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(54) **NON-CONTACT APPARATUS FOR MONITORING CARDIOPULMONARY ACTIVITY SIGNALS AND METHOD FOR THE SAME**

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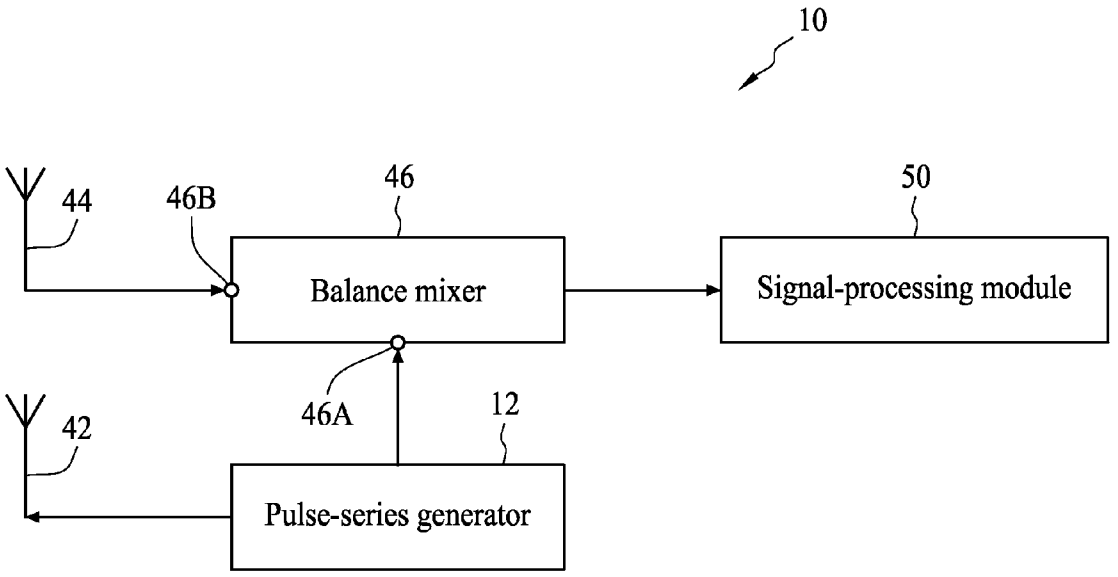
(57) **ABSTRACT**

A laser apparatus includes an optical fiber component and a pump light source coupled to the optical fiber component. The optical fiber component includes a first fiber segment, a second fiber segment and a connecting segment that connects the first and second fiber segments. The first fiber segment includes a fiber core having a first diameter, and the second fiber segment includes a fiber core having a second diameter. The first diameter may be greater than the second diameter, and the connecting segment may have a periodically varying refractive index.



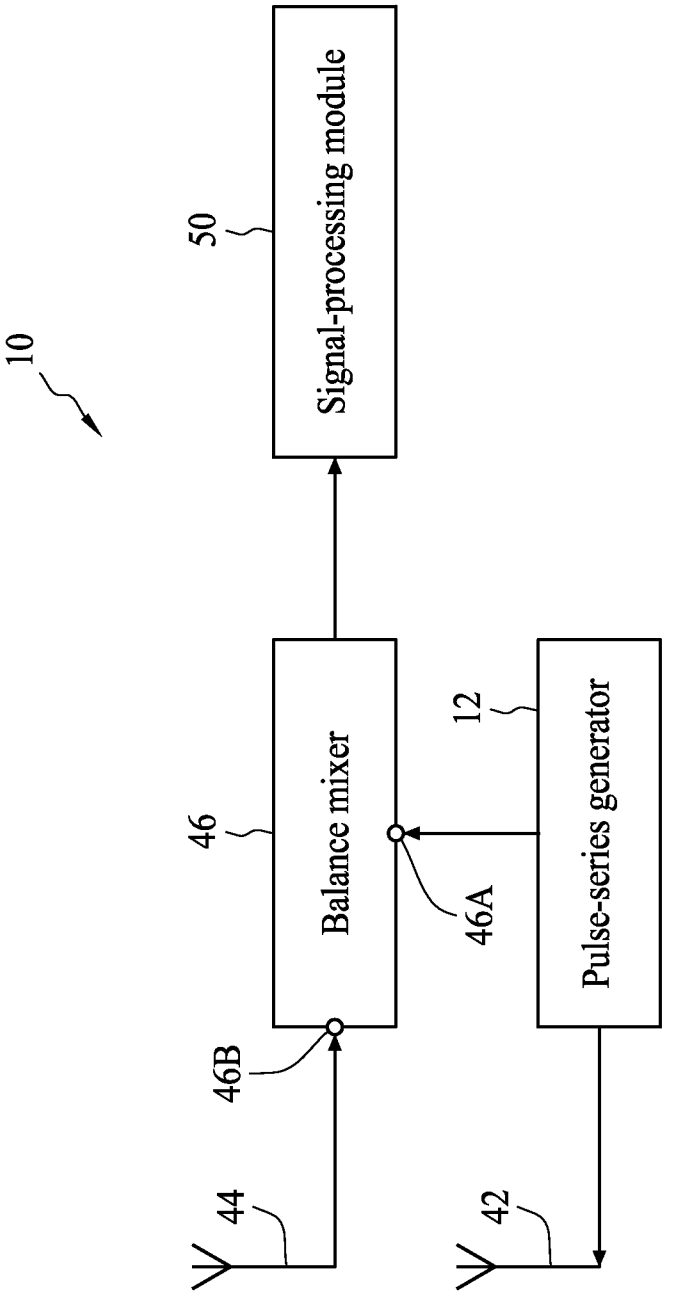

10
50
Signal-processing module
46
Balance mixer
46A
46B
12
Pulse-series generator
44
42

FIG. 1

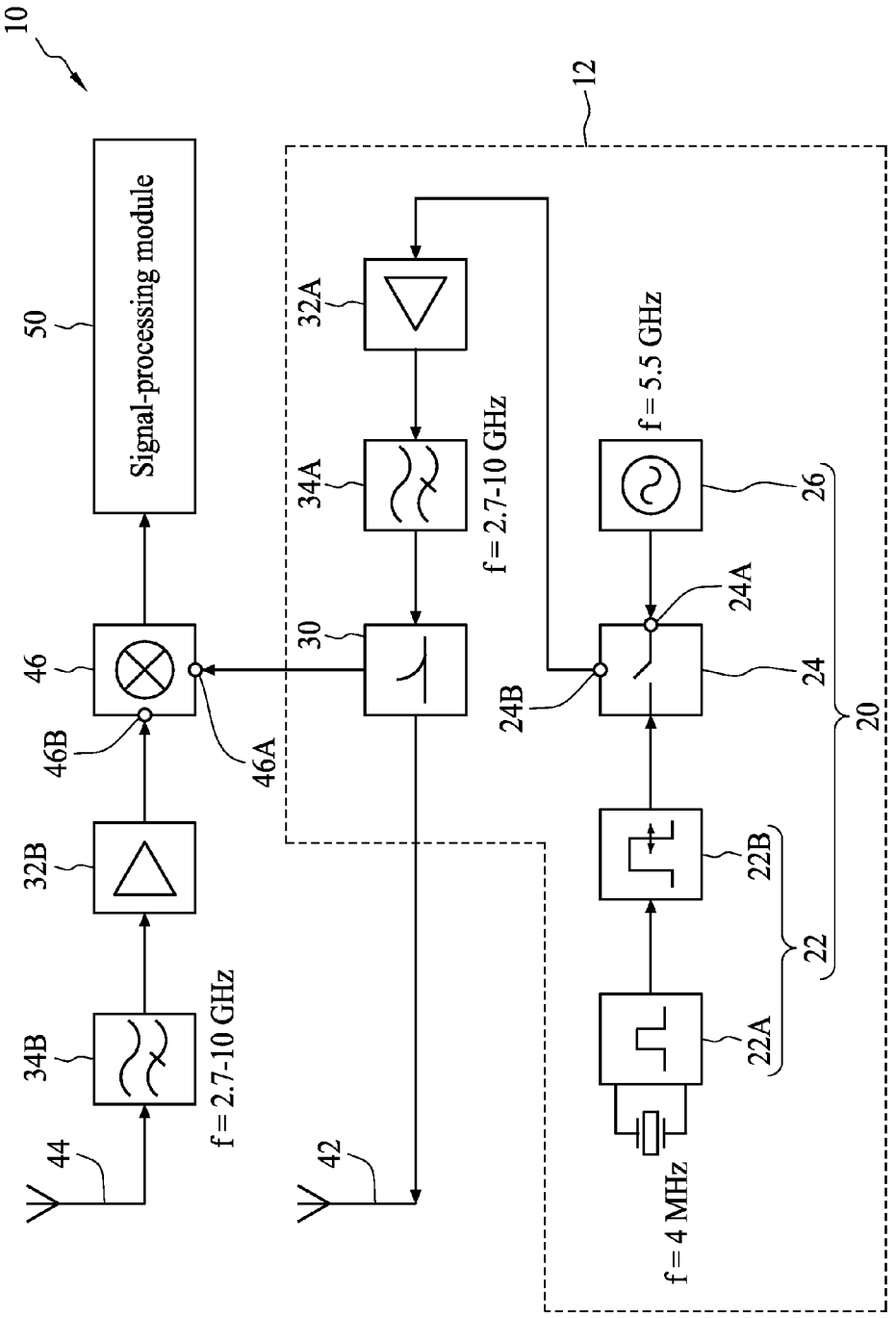

10
12
Signal-processing module
50
32A
34A
f = 2.7-10 GHz
30
46
46B
46A
32B
34B
f = 2.7-10 GHz
44
42
24B
24
24A
f = 5.5 GHz
26
22B
22A
22
20
f = 4 MHz

FIG. 2

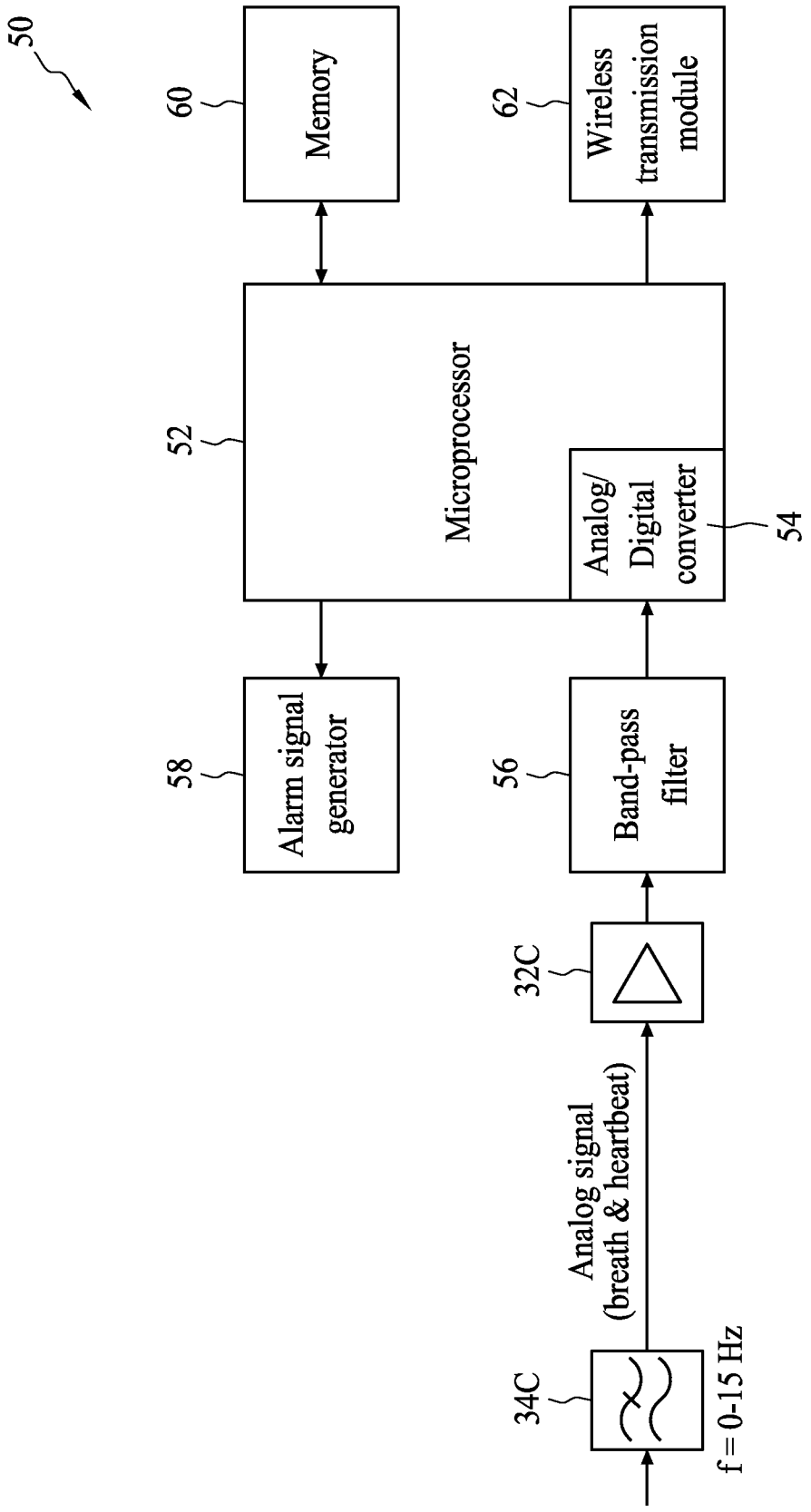

50
60
Memory
62
Wireless transmission module
52
Microprocessor
Analog/ Digital converter
54
58
Alarm signal generator
56
Band-pass filter
32C
Analog signal (breath & heartbeat)
34C
f = 0-15 Hz

FIG. 3

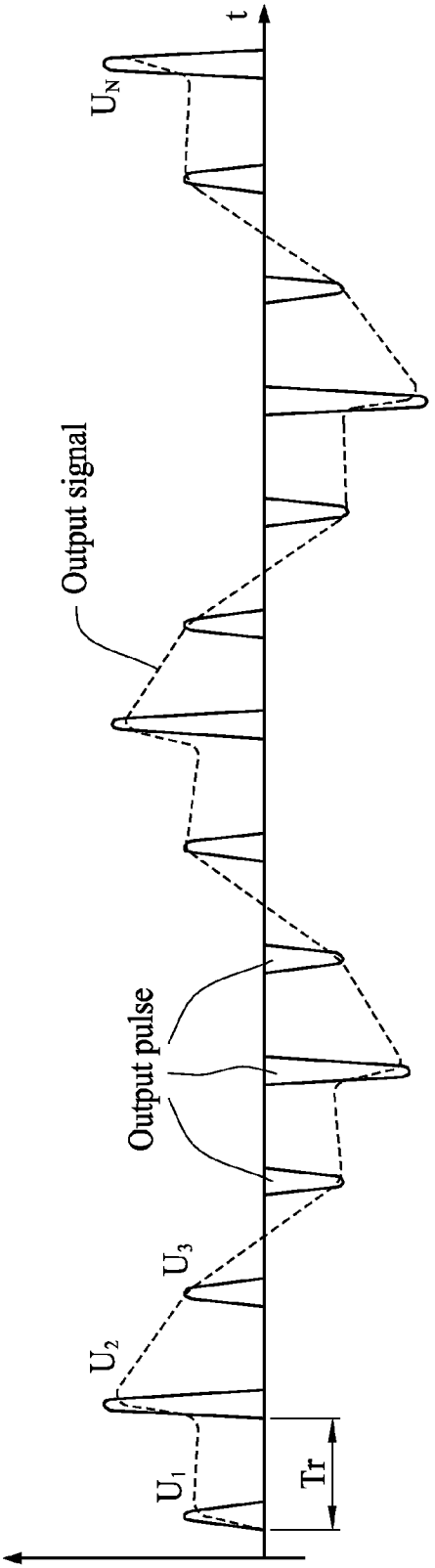


FIG. 4

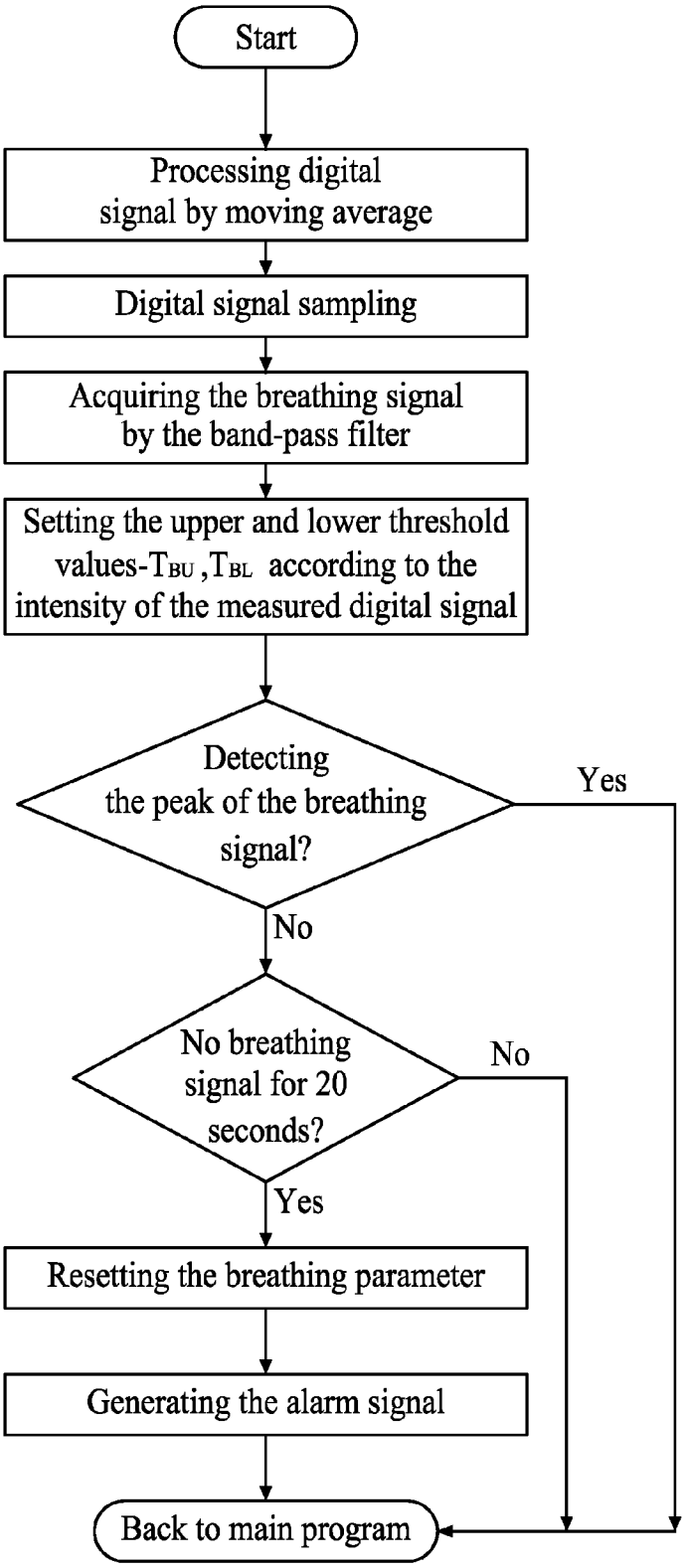

Start
Processing digital signal by moving average
Digital signal sampling
Acquiring the breathing signal by the band-pass filter
Setting the upper and lower threshold values-T_{BU} ,T_{BL} according to the intensity of the measured digital signal
Detecting the peak of the breathing signal?
Yes
No
No breathing signal for 20 seconds?
No
Yes
Resetting the breathing parameter
Generating the alarm signal
Back to main program

FIG. 5

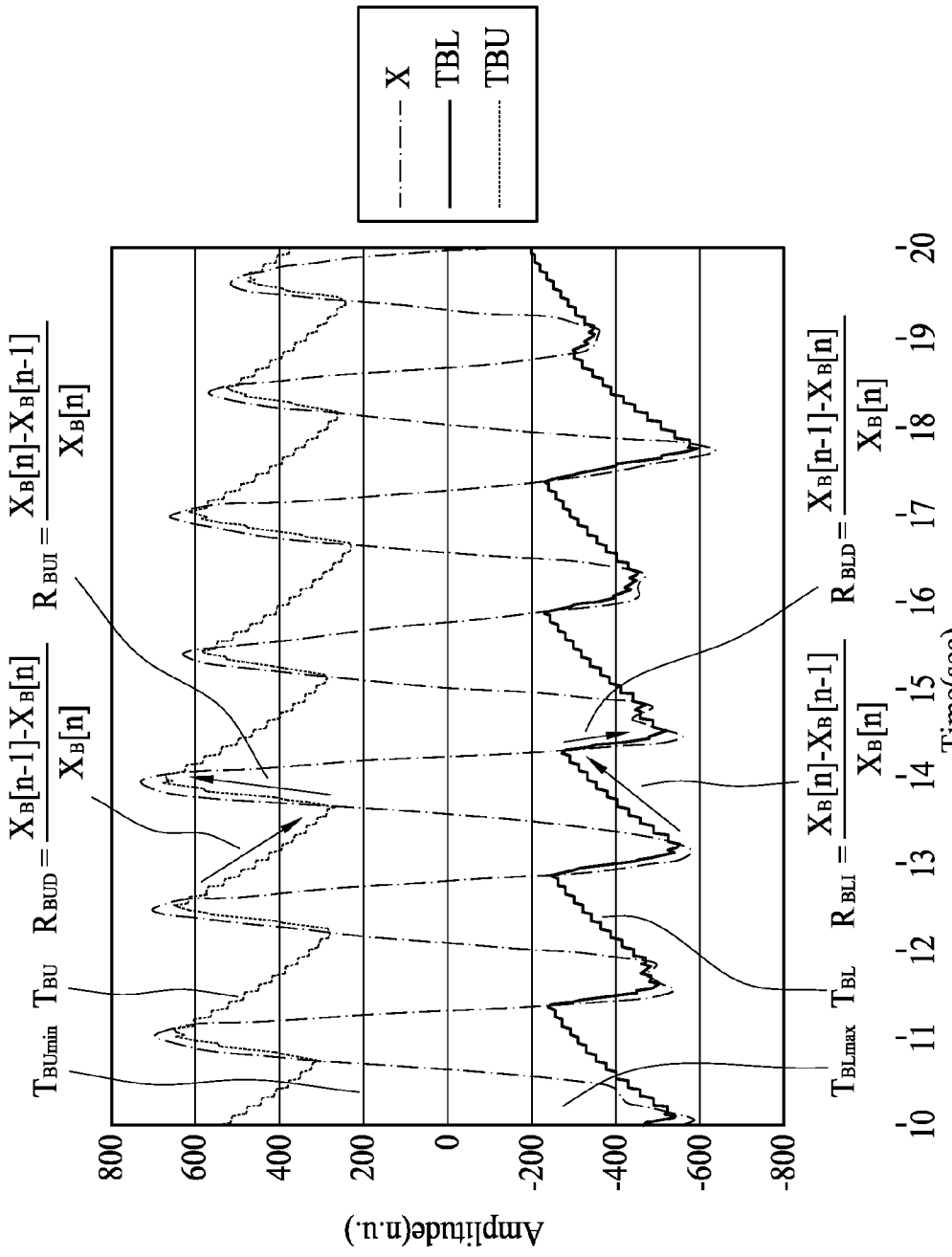

X
TBL
TBU
Amplitude(n.u.)
800
600
400
200
0
-200
-400
-600
-800
10
11
12
13
14
15
16
17
18
19
20
Time(sec)
T_{BUmin} T_{BU} $R_{BUD}=\frac{X_B[n-1]-X_B[n]}{X_B[n]}$ $R_{BUI}=\frac{X_B[n]-X_B[n-1]}{X_B[n]}$
T_{BLmax} T_{BL} $R_{BLI}=\frac{X_B[n]-X_B[n-1]}{X_B[n]}$ $R_{BLD}=\frac{X_B[n-1]-X_B[n]}{X_B[n]}$

FIG. 6

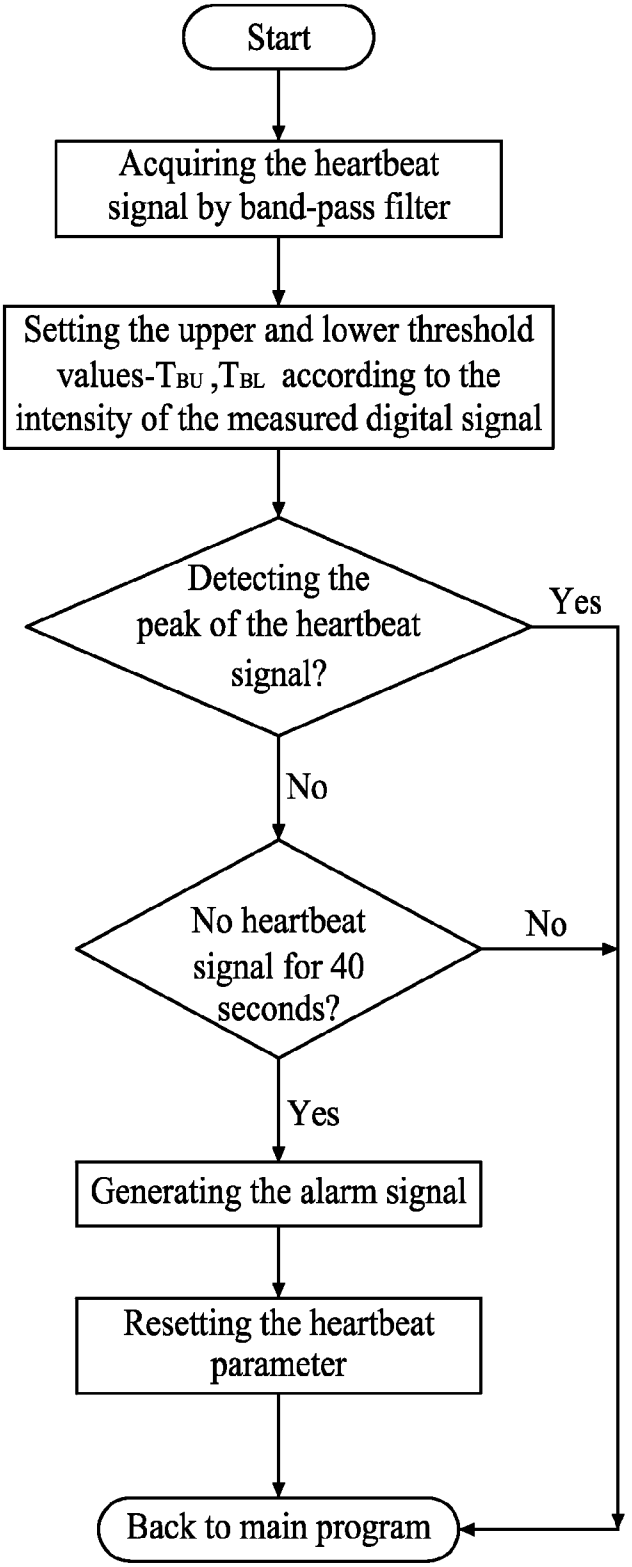

Start
Acquiring the heartbeat signal by band-pass filter
Setting the upper and lower threshold values-T_{BU} ,T_{BL} according to the intensity of the measured digital signal
Detecting the peak of the heartbeat signal?
Yes
No
No heartbeat signal for 40 seconds?
No
Yes
Generating the alarm signal
Resetting the heartbeat parameter
Back to main program

FIG. 7

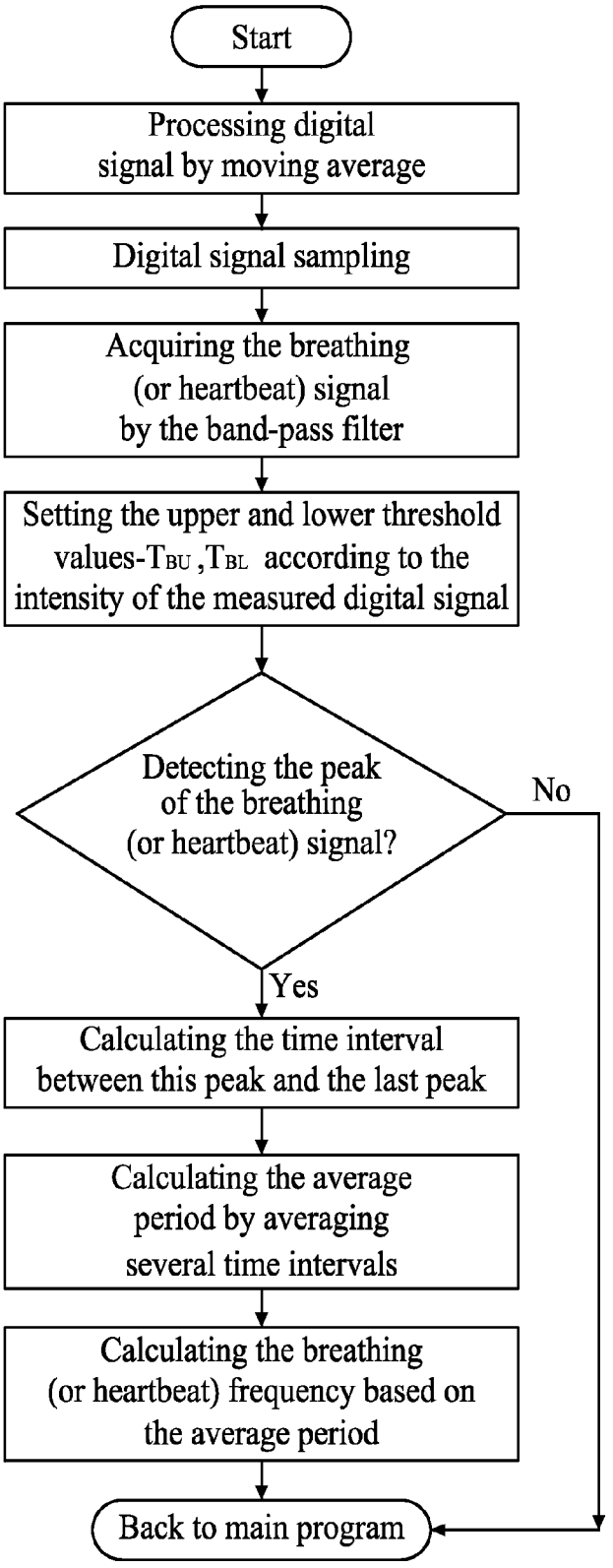

Start
Processing digital signal by moving average
Digital signal sampling
Acquiring the breathing (or heartbeat) signal by the band-pass filter
Setting the upper and lower threshold values-T_{BU} ,T_{BL} according to the intensity of the measured digital signal
Detecting the peak of the breathing (or heartbeat) signal?
No
Yes
Calculating the time interval between this peak and the last peak
Calculating the average period by averaging several time intervals
Calculating the breathing (or heartbeat) frequency based on the average period
Back to main program

FIG. 8

NON-CONTACT APPARATUS FOR MONITORING CARDIOPULMONARY ACTIVITY SIGNALS AND METHOD FOR THE SAME

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is a divisional application of prior application Ser. No. 11/954,586, filed on 12 Dec. 2007 by the present inventor, entitled "NON-CONTACT APPARATUS FOR MONITORING CARDIOPULMONARY ACTIVITY SIGNALS AND METHOD FOR THE SAME," which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to a technology for monitoring cardiopulmonary activity signals, and more particularly, to a non-contact apparatus and method for monitoring cardiopulmonary activity signals.

[0003] Breathing disorders commonly occur in premature infants, which manifest themselves in symptoms such as apnea or intermittent breathing etc., and can further develop into two types of complications: one of which occurs with apnea of premature birth infants, also known as apnea of prematurity (AOP); the other is sudden infant death syndrome (SIDS) or apparent life threatening event (ALTE). If AOP is not properly diagnosed and treated, premature infants diagnosed with this type of symptom will be highly susceptible to SIDS and are accident-prone at home. Cessation of breathing might lead to hemodynamic chain reactions such as slow-down of the heartbeat rate, and even lowered blood pressure. These changes in hemodynamics can induce temporary loss of blood and oxygen to critical organs, especially to the brain cells and may even cause permanent damage to them. In clinical trials, premature infants often become stable in all other aspects and could be discharged from the hospital, if it were not for this type of irregular apnea symptom.

[0004] Infant monitors currently in clinical use are based on traditional bedside monitors of patients' physical condition and use three electrodes attached to the skin of the infant's chest, acquiring the signals from the changes in the chest impedance by breathing and heartbeat signals; these two signals are then converted into the separate breathing frequency and heartbeat rate by the filter. A major drawback of this type of monitoring technology is that prolonged contact with the sensor plates will cause skin redness, sensitivity, or deterioration; furthermore, monitors used clinically are often expensive and therefore not suitable for home caretaking purposes.

[0005] To solve the above-mentioned problem, U.S. Pat. No. 4,738,264 disclosed a vibration measurement apparatus that is separated from the patient and is disposed on the bed. The main principle behind the apparatus is that tiny vibrations of the body surfaces from normal breathing and heartbeat are transferred to the measurement apparatus through the bed, and then the apparatus converts the signals into a comprehensive energy index to represent the infant's breathing and heartbeat conditions. The drawback of this technique is that it cannot accurately distinguish and measure the infant's breathing frequency and heartbeat rate, and therefore cannot fulfill the clinical requirements for detecting the AOP alert threshold (i.e. breathing frequency is less than 20/minute of breathing ceases for over 15 seconds, and heartbeat rate is less than 80/minute).

[0006] In addition, U.S. Pat. No. 5,964,720 disclosed a distributed vibration measurement system that uses the piezoelectric crystals as the vibration sensors and uses strips of conducting film as the base of the sensors. These conductive strips can be embedded in the bed mattresses, seat backs, or cushions to detect tiny vibrations of the body surface resulting from normal breathing and the heartbeat of the patient. The major drawback of this technique is that the heart and chest vibration signals captured by the sensors tend to be subject to interference from vibration noise from the surroundings that travel through the human body and bed or seat to the sensor.

SUMMARY OF THE INVENTION

[0007] One exemplary example consistent with the present invention provides a non-contact apparatus for monitoring cardiopulmonary activity signals using a series of high-frequency sinusoidal pulses to detect cardiopulmonary activity signals such as the heartbeat and breathing.

[0008] A non-contact apparatus for monitoring cardiopulmonary activity signals according to this example of the present invention comprises a pulse-series generator configured to generate a series of probing pulses and a series of reference pulses, a transmitting antenna configured to transmit the probing pulses to a chest portion and a series of scattered pulses being generated from the probing pulses by the scattering of the chest portion, a receiving antenna configured to receive the scattered pulses, a mixer including a first input port configured to receive the reference pulses and a second input port electrically connected to the receiving antenna to receive scattered pulses, and a signal-processing module configured to generate the cardiopulmonary activity signals after the scattered pulses and the reference pulses are processed by the mixer.

[0009] Another exemplary example consistent with of the present invention provides a method for acquiring cardiopulmonary activity signals comprising the steps of transmitting probing pulses to the chest portion to generate scattered pulses from the probing pulses by the scattering of the chest portion, generating a phase-difference signal between the scattered pulses and reference pulses by a mixer, converting the phase-difference signal into a digital signal representing the cardiopulmonary activity signal, and checking to determine if the cardiopulmonary activity is normal and generating an alarm signal if the checking result is negative.

[0010] A further exemplary example consistent with of the present invention provides a method for acquiring cardiopulmonary activity signals comprising the steps of transmitting probing pulses to a chest portion to generate scattered pulses from the probing pulses by the scattering of the chest portion, generating a phase-difference signal between the scattered pulses and reference pulses by a mixer, converting the phase-difference signal into a digital signal representing the cardiopulmonary activity, and calculating the frequency of the cardiopulmonary activity based on the digital signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The objectives and advantages of the present invention will become apparent upon reading the following description and upon reference to the accompanying drawings in which:

[0012] FIG. **1** illustrates the functional block diagram of a non-contact apparatus for monitoring cardiopulmonary activity signals according to one embodiment of the present invention;

[0013] FIG. **2** illustrates the system architecture of the non-contact apparatus according to one embodiment of the present invention;

[0014] FIG. **3** illustrates the functional block diagram of the signal-processing module according to one embodiment of the present invention;

[0015] FIG. **4** illustrates the output signals of the balance mixer according to one embodiment of the present invention;

[0016] FIG. **5** illustrates a method for processing the digital signal after it is generated by the mixer according to one embodiment of the present invention;

[0017] FIG. **6** illustrates cardiopulmonary activity signals according to one embodiment of the present invention;

[0018] FIG. **7** illustrates a method for acquiring cardiopulmonary activity signals according to the another embodiment of the present invention; and

[0019] FIG. **8** illustrates a method for measuring the breathing frequency (heartbeat rate) of a patient according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0020] FIG. **1** illustrates the functional block diagram of a non-contact apparatus **10** for monitoring cardiopulmonary activity signals according to one embodiment of the present invention. The non-contact apparatus **10** comprises a pulse-series generator **12** configured to generate a series of high-frequency sinusoidal probing pulses and reference pulses, a transmitting antenna **42** configured to emit the probing pulses to the chest portion to generate a series of scattered pulses from the probing pulses by the scattering of the chest portion, a receiving antenna **44** configured to receive the scattered pulses by the chest portion, a balance mixer **46** having a first input port **46**A configured to receive the reference pulses and a second input port **46**B electrically connected to the receiving antenna **44** to receive scattered pulses, and a signal-processing module **50** configured to generate the cardiopulmonary activity signals after the scattered pulses and the reference pulses are mixed by the balance mixer **46**.

[0021] FIG. **2** illustrates the system architecture of the non-contact apparatus **10** according to one embodiment of the present invention. The pulse-series generator **12** comprises a pulse generator **20** configured to generate a series of high-frequency sinusoidal pulses, from which the probing pulses and the reference pulses are generated by the splitter **30** such as a Wilkinson splitter coupled to the high-frequency filter **34**A. The pulse generator **20** comprises a sinusoidal-signal generator **26** configured to generate a 5.5 GHz continuous sinusoidal signal, a switching-signal generator **22** configured to generate a switching signal, and a switching device **24** having an input port **24**A and an output port **24**B and configured to turn on according to the switching signal such that the continuous sinusoidal signal can pass through the switching device **22** to form the high-frequency sinusoidal pulses. The switching-signal generator **22** comprises a clock generator **22**A configured to generate a clock signal, and a waveform shaper **22**B configured to adjust the time interval, 6.0 ns nominal, of the clock signal to generate the switching signal.

[0022] The non-contact apparatus **10** further comprises a first amplifier **32**A electrically coupled to the output port of the pulse generator **20**, a first high-frequency filter **34**A electrically coupled to the first amplifier **32**A and the splitter **30**, a second high-frequency filter **34**B electrically coupled to the receiving antenna **44**, and a second low noise amplifier **32**B electrically coupled to the second high-frequency filter **34**B and the balance mixer **46**. FIG. **3** illustrates the functional block diagram of the signal-processing module **50** according to one embodiment of the present invention. The signal-processing module **50** comprises a low-frequency filter **34**C electrically coupled to the output port of the balance mixer **46**, a third amplifier **32**C electrically coupled to the low-frequency filter **34**C, a band-pass filter **56** electrically coupled to the third amplifier **32**C, a microprocessor **52** with a built-in analog/digital converter **54** electrically coupled to the band-pass filter **56**, an alarm signal generator **58**, a memory unit **60** configured to store data, and a wireless transmission module **62**.

[0023] The signal-processing module **50** serves to output the analog signal representing breathing or heartbeat, and the analog/digital converter **54** then converts the analog signal into a digital signal. The breathing or heartbeat signals can be extracted from the digital signal by the firmware of the microprocessor **52**, and the breathing frequency or heartbeat rate can be calculated with a certain signal-processing algorithm. The alarm signal generator **58** is configured to send an alarm signal when there is an anomaly, and the processed signals can be sent through the wireless transmission module **62** to the data server for further statistical analysis, printing, and storage.

[0024] FIG. **4** illustrates the output signals of the balance mixer **46** according to one embodiment of the present invention. The high-frequency sinusoidal pulses are filtered by the first high-frequency filter **34**A and then split into two parts by the splitter **30**; one is the probing pulses transmitted to the chest portion by the transmitting antenna **42** and the other is the reference pulses fed into the first input port **46**A of the balance mixer **46**. The transmitted high-frequency sinusoidal probing pulses are then scattered by the chest portion of the subject to generate the scattered pulses, which is then received by the receiving antenna **44**. Subsequently, the scattered pulses are mixed with the high-frequency sinusoidal reference pulses by the balance mixer **46**. The output of the balance mixer **46** is a series of high-frequency pulses, with the polarity and amplitude of each pulse corresponding to the phase difference of the scattered pulses and the reference pulses. The low-frequency filter **34**C will capture the envelop (the dotted lines in FIG. **4**) of the high-frequency pulses to obtain the breathing and heartbeat signals of the patient, while the third amplifier **32**C will magnify the amplitude of the signal and the band-pass filter **56** further removes baseline drift and high frequency noises.

[0025] FIG. **5** illustrates a method for processing the digital signal after it is generated by the mixer **46** according to one embodiment of the present invention. The moving average method is used to reduce the high frequency noise. A band-pass filter with −3 dB bandwidth from 0.1 Hz to 0.5 Hz is employed to reduce the noise outside the range of subject's normal range of breathing. To set-up the threshold values, the minimum of the upper threshold value (T_{Bumin}) and the maximum of the lower threshold value (T_{BLmax}), are first defined as two times of the magnitude of the background noise. For example, if the background noise is between −100~100, then the T_{BUmin} is 200 and T_{BLmax} is −200. Then the upper threshold value (T_{BU}) and the lower threshold (T_{BL}) are adjusted as shown in FIG. **6**. If the signal value X_B [n] is larger than T_{BU}[n], the value of T_{BU} [n+1] is increased with ratio R_{BUI}.

$$T_{BU}[n+1]=(1+R_{BUI})^* T_{BU}[n]$$

Where $R_{BUI}=(X_B[n]-X_B[n-1])/X_B[n]$

[0026] If the signal value $X_B[n]$ is smaller than $T_{BU}[n]$, the upper threshold value $T_{BU}[n+1]$ is then reduced with ratio R_{BUD}.

$$T_{BU}[n+1]=(1-R_{BUD})*T_{BU}[n]$$

Where $R_{BUD}=(X_B[n-1]-X_B[n])/X_B[n]$

[0027] Similarly, if the signal value is less than the lower threshold, the lower threshold is reduced with ratio R_{BLD}.

$$T_{BL}[n+1]=(1-R_{BLD})*T_{BL}[n]$$

Where $R_{BLD}=(X_B[n-1]X_B[n])/X_B[n]$

[0028] If the signal value is higher than the lower threshold, the lower threshold is then increased with ratio R_{BLI}.

$$T_{BL}[n+1]=(1+R_{BLI})*T_{BL}[n]$$

Where $R_{BLI}=(X_B[n]-X_B[n-1])/X_B[n]$

[0029] Subsequently, the intensity of the measured digital signal is compared with thresholds to check whether a signal peak representing the breathing activity is detected. If the signal is larger than T_{BU}, the "peak searching procedure" begins to record the location of current maximum value. The location would be continuously updated until the signal lower than T_{BL}. If there is no digital signal with intensity greater than T_{BU} for a predetermined time (for example, 20 seconds), an alarm signal will be generated and all breathing parameters will be reset to zero to restart the calculation process.

[0030] FIG. **7** illustrates a method for acquiring cardiopulmonary activity signals according to another embodiment of the present invention, in which an alarm signal will be sent when the heartbeat is irregular. The digital signals captured by the non-contact apparatus **10** are heartbeat signals, while the alarm signal represents the cessation of the heartbeat. The microprocessor **52** of the signal-processing module **50** is configured to filter out the heartbeat signal through a band-pass filter with −3 dB bandwidth from 0.7 Hz to 2.5 Hz that is implemented in the software, and then set thresholds according to the empirical value or the intensity of the measured digital signal. The "peak searching procedure" is the same as that in breathing signal detection.

[0031] FIG. **8** illustrates a method for measuring the breathing frequency (heartbeat rate) of a patient according to one embodiment of the present invention. The digital signal processing is the same as previous procedure and then peak detecting is performed to record location of each peak. When the peak of the breathing (heartbeat) signals is detected, the time interval between the current breathing (heartbeat) peak and the previous breathing (heartbeat) peak is calculated and saved to the memory **60**. The time intervals between a plurality signal peaks are averaged to obtain the average interval, and the breathing frequency (heartbeat rate) is calculated by using the average interval. Furthermore, the present invention can selectively capture a portion of the digital signal (for example setting the sampling rate at ⅕) or discard unstable signals during system startup stage after applying the moving average method to the data signal.

[0032] After the calculation of the breathing frequency (heartbeat rate) is completed, the breathing frequency (heartbeat rate) is checked to determine whether it falls in a predetermined range. If the calculated breathing frequency (heartbeat rate) is higher than the predetermined range, an alarm signal indicating the breathing frequency (heartbeat rate) is too high is generated; in contrast, if the calculated breathing frequency (heartbeat rate) is lower than the predetermined range, an alarm signal indicating the breathing frequency (heartbeat rate) is too low is generated.

[0033] The above-described embodiments of the present invention are intended for illustration purposes only. Numerous alternative embodiments may be devised by those skilled in the art without departing from the scope of the following claims.

What is claimed is:

1. A method for acquiring cardiopulmonary activity signals, comprising the steps of:
- transmitting probing pulses to the chest portion to generate scattered pulses from the probing pulses by the scattering of the cardiopulmonary portion;
- generating a phase-difference signal between the scattered pulses and reference pulses by a mixer;
- converting the phase-difference signal into a digital signal representing the cardiopulmonary activity; and
- checking to determine whether the cardiopulmonary activity is normal and generating an alarm signal if the checking result is negative.

2. The method for acquiring cardiopulmonary activity signals of claim **1**, wherein the digital signal is a breathing signal and the step of checking to determine whether the cardiopulmonary activity is normal and generating an alarm signal if the checking result is negative includes:
- setting a threshold value;
- checking to determine whether the intensity of the digital signal is greater than the threshold value; and
- generating the alarm signal if the intensity of the digital signal is not greater than the threshold value for a predetermined interval.

3. The method for acquiring cardiopulmonary activity signals of claim **2**, wherein the alarm signal is a suffocation signal.

4. The method for acquiring cardiopulmonary activity signals of claim **1**, wherein the digital signal is a heartbeat signal and the step of checking to determine whether the cardiopulmonary activity is normal and generating an alarm signal if the checking result is negative includes:
- setting a threshold value;
- checking to determine whether the intensity of the digital signal is greater than the threshold value; and
- generating the alarm signal if the intensity of the digital signal is not greater than the threshold value for a predetermined interval.

5. The method for acquiring cardiopulmonary activity signals of claim **2**, wherein the alarm signal is a cessation signal of the heartbeat.

6. The method for acquiring cardiopulmonary activity signals of claim **1**, wherein the threshold value is set according to the intensity of the digital signal.

7. The method for acquiring cardiopulmonary activity signals of claim **1**, wherein the probing pulses is a series of high-frequency sinusoidal pulses.

8. A method for acquiring cardiopulmonary activity signals, comprising the steps of:
- transmitting probing pulses to the chest portion to generate scattered pulses from the probing pulses by the scattering of the chest portion;
- generating a phase-difference signal between the scattered pulses and a reference pulses by a mixer;
- converting the phase-difference signal into a digital signal representing the cardiopulmonary activity; and

calculating a frequency of the cardiopulmonary activity based on the digital signal.

9. The method for acquiring cardiopulmonary activity signals of claim **8**, wherein the step of calculating a frequency of the cardiopulmonary activity based on the digital signal includes:

setting a threshold value;

checking to determine whether the intensity of the digital signal is greater than the threshold value and determining a signal peak of the cardiopulmonary activity is detected if the checking result is positive;

calculating time intervals of a plurality of signal peaks of the cardiopulmonary activity; and

averaging the time intervals to generate the frequency of the cardiopulmonary activity.

10. The method for acquiring cardiopulmonary activity signals of claim **8**, wherein the digital signal is a breathing signal.

11. The method for acquiring cardiopulmonary activity signals of claim **8**, further comprising the steps of:

checking to determine whether the frequency of the cardiopulmonary activity is in a predetermined range: and

generating an alarm signal if the frequency of the cardiopulmonary activity is outside the predetermined range.

12. The method for acquiring cardiopulmonary activity signals of claim **11**, wherein the digital signal is a heartbeat signal and the alarm signal is an over-beating signal.

13. The method for acquiring cardiopulmonary activity signals of claim **11**, wherein the digital signal is a heartbeat signal and the alarm signal is an under-beating signal.

14. The method for acquiring cardiopulmonary activity signals of claim **8**, wherein the threshold value is set according to the intensity of the digital signal.

15. The method for acquiring cardiopulmonary activity signals of claim **8**, wherein the probing pulses are a series of high-frequency sinusoidal pulses.

* * * * *