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(54) SYSTEM AND METHOD TO DETERMINE HEART RATE VARIABILITY COHERENCE INDEX

(71) Applicant: **Hill-Rom Services PTE. LTD.**, Singapore (SG)

(72) Inventors: **Aye AUNG**, Singapore (SG); **Yaolong LOU**, Singapore (SG); **Yuan Ing CHOW**, Singapore (SG)

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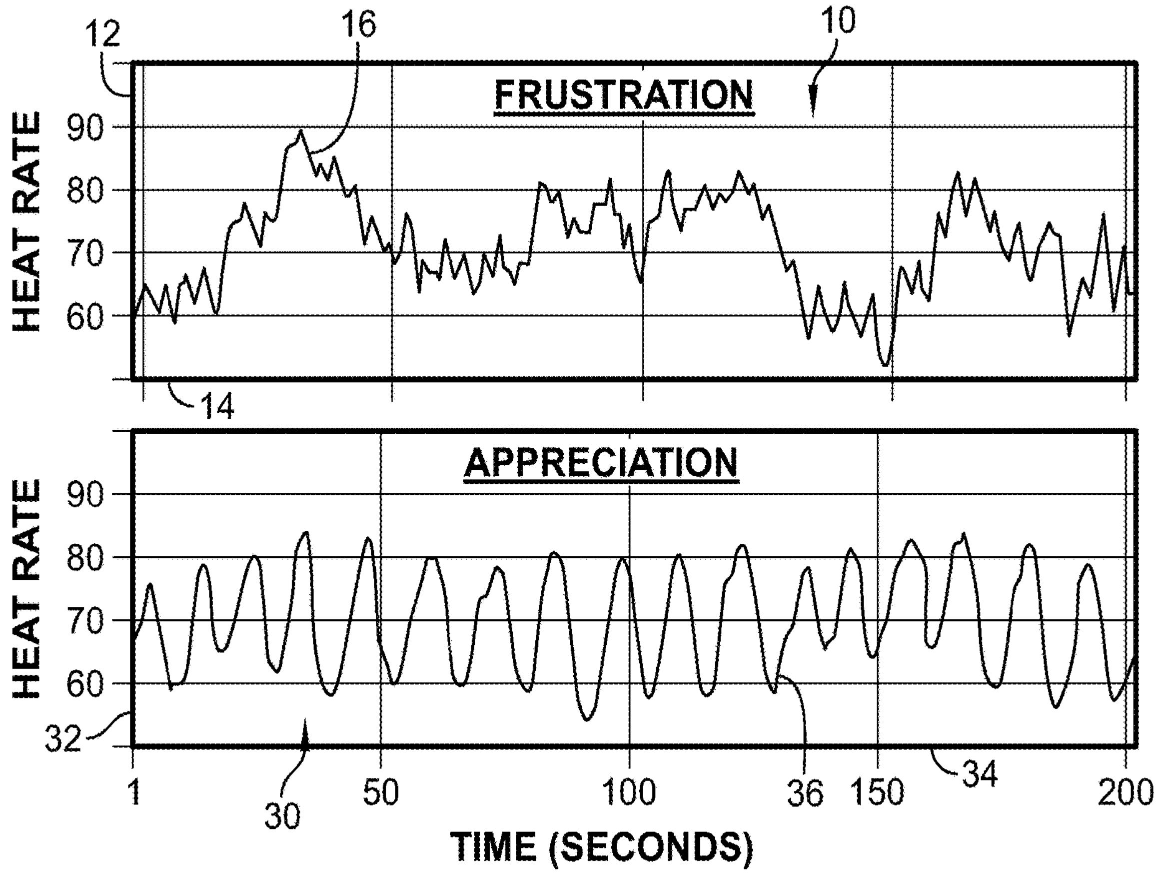
(57) **ABSTRACT**

A stress level monitoring system includes a controller and a pulse oximeter electrically coupled to the controller. The pulse oximeter measures a photoplethysmograph signal. The controller determines a stress level of a patient from the photoplethysmograph signal.



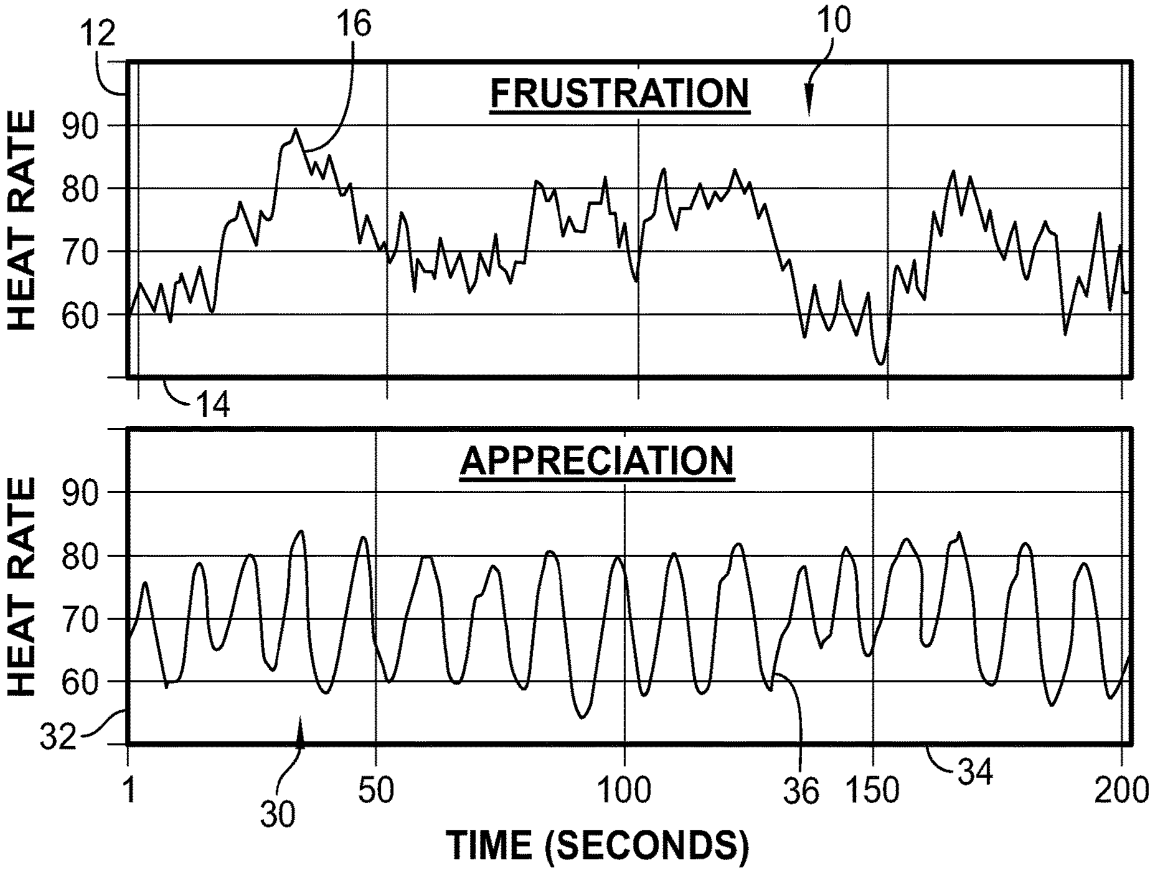

12
16
10
FRUSTRATION
HEAT RATE
90
80
70
60
14
APPRECIATION
HEAT RATE
90
80
70
60
32
30
36
34
1
50
100
150
200
TIME (SECONDS)

FIG. 1

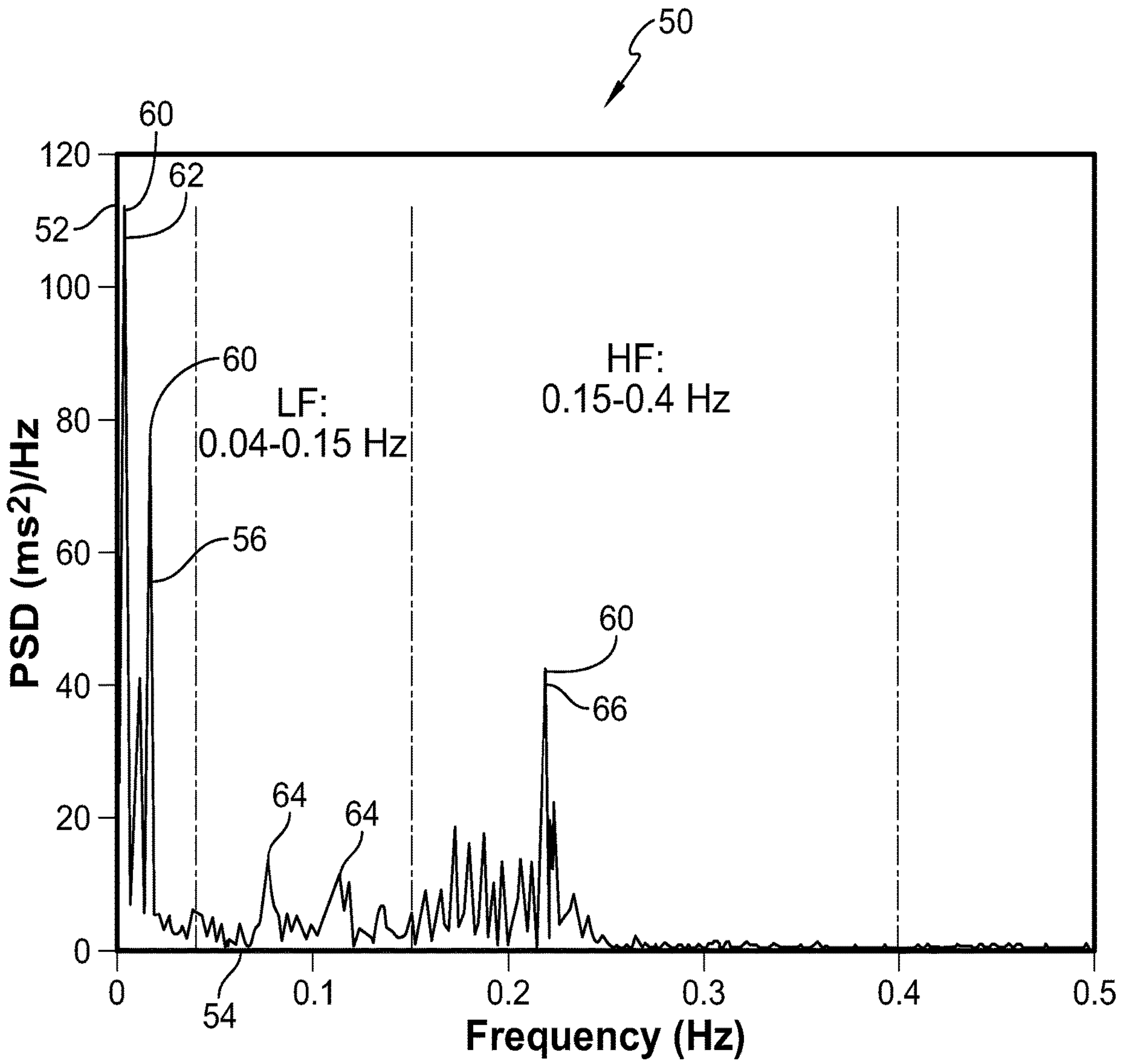

50
60
62
52
60
56
60
66
64
64
54
LF:
0.04-0.15 Hz
HF:
0.15-0.4 Hz
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
PSD (ms^2)/Hz
Frequency (Hz)

FIG. 2

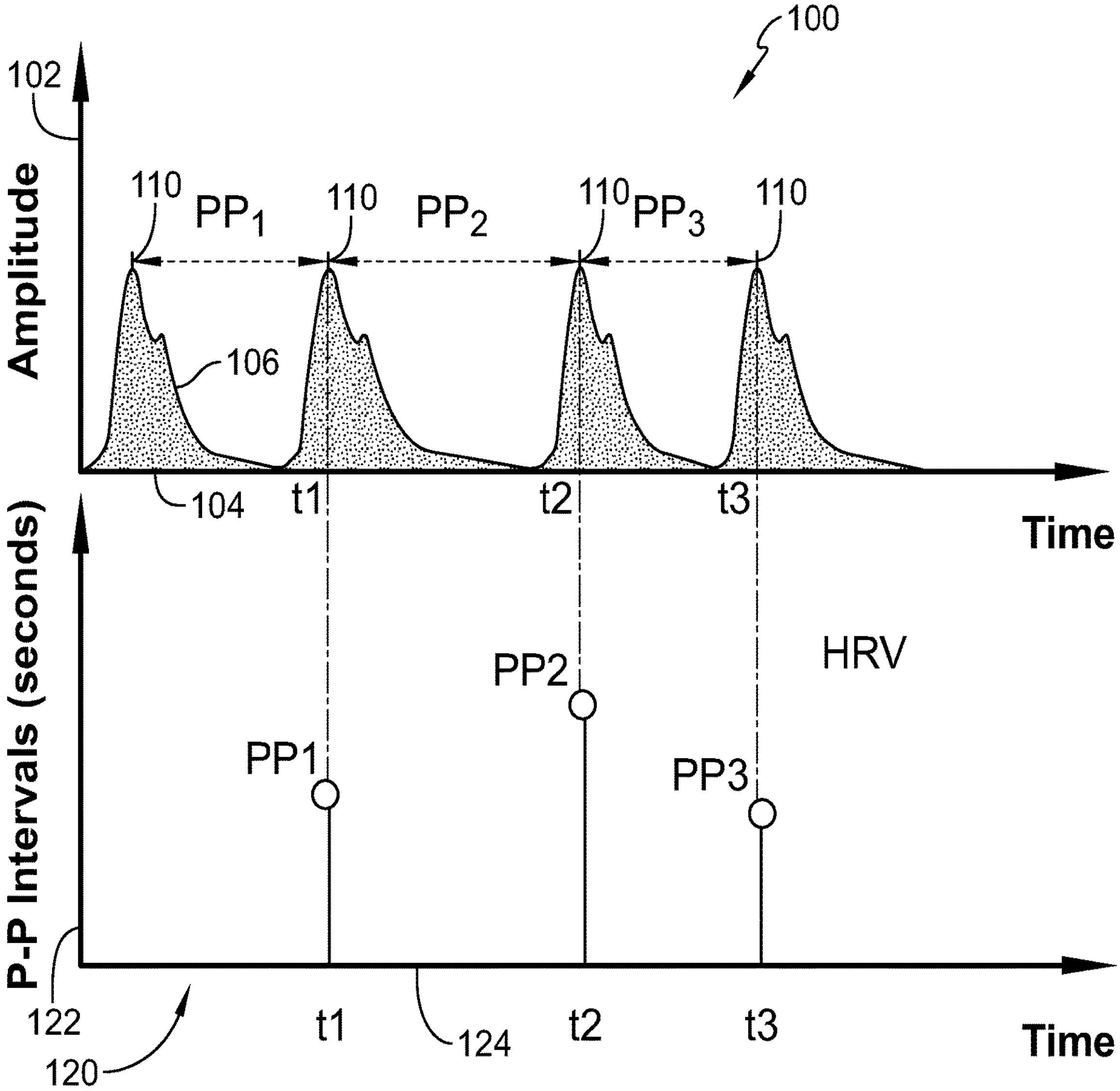
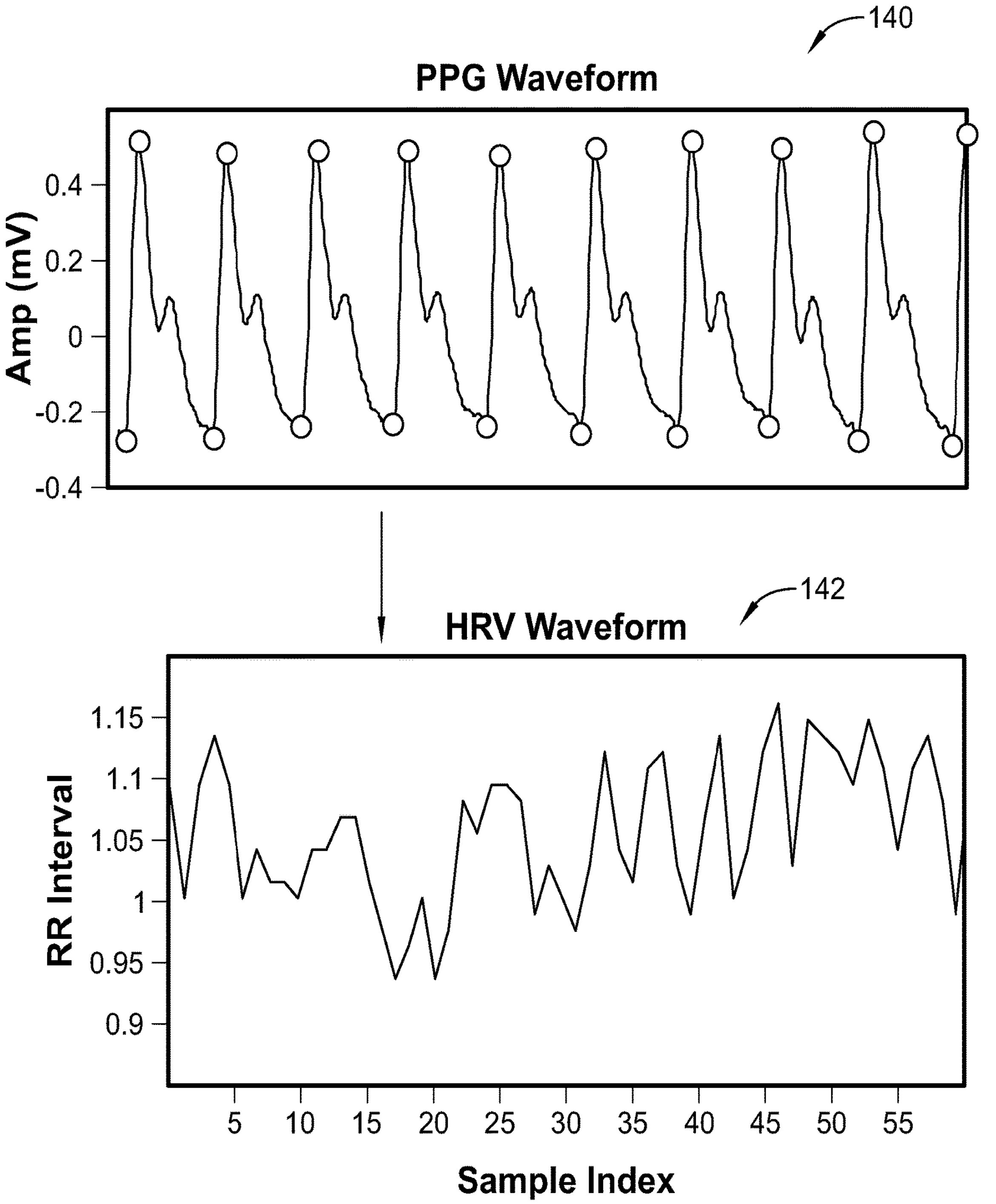

100
102
Amplitude
110
PP_1
110
PP_2
110
PP_3
110
106
104
t1
t2
t3
Time
P-P Intervals (seconds)
HRV
PP2
PP1
PP3
122
120
t1
124
t2
t3
Time

FIG. 3



140
PPG Waveform
Amp (mV)
0.4
0.2
0
-0.2
-0.4
142
HRV Waveform
RR Interval
1.15
1.1
1.05
1
0.95
0.9
5
10
15
20
25
30
35
40
45
50
55
Sample Index

FIG. 4

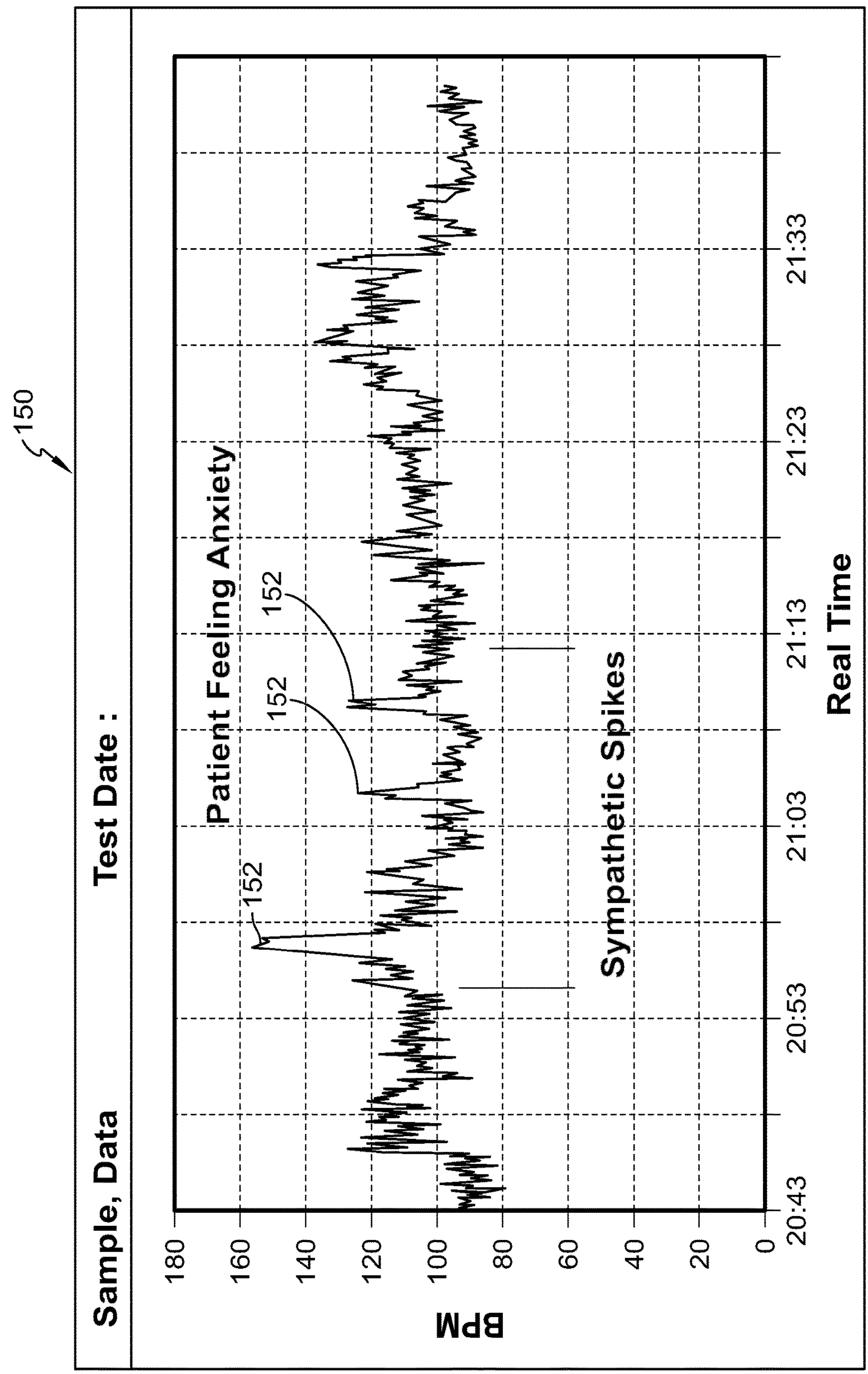

150
Sample, Data
Test Date :
Patient Feeling Anxiety
152
152
152
Sympathetic Spikes
BPM
180
160
140
120
100
80
60
40
20
0
20:43
20:53
21:03
21:13
21:23
21:33
Real Time

FIG. 5

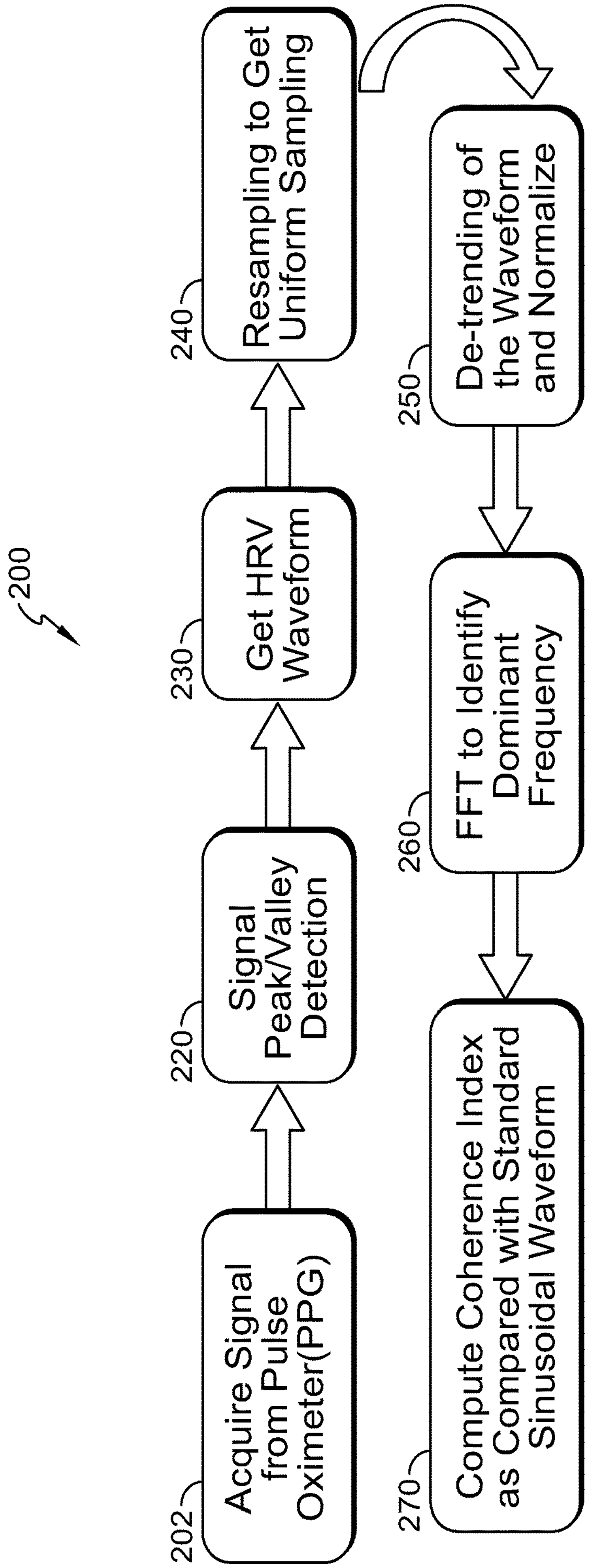

200
202
Acquire Signal from Pulse Oximeter(PPG)
220
Signal Peak/Valley Detection
230
Get HRV Waveform
240
Resampling to Get Uniform Sampling
250
De-trending of the Waveform and Normalize
260
FFT to Identify Dominant Frequency
270
Compute Coherence Index as Compared with Standard Sinusoidal Waveform

FIG. 6

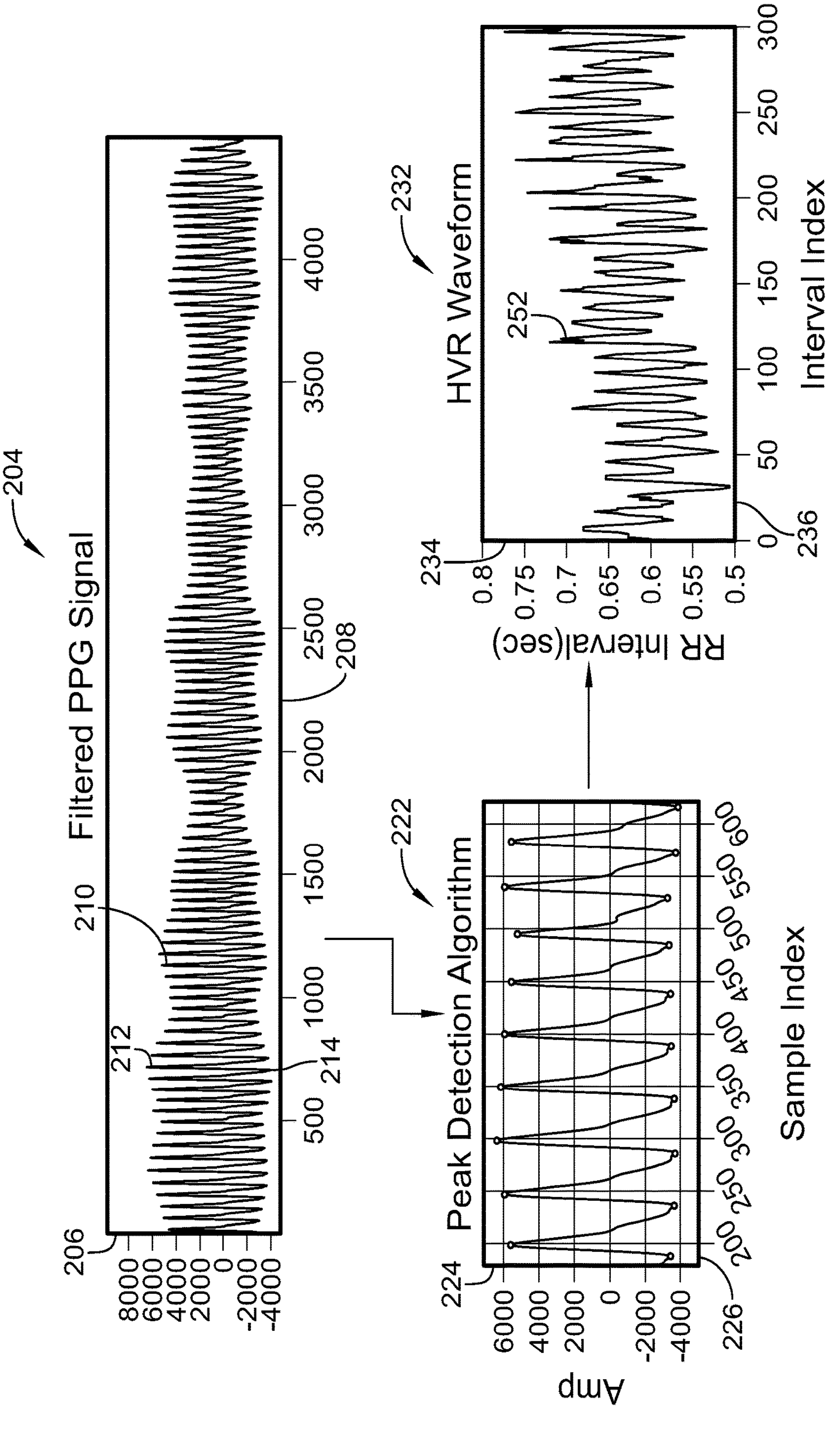

204
Filtered PPG Signal
206
8000
6000
4000
2000
0
-2000
-4000
500
1000
1500
2000
2500
3000
3500
4000
208
210
212
214
222
Peak Detection Algorithm
224
226
Amp
6000
4000
2000
0
-2000
-4000
200
250
300
350
400
450
500
550
600
Sample Index
232
HVR Waveform
234
236
252
RR Interval(sec)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0
50
100
150
200
250
300
Interval Index

FIG. 7

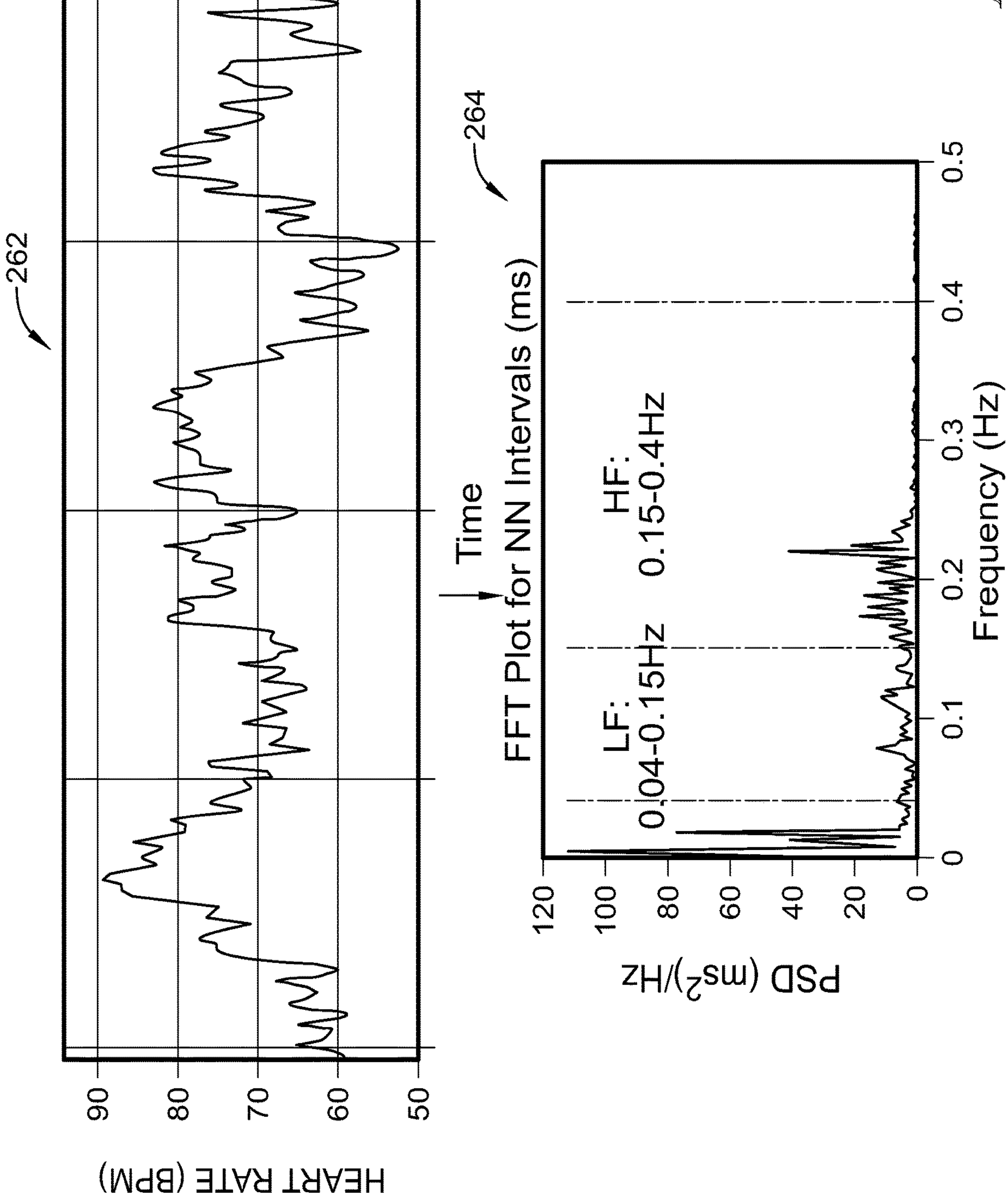

262
HEART RATE (BPM)
90
80
70
60
50
Time
264
FFT Plot for NN Intervals (ms)
LF:
0.04-0.15Hz
HF:
0.15-0.4Hz
PSD (ms²)/Hz
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
Frequency (Hz)

FIG. 8

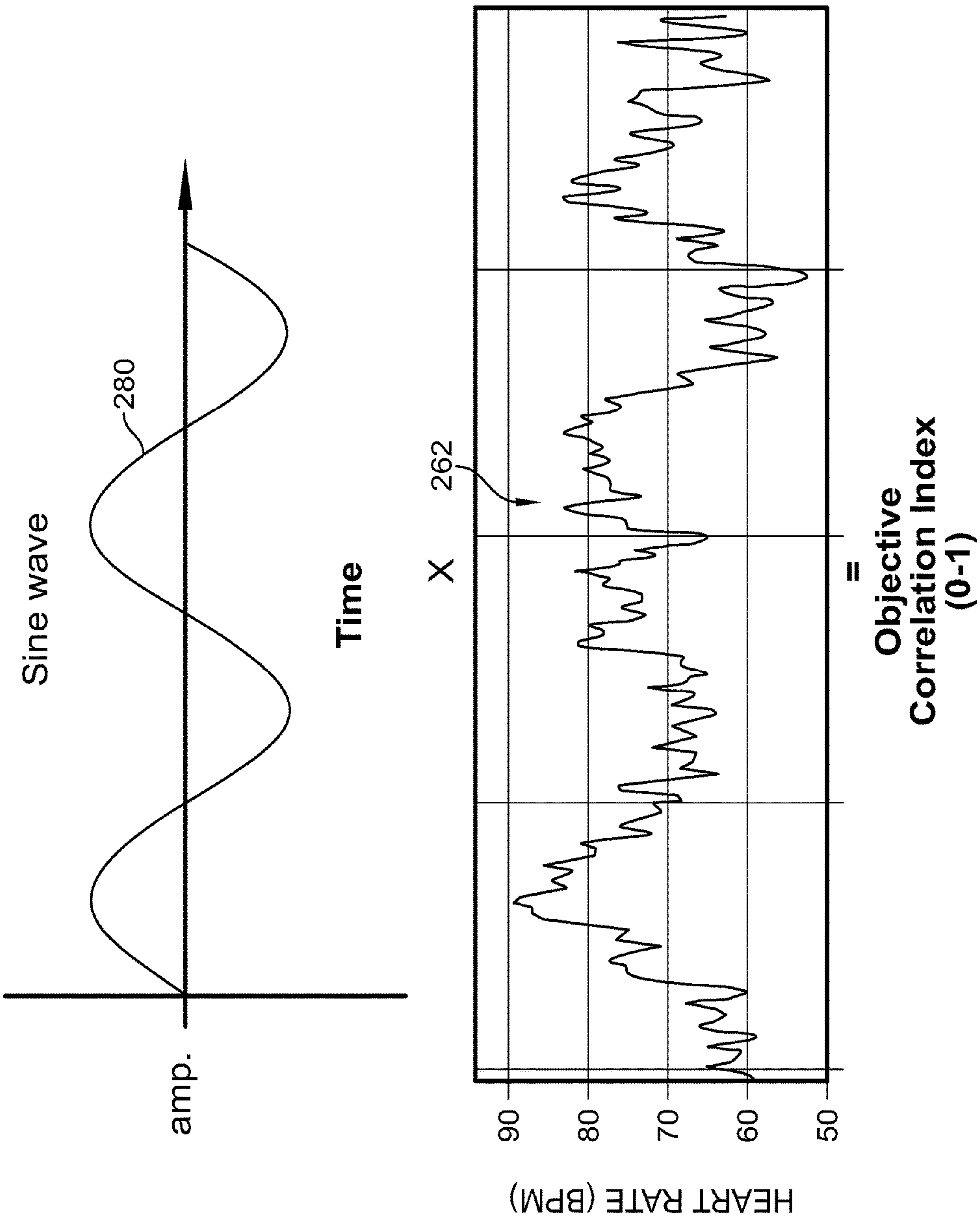

Sine wave
280
amp.
Time
X
262
=
Objective
Correlation Index
(0-1)
90
80
70
60
50
HEART RATE (BPM)

FIG. 9

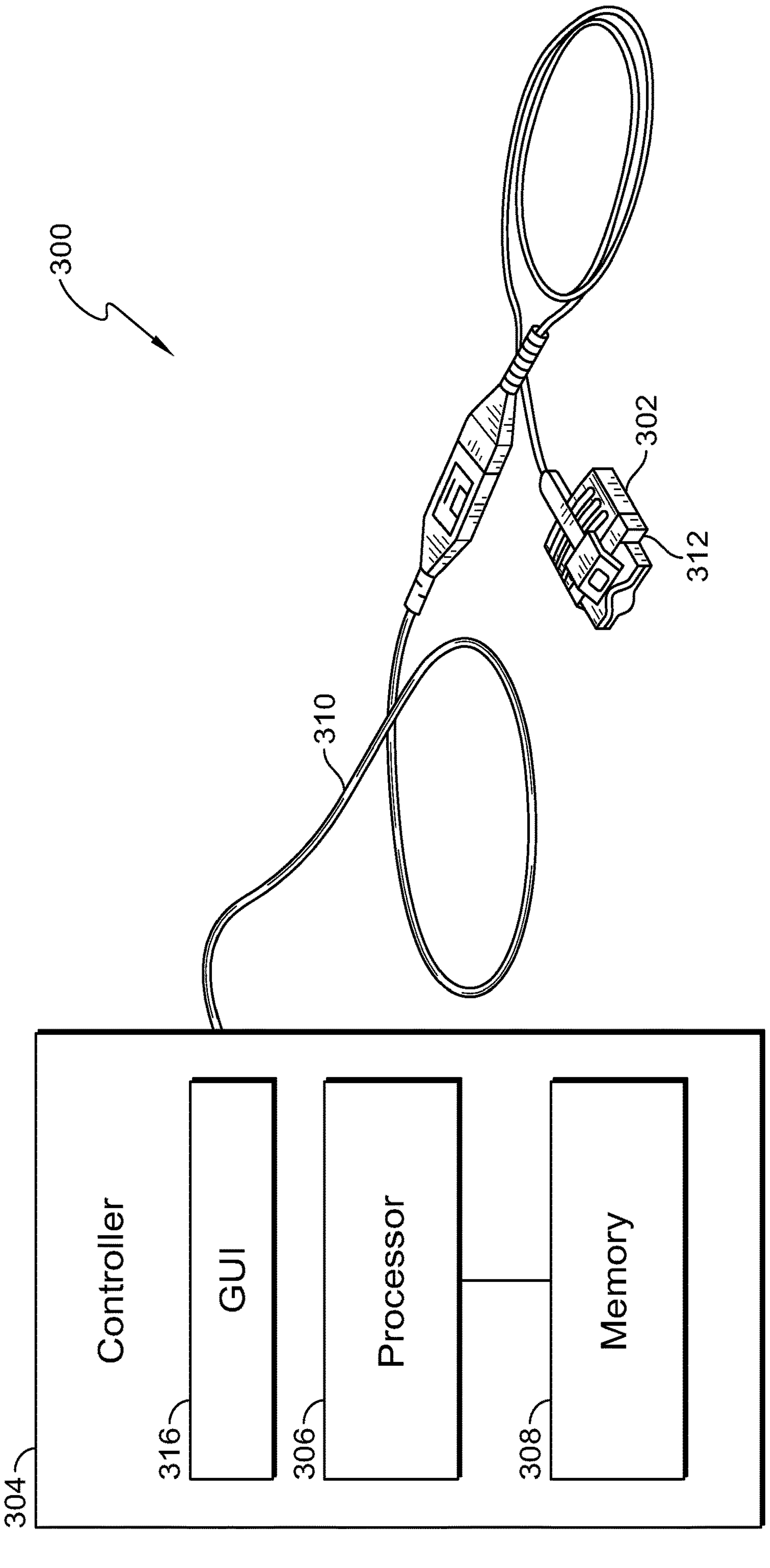

300
302
312
310
Controller
GUI
Processor
Memory
316
306
308
304

FIG. 10

SYSTEM AND METHOD TO DETERMINE HEART RATE VARIABILITY COHERENCE INDEX

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Ser. No. 62/669,444, filed May 10, 2018, and titled "SYSTEM AND METHOD TO DETERMINE HEART RATE VARIABILITY COHERENCE INDEX," which is expressly incorporated by reference herein.

BACKGROUND

[0002] The present disclosure relates to photoplethysmograph signals from a pulse oximeter and particularly, to a method for objectively determining patient stress from a photoplethysmograph signal.

[0003] Often, patients experience stress when in a caregiver facility or when receiving care at home. For example, the patient may experience stress due to medical procedures, medications, or length of stay at a facility, to name a few stress inducers. Generally, it is very subjective to determine a patient's stress level. However, to properly manage care, the caregiver must be aware of the patient's stress levels. It is desirable to determine a patient's stress level without subjecting the patient to additional tests, procedures, or medical equipment. That is, it is desirable to determine the patient's stress level with existing equipment that is being used to monitor the patient. It is also desirable to objectively quantify a level of the patient's stress. By quantifying stress, the caregiver may provide more accurate care to the patient.

SUMMARY

[0004] The present disclosure includes one or more of the features recited in the appended claims and/or the following features which, alone or in any combination, may comprise patentable subject matter.

[0005] According to an aspect of the disclosed embodiments, a method of determining a stress level of a patient from a photoplethysmograph signal may include acquiring a photoplethysmograph signal from a pulse oximeter. The method may also include detecting peaks and valleys in the photoplethysmograph signal to determine a heart rate variability waveform. The method may also include detrending the heart rate variability waveform to determine a detrended waveform. The method may also include normalizing the detrended waveform to determine a normalized waveform. The method may also include determining a dominant frequency of the normalized waveform. The method may also include determining a coherence index of the heart rate variability waveform based on the dominant frequency.

[0006] It may be contemplated that the coherence index is between 0 and 1. A smoothness of the heart rate variability waveform may indicate a stress level of a patient.

[0007] In some embodiments, a dominant frequency within a range of 0.04 to 0.15 Hz may indicate a combination of sympathetic nervous system influence and parasympathetic nervous system influence. A dominant frequency within a range of 0.15 to 0.4 Hz may indicate parasympathetic nervous system activity. The coherence index may be a ratio of dominant frequencies within a range of 0.04 to 0.15 Hz to dominant frequencies within a range of 0.15 to 0.4 Hz.

[0008] Optionally, the method may include sampling at least one minute of the photoplethysmograph signal. The method may also include detecting peaks and valleys in the photoplethysmograph signal further comprises performing a peak to peak detection algorithm on a sample of the photoplethysmograph signal. The method may also include determining a coherence index further comprises deriving a normalized correlation index of the heart rate variability waveform with a sine waveform having the dominant frequency. The method may also include determining a coherence index further comprises multiplying the sine waveform having the dominant frequency with the heart rate variability waveform. The method may also include resampling the photoplethysmograph signal to acquire uniform heart rate variability waveforms.

[0009] According to another aspect of the disclosed embodiments, a stress level monitoring system may include a controller and a pulse oximeter electrically coupled to the controller. The pulse oximeter may measure a photoplethysmograph signal. The controller may determine a stress level of a patient from the photoplethysmograph signal by acquiring a photoplethysmograph signal from a pulse oximeter. The controller may also detect peaks and valleys in the photoplethysmograph signal to determine a heart rate variability waveform. The controller may also detrend the heart rate variability waveform to determine a detrended waveform. The controller may also normalize the detrended waveform to determine a normalized waveform. The controller may also determine a dominant frequency of the normalized waveform. The controller may also determine a coherence index of the heart rate variability waveform based on the dominant frequency.

[0010] It may be contemplated that the coherence index is between 0 and 1. A smoothness of the heart rate variability waveform may indicate a stress level of a patient.

[0011] In some embodiments, a dominant frequency within a range of 0.04 to 0.15 Hz may indicate a combination of sympathetic nervous system influence and parasympathetic nervous system influence. A dominant frequency within a range of 0.15 to 0.4 Hz may indicate parasympathetic nervous system activity. The coherence index may be a ratio of dominant frequencies within a range of 0.04 to 0.15 Hz to dominant frequencies within a range of 0.15 to 0.4 Hz.

[0012] Optionally, the controller may sample at least one minute of the photoplethysmograph signal. The controller may perform a peak to peak detection algorithm on a sample of the photoplethysmograph signal. The controller may derive a normalized correlation index of the heart rate variability waveform with a sine waveform having the dominant frequency. The controller may multiply the sine waveform having the dominant frequency with the heart rate variability waveform. The controller may resample the photoplethysmograph signal to acquire uniform heart rate variability waveforms.

[0013] According to yet another aspect of the disclosed embodiments, a method of determining a stress level of a patient from a photoplethysmograph signal includes acquiring a photoplethysmograph signal from a pulse oximeter. The method may also include calculating a heart rate waveform from the photoplethysmograph signal. The method may also include determining a dominant frequency of the heart rate waveform. The method may also include generating a sine wave from the dominant frequency. The method may also include determining a coherence index of the heart rate waveform by multiplying the heart rate waveform by the sine wave.

[0014] In some embodiments, the coherence index may be between 0 and 1. A smoothness of the heart rate waveform may indicate a stress level of a patient. A dominant frequency within a range of 0.04 to 0.15 Hz may indicate a combination of sympathetic nervous system influence and parasympathetic nervous system influence. A dominant frequency within a range of 0.15 to 0.4 Hz may indicate parasympathetic nervous system influence. The coherence index may be a ratio of dominant frequencies within a range of 0.04 to 0.15 Hz to dominant frequencies within a range of 0.15 to 0.4 Hz.

[0015] Optionally, the method includes sampling at least one minute of the photoplethysmograph signal. The method may also include resampling the photoplethysmograph signal to acquire uniform heart rate variability waveforms.

[0016] Additional features, which alone or in combination with any other feature(s), such as those listed above and/or those listed in the claims, can comprise patentable subject matter and will become apparent to those skilled in the art upon consideration of the following detailed description of various embodiments exemplifying the best mode of carrying out the embodiments as presently perceived.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The detailed description particularly refers to the accompanying figures in which:

[0018] FIG. **1** is a pair of graphs illustrating heart rates of a patient, wherein a first graph illustrates the heart rate of a patient having high stress, and a second graph illustrates the heart rate of a patient having low stress;

[0019] FIG. **2** is a graph illustrating a Fast Fourier Transform of a patient's heart rate waveform; wherein the graph has numerous peaks indicative of sympathetic and parasympathetic nervous system influence on the heart rate;

[0020] FIG. **3** is a first graph of a photoplethysmograph signal, and a second graph of a peak to peaks detection of the photoplethysmograph signal;

[0021] FIG. **4** is a graph illustrating a peak and valley detection of a photoplethysmograph signal that is converted into a heart rate variation graph;

[0022] FIG. **5** is a sample heart rate waveform of a patient experiencing stress;

[0023] FIG. **6** is a flowchart of a method for objectively quantifying a patient's stress level from a photoplethysmograph signal;

[0024] FIG. **7** is a graph of a filtered photoplethysmograph signal that has undergone peak and valley detection to generate a heart rate variation graph;

[0025] FIG. **8** is a graph of a heart rate waveform and a Fast Fourier Transform of the heart rate waveform;

[0026] FIG. **9** is a graph of a heart rate waveform multiplied by a sine wave to determine an objective correlation index; and

[0027] FIG. **10** is a perspective view of a system for determining a patient's stress level from a photoplethysmograph signal.

DETAILED DESCRIPTION

[0028] While the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific exemplary embodiments thereof have been shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the concepts of the present disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

[0029] Generally, a patient's level of stress can be subjectively measured based on a heart rate variability of the patient. For example, referring to FIG. **1**, a heart rate graph **10** is provided illustrating a patient that is generally frustrated or exposed to high levels of stress. The graph **10** illustrates a heart rate **12** of the patient on the y-axis and a time **14** on the x-axis of the graph **10**. In the illustrative embodiment, the heart rate **12** is measured between 60 beats per minute and 90 beats per minute. The time **14** is measured over 200 seconds. A heart rate waveform **16** illustrates the patient's heart rate **12** over 200 seconds **14**. As can be seen in the graph **10**, the waveform **16** includes numerous jagged peaks and valleys. That is, the waveform **16** is not smooth. Generally, a waveform **16** that is not smooth is indicative of high stress in the patient.

[0030] Also seen in FIG. **1**, a graph **30** illustrates a heart rate **32** on the y-axis over time **34** on the x-axis. In the illustrative graph **30**, the heart rate **32** is illustrated between 60 beats per minute and 90 beats per minute. The time **34** is measured over 200 seconds. A waveform **36** illustrates the patient's heart rate **32** over 200 seconds **34**. As can be seen in the graph **30**, the waveform **36** is generally smooth and does not include jagged peaks and valleys. Generally, a waveform **36** that is smooth is indicative of low stress levels in the patient.

[0031] Further information regarding the patient's stress can be derived from a Fourier Transform of the heart rate waveform. For example, by taking a Fast Fourier Transform of the heart rate waveform, additional information regarding stress levels can be subjectively obtained. FIG. **2** illustrates a Fast Fourier Transform **50** of a patient's heart rate waveform. The Fast Fourier Transform **50** includes a y-axis **52** that measures time squared over frequency in Hertz. The Fast Fourier Transform **50** also includes an x-axis **54** that measures frequency in Hertz. Generally, a line **56** on the Fast Fourier Transform **50** includes numerous peaks **60**. A first peak **62** appears at approximately 0 Hertz. Other peaks **64** occur between 0.04 Hz and 0.15 Hz. Generally, a peak that occurs between 0.04 Hz and 0.15 Hz indicates a combination of sympathetic nervous system influence and parasympathetic nervous system influence on the patient's heart rate. Additional peaks **66** occur between 0.15 Hz. and 0.4 Hz. Generally, a peak that occurs between 0.15 Hz. and 0.4 Hz indicates parasympathetic nervous system influence on the patient's heart rate.

[0032] Accordingly, based on the heart rate variability, as seen in FIG. **1**, and the peaks of the Fast Fourier Transform, as seen in FIG. **2**, a caregiver can subjectively assess a stress level of the patient. That is, a smoothness of the heart rate may generally indicate stress. Moreover, the peaks of the Fast Fourier Transform may indicate whether the sympathetic nervous system or the parasympathetic nervous system has contributed to the patient's heart rate. Unfortunately, assessments made from heart rate waveform and Fast Fourier Transforms are subjective and do not provide an objective assessment of the patient's stress level.

[0033] Referring to FIG. **3** a photoplethysmograph signal taken from a pulse oximeter can be manipulated to determine a heart rate variability. Accordingly, the patient's heart rate can be determined without having to use additional equipment in the healthcare facility, and a pulse oximeter alone can determine the patient's heart rate. The photoplethysmograph signal is shown in a graph **100** displaying amplitude **102** on the y-axis and time **104** on the x-axis. A line **106** displays the patient's oxygen levels as a function of amplitude **102** over time **104**. The line **106** includes a plurality of peaks **110** and valleys **112**. A second graph **120** illustrates peak to peak detection, as performed on the graph **100**. The peak to peak detection **120** illustrates the peak to peak intervals **122** over time **124**. In the exemplary embodiment, three peak to peak detections are illustrated on the graph **120**. It should be noted that the number of peak to peak detections is dependent on a length of a time sample taken from the graph **100**.

[0034] FIG. **4** illustrates a photoplethysmograph signal **140** converted to a heart rate variability waveform **142** using peak to peak detection. From the heart rate variability waveform **142** a general subjective assessment of the patient's stress levels can be determined. For example, the heart rate variability waveform **142** can be converted to a heart rate waveform **150**, as illustrated in FIG. **5**. The heart rate waveform of FIG. **5** may be indicative of a patient experiencing stress and frustration. As set forth above, the jagged peaks and valleys of the heart rate waveform **150** are indicative of high stress levels. Additionally, sympathetic spikes **152** in the heart rate waveform **150** also indicate general stress within the patient. Unfortunately, as set forth above, the determination of stress levels is still subjective and can't be quantified by the caregiver.

[0035] FIG. **6** illustrates a method **200** for objectively quantifying a patient's stress level using a photoplethysmograph signal. At block **202** a photoplethysmograph signal is acquired from a pulse oximeter. For example, the pulse oximeter is coupled to the patient's finger to retrieve a signal related to the patient's oxygen saturation in the blood. The photoplethysmograph signal is filtered, for example, using a band pass filter. An example of a filter photoplethysmograph signal is provided in the graph **204** in FIG. **7**. The graph **204** includes a y-axis indicating an amplitude 206 of the signal and an x-axis indicating a sample index **208** of the signal. The line **210** shows the amplitude 206 as a function of sample index **208**. The line **210** includes a series of peaks **212** and valley **214**.

[0036] At block **220** of the method **200**, peak and valley detection is performed on the filtered signal **210** to identify the peaks **212** and valleys **214** of the signal **210**. The peaks **212** and valleys **214** can be graphed, as shown in the graph **222** of FIG. **7**. The graph **222** includes amplitude **224** (y-axis) as a function of sample index **226** (x-axis). The graph **222** is utilized to derive the heart rate variation of the patient, at block **230**, and as illustrated in graph **232** of FIG. **7**. The graph **232** includes the respiratory rate interval **234** in seconds (y-axis) as a function of interval index **236** (x-axis). As set forth above, subjective determinations regarding the patient's stress level can be made from the graph **232**. At block **240**, the photoplethysmograph signal is resampled to achieve uniform sampling of the photoplethysmograph signal.

[0037] Once uniform sampling is achieved, at block **250**, the waveform **252** of graph **232** is de-trended and normalized. That is, shifted and scaled versions of the data are created with the intention is that the normalized values allow the comparison of corresponding normalized values for different datasets in a way that eliminates the effects of certain gross influences, as in an anomaly time series. Some types of normalization involve only a rescaling to arrive at values relative to some size variable.

[0038] At block **260**, the heart rate waveform **262**, as illustrated in FIG. **8**, is transformed with a Fast Fourier Transform. A Fast Fourier Transform **264** is also illustrated in FIG. **8**. As described above, the dominant peaks in the Fast Fourier Transform **264** may be analyzed to determine subjective data about the patient's stress levels. To determine objective data about the patient's stress levels, the method **200** continues at block **270**, where a coherence index is calculated.

[0039] FIG. **9** graphically illustrates the method for determining the coherence index or objective correlation index. A sine wave is produced based on a peak frequency of the Fast Fourier Transform **264**. For example, the Fast Fourier Transform **264** includes a peak frequency at 0.22 Hz. Accordingly, a sine wave **280** is generated with a frequency of 0.22 Hz. The sine wave **280** is multiplied by the heart rate waveform **262** to achieve a number between 0 and 1. The number between 0 and 1 provides a coherence index that objectively determines a patient's stress levels. For example, a number closer to 0 is indicative of a high stress level, whereas, a number closer to 1 is indicative of a low stress level in the patient. In some embodiments, the coherence index is a ratio of dominant frequencies within a range of 0.04 to 0.15 Hz to dominant frequencies within a range of 0.15 to 0.4 Hz.

[0040] Accordingly, a photoplethysmograph signal can be utilized to provide various information regarding the patient. First, the photoplethysmograph signal is indicative of the oxygen saturation of the patient. Second, the photoplethysmograph signal can be converted to determine a heart rate variation of the patient. Third, subjective information regarding stress levels can be derived from the heart rate waveform of the patient and a Fast Fourier Transform of the heart rate waveform. Lastly, a quantifiable objective score can be given to the patient's stress levels.

[0041] Heart rate variability is the patient's heart response to the central nervous system, which can measure the activation of the patient's autonomic nervous systems. Heart rate variability is a variation of heart beat-to-beat intervals, which can be extracted from a photoplethysmograph signal. The beat-to-beat intervals can be derived by using the peak detection algorithm. The coherence index is derived from the similarity of heart rate variability waveform with a pure sinusoidal wave by using a correlation analysis. The coherence index measures the heart rhythm coherence (sine wave-like rhythmic pattern) which implies the increased parasympathetic activity. The lower the index, the higher the stress condition is. As such, an objective score to provide the patient's stress condition is provided.

[0042] The system and method described herein require almost no additional when using an existing vital signs monitor and only additional software modification is required. The system and method described herein are non-invasive, portable, and suitable for homecare.

[0043] Referring to FIG. **10**, a stress level monitoring system **300** includes a pulse oximeter **302** coupled to a controller **304**. The controller **304** includes a processor **306** and a memory **308**. The processor **306** may be embodied as any type of processor capable of performing the functions described herein. The processor **306** may be embodied as a dual-core processor, a multi-core or multi-threaded processor, digital signal processor, microcontroller, or other processor or processing/controlling circuit with multiple processor cores or other independent processing units. The memory **308** may be embodied as any type of volatile or non-volatile memory or data storage capable of performing the functions described herein. In operation, the memory **308** may store various data and software used during operation of the electronic controller **304** such as operating systems, applications, programs, libraries, and drivers. The memory **308** includes a plurality of instructions that, when read by the processor, cause the processor **306** to perform the functions described herein.

[0044] The pulse oximeter **302** is electrically coupled to the controller **304** via a cable **310**. In some embodiments, the cable **310** includes a universal serial bus (USB) connector that is configured to connect to a USB port (not shown) provided on the controller **304**. The pulse oximeter **302** provides a non-invasive method for monitoring a patient's oxygen saturation (SO_2) through a finger monitor **312** that is positioned on the patient's finger. In some embodiments, the pulse oximeter provides data related to the patient's peripheral oxygen saturation (SpO_2). In other embodiments, a monitor may be provided to measure the patient's arterial oxygen saturation (SaO_2) from arterial blood gas analysis. In some embodiments, the pulse oximeter **302** may be coupled to the patient's earlobe, foot, or any other thin part of the patient's body. The pulse oximeter **302** passes two wavelengths of light through the body part to a photodetector. The pulse oximeter **302** measures the changing absorbance at each of the wavelengths, allowing the pulse oximeter **302** to determine absorbency due to the pulsing arterial blood alone, excluding venous blood, skin, bone, muscle, and fat.

[0045] The pulse oximeter **302** is operable to detect data related to the patient's SpO_2 and heart rate. The pulse oximeter **302** also detects a photoplethysmograph signal (PPG) of the patient. The data acquired by the pulse oximeter **302** is transmitted to the controller **304**. The controller **304** may display the data on the graphical user interface **316**. The controller **304** is also operable to use the data to determine a heart rate variation waveform related to the patient's respiratory rate. While it may be known to acquire heart rate variation waveforms from raw PPG data, the methods described herein provide unique steps and data manipulation that are not currently applied to raw PPG data. As a result, the methods described herein represent an improvement over known methods for acquiring variation waveforms.

[0046] Any theory, mechanism of operation, proof, or finding stated herein is meant to further enhance understanding of principles of the present disclosure and is not intended to make the present disclosure in any way dependent upon such theory, mechanism of operation, illustrative embodiment, proof, or finding. It should be understood that while the use of the word preferable, preferably or preferred in the description above indicates that the feature so described can be more desirable, it nonetheless cannot be necessary and embodiments lacking the same can be contemplated as within the scope of the disclosure, that scope being defined by the claims that follow.

[0047] In reading the claims it is intended that when words such as "a," "an," "at least one," "at least a portion" are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language "at least a portion" and/or "a portion" is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

[0048] It should be understood that only selected embodiments have been shown and described and that all possible alternatives, modifications, aspects, combinations, principles, variations, and equivalents that come within the spirit of the disclosure as defined herein or by any of the following claims are desired to be protected. While embodiments of the disclosure have been illustrated and described in detail in the drawings and foregoing description, the same are to be considered as illustrative and not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Additional alternatives, modifications and variations can be apparent to those skilled in the art. Also, while multiple inventive aspects and principles can have been presented, they need not be utilized in combination, and many combinations of aspects and principles are possible in light of the various embodiments provided above.

1. A method of determining a stress level of a patient from a photoplethysmograph signal, the method comprising:
- (i) acquiring a photoplethysmograph signal from a pulse oximeter;
- (ii) detecting peaks and valleys in the photoplethysmograph signal to determine a heart rate variability waveform;
- (iii) detrending the heart rate variability waveform to determine a detrended waveform;
- (iv) normalizing the detrended waveform to determine a normalized waveform;
- (v) determining a dominant frequency of the normalized waveform; and
- (vi) determining a coherence index of the heart rate variability waveform based on the dominant frequency.

2. The method of claim **1**, wherein the coherence index is between 0 and 1.

3. The method of claim **1**, wherein a smoothness of the heart rate variability waveform indicates a stress level of a patient.

4. The method of claim **1**, wherein a dominant frequency within a range of 0.04 to 0.15 Hz indicates a combination of sympathetic nervous system influence and parasympathetic nervous system influence.

5. The method of claim **4**, wherein a dominant frequency within a range of 0.15 to 0.4 Hz indicates parasympathetic nervous system influence.

6. The method of claim **5**, wherein the coherence index is a ratio of dominant frequencies within a range of 0.04 to 0.15 Hz to dominant frequencies within a range of 0.15 to 0.4 Hz.

7. The method of claim **1**, further comprising sampling at least one minute of the photoplethysmograph signal.

8. The method of claim **1**, wherein detecting peaks and valleys in the photoplethysmograph signal further comprises performing a peak to peak detection algorithm on a sample of the photoplethysmograph signal.

9. The method of claim **1**, wherein determining a coherence index further comprises deriving a normalized correlation index of the heart rate variability waveform with a sine waveform having the dominant frequency.

10. The method of claim **9**, wherein determining a coherence index further comprises multiplying the sine waveform having the dominant frequency with the heart rate variability waveform.

11. The method of claim **1**, further comprising resampling the photoplethysmograph signal to acquire uniform heart rate variability waveforms.

12. A stress level monitoring system comprising:

a controller, and

a pulse oximeter electrically coupled to the controller, the pulse oximeter measuring a photoplethysmograph signal,

wherein the controller determines a stress level of a patient from the photoplethysmograph signal by:

(i) acquiring a photoplethysmograph signal from a pulse oximeter;

(ii) detecting peaks and valleys in the photoplethysmograph signal to determine a heart rate variability waveform;

(iii) detrending the heart rate variability waveform to determine a detrended waveform;

(iv) normalizing the detrended waveform to determine a normalized waveform;

(v) determining a dominant frequency of the normalized waveform; and

(vi) determining a coherence index of the heart rate variability waveform based on the dominant frequency.

13. The system of claim **12**, wherein the coherence index is between 0 and 1.

14. The system of claim **12**, wherein a smoothness of the heart rate variability waveform indicates a stress level of a patient.

15. The system of claim **12**, wherein a dominant frequency within a range of 0.04 to 0.15 Hz indicates a combination of sympathetic nervous system influence and parasympathetic nervous system influence.

16. The system of claim **15**, wherein a dominant frequency within a range of 0.15 to 0.4 Hz indicates parasympathetic nervous system activity.

17. The system of claim **16**, wherein the coherence index is a ratio of dominant frequencies within a range of 0.04 to 0.15 Hz to dominant frequencies within a range of 0.15 to 0.4 Hz.

18. The system of claim **12**, wherein the controller samples at least one minute of the photoplethysmograph signal.

19. The system of claim **12**, wherein the controller performs a peak to peak detection algorithm on a sample of the photoplethysmograph signal.

20. The system of claim **12**, wherein the controller derives a normalized correlation index of the heart rate variability waveform with a sine waveform having the dominant frequency.

21. The system of claim **20**, wherein the controller multiplies the sine waveform having the dominant frequency with the heart rate variability waveform.

22. The system of claim **12**, wherein the controller resamples the photoplethysmograph signal to acquire uniform heart rate variability waveforms.

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申请(专利权)人(译)	HILL-ROM SERVICES PTE. LTD.		
当前申请(专利权)人(译)	HILL-ROM SERVICES PTE. LTD.		
[标]发明人	AUNG AYE LOU YAOLONG		
发明人	AUNG, AYE LOU, YAOLONG CHOW, YUAN ING		
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摘要(译)

压力水平监测系统包括控制器和电耦合到该控制器的脉搏血氧仪。脉搏血氧仪测量光电容积描记器信号。控制器根据光电容积描记器信号确定患者的压力水平。