference between an end of one of the detected cepstral peaks and a start of a next one of the detected cepstral peaks; and

if the percentage is determined to be less than the predetermined percentage of the smoothed cepstrum, setting the average heart rate equal to null.

17. The BCG system in accordance with Claim 15 wherein the BCG analyzer further determines the heart rate by determining whether the average heart rate of the fused cepstrum is within a predefined error margin of the average heart rates of each of n cepstra, wherein n is greater than a predetermined number.

18. The BCG system in accordance with Claim 10 wherein the BCG analyzer further calculates quality rankings for each of the plurality of communication channels in response to the average heart rate of each of the plurality of smoothed cepstra corresponding to each of the plurality of communication channels, the BCG analyzer further dynamically selecting one of the plurality of communication channels for monitoring heart beats in response to the average heart rate of one of the plurality of smoothed cepstra corresponding to the quality ranking of the selected one of the plurality of communication channels indicating that it has a highest value average heart beat that corresponds to the average heart rate of the fused cepstrum.

19. The BCG system in accordance with Claim 10 further comprising a bandpass filter coupled to each of the plurality of communication channels for passing to the BCG analyzer signals including frequencies corresponding to heart beat related information while rejecting signals including other frequencies.

20. The BCG system in accordance with Claim 19 wherein the other frequencies include frequencies corresponding to unrelated movement including low frequency respiratory information.

21. The BCG system in accordance with Claim 10 wherein the plurality of communication channels comprise a plurality of communication channels, each of the plurality of communication channels including a transmitter coupled to a corresponding one of the plurality of BCG sensors, and wherein the BCG analyzer includes a receiver coupled to the plurality of communication channels.

22. The BCG system in accordance with Claim 10 wherein each of the plurality of BCG sensors is a seismic sensor.

23. The BCG system in accordance with Claim 10 wherein each of the BCG sensors is embedded on a supporting material, the location of each of the BCG sensors on the supporting material being defined in accordance with a predefined spatial layout and the plurality of BCG sensors generating the corresponding plurality of BCG signals in response to the subject's movement while the subject is supported on the supporting material.

24. The BCG system in accordance with Claim 23 wherein the supporting material is a bed mattress.