US 20180338728A1

(19) **United States**

(12) **Patent Application Publication**

LI et al.

(10) **Pub. No.: US 2018/0338728 A1**

(43) **Pub. Date: Nov. 29, 2018**

(54) WEARABLE DEVICE, METHOD AND APPARATUS FOR ELIMINATING MOTION INTERFERENCE

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(21) Appl. No.: **16/049,075**

(22) Filed: **Jul. 30, 2018**

Related U.S. Application Data

(63) Continuation of application No. PCT/CN2017/083846, filed on May 10, 2017.

Publication Classification

(51) **Int. Cl.**

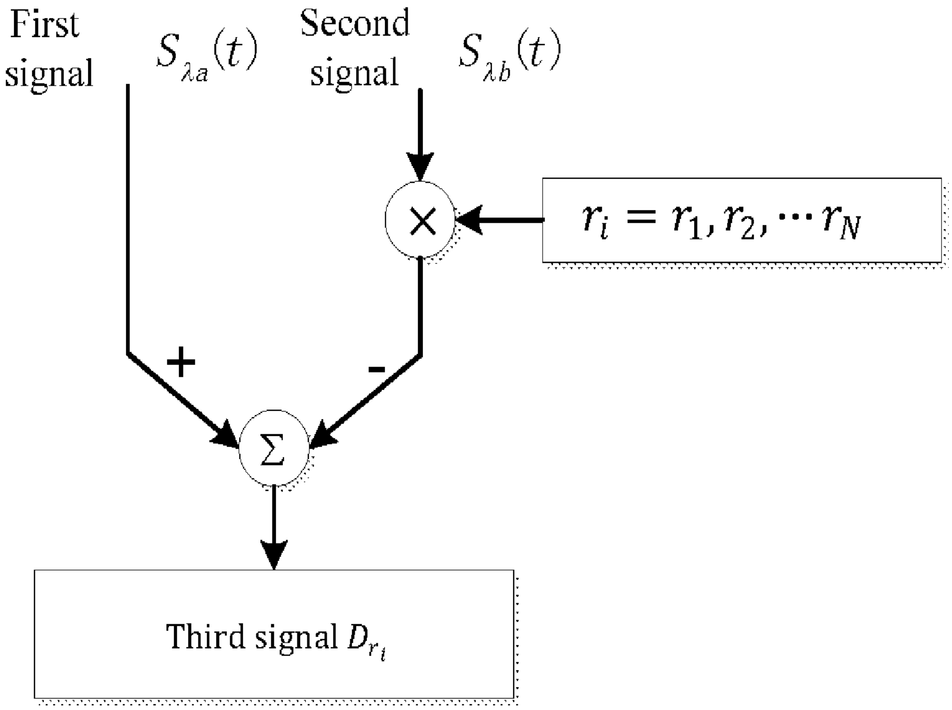
A61B 5/00	(2006.01)
A61B 5/024	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 5/721*** (2013.01); ***A61B 5/02416*** (2013.01); *A61B 2562/0219* (2013.01); ***A61B 5/7225*** (2013.01); ***A61B 5/7246*** (2013.01); ***A61B 5/02438*** (2013.01)

(57) ABSTRACT

A method for eliminating motion interference includes: performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference; mixing the first signal and the second signal through a plurality of preset coefficients r_i respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients; calculating a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal; obtaining a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients; and calculating a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.



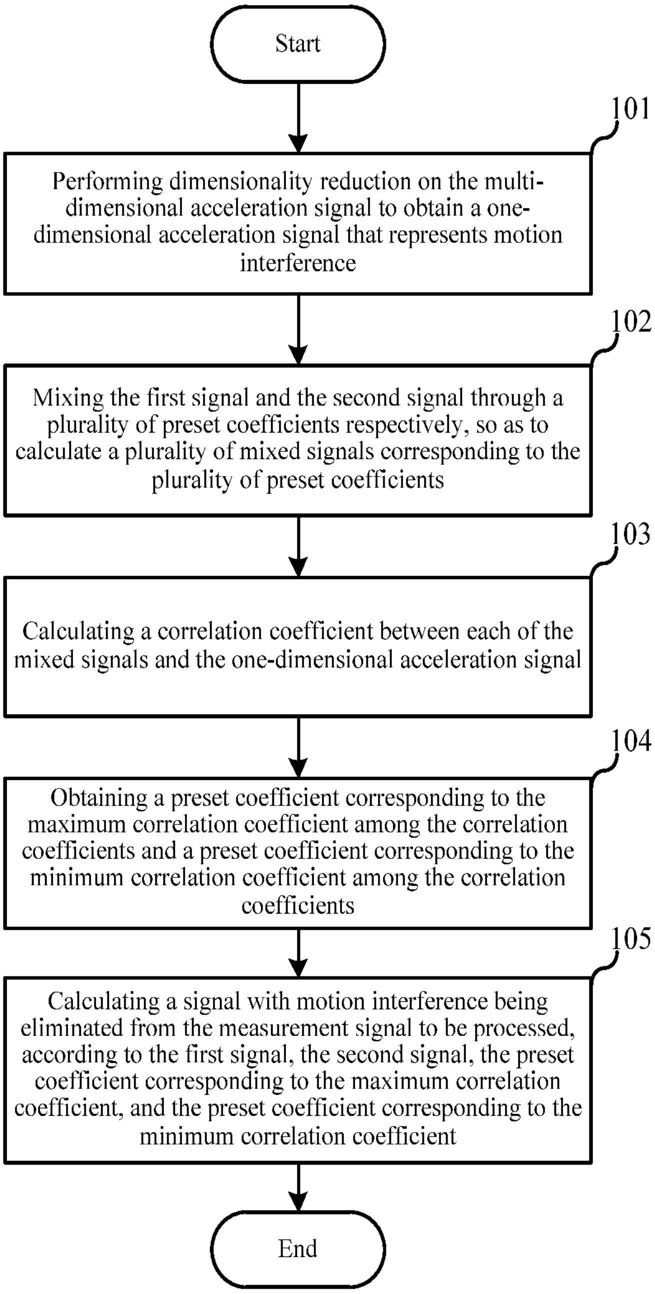

Start
101
Performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference
102
Mixing the first signal and the second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients
103
Calculating a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal
104
Obtaining a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients
105
Calculating a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient
End

FIG. 1

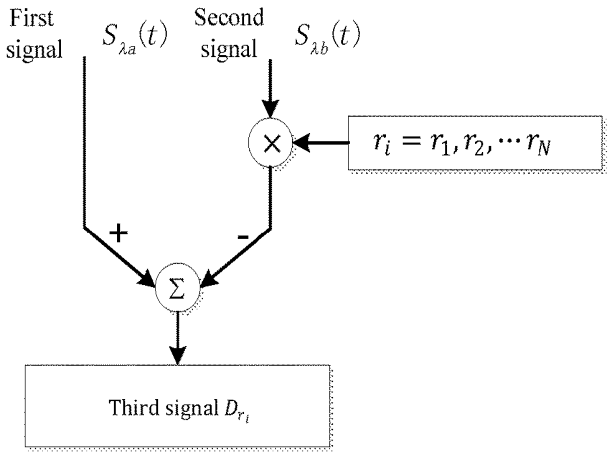

First signal
$S_{\lambda a}(t)$
Second signal
$S_{\lambda b}(t)$
×
$r_i = r_1, r_2, \cdots r_N$
+
-
Σ
Third signal D_{r_i}

FIG. 2

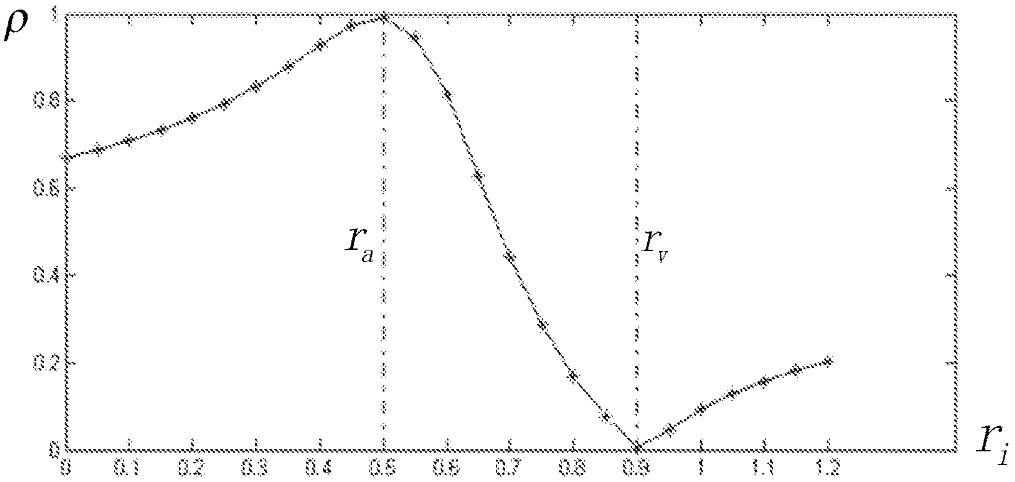

ρ
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
r_a
r_v
r_i

FIG. 3

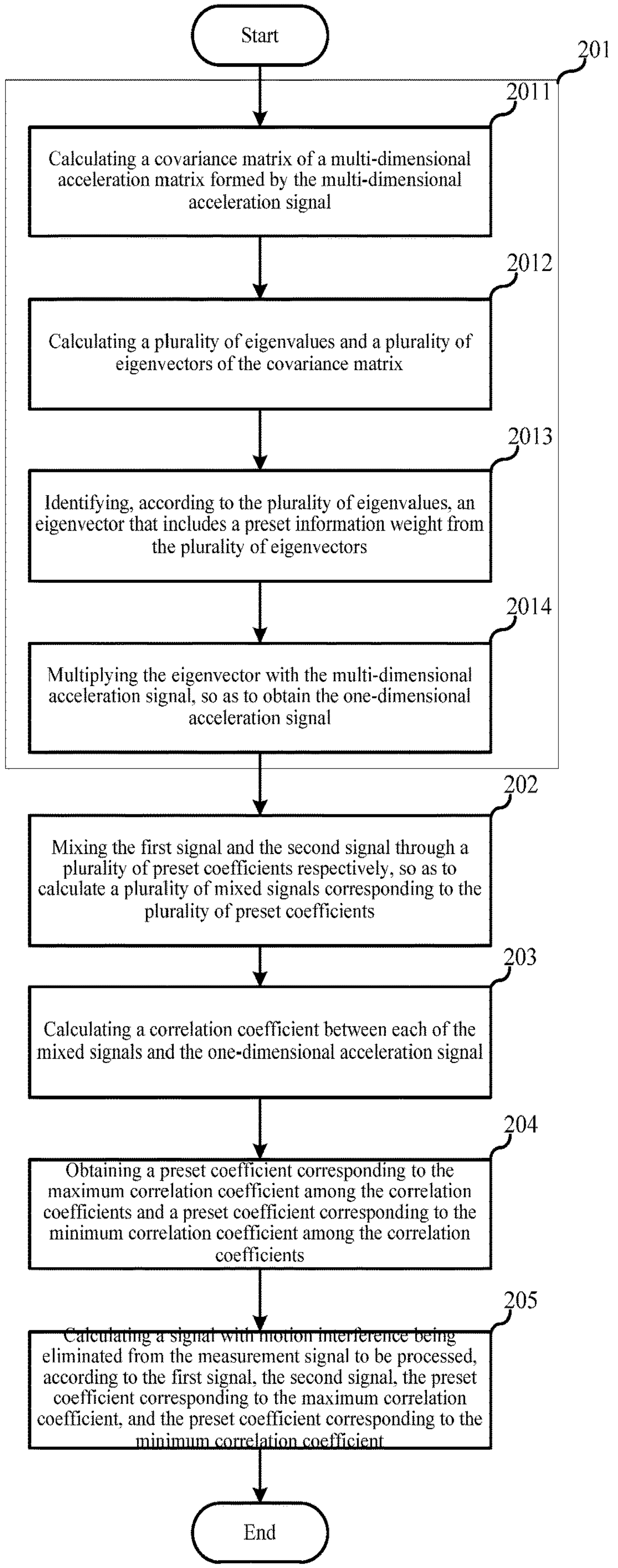

Start
201
2011
Calculating a covariance matrix of a multi-dimensional acceleration matrix formed by the multi-dimensional acceleration signal
2012
Calculating a plurality of eigenvalues and a plurality of eigenvectors of the covariance matrix
2013
Identifying, according to the plurality of eigenvalues, an eigenvector that includes a preset information weight from the plurality of eigenvectors
2014
Multiplying the eigenvector with the multi-dimensional acceleration signal, so as to obtain the one-dimensional acceleration signal
202
Mixing the first signal and the second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients
203
Calculating a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal
204
Obtaining a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients
205
Calculating a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient
End

FIG. 4

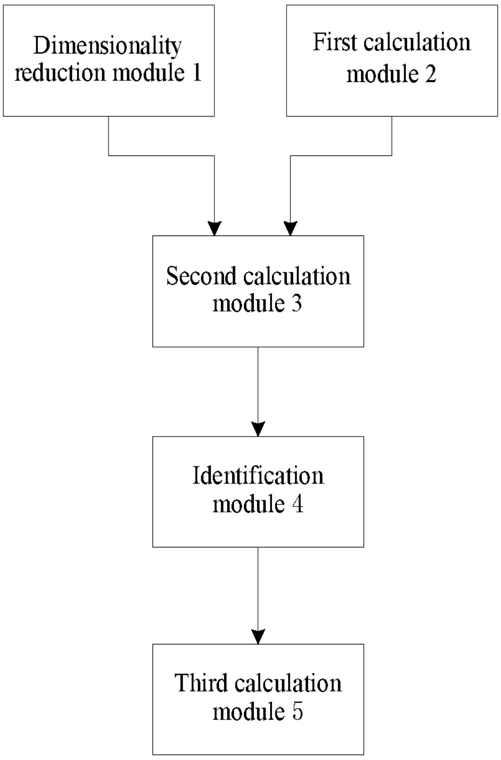

Dimensionality reduction module 1
First calculation module 2
Second calculation module 3
Identification module 4
Third calculation module 5

FIG. 5

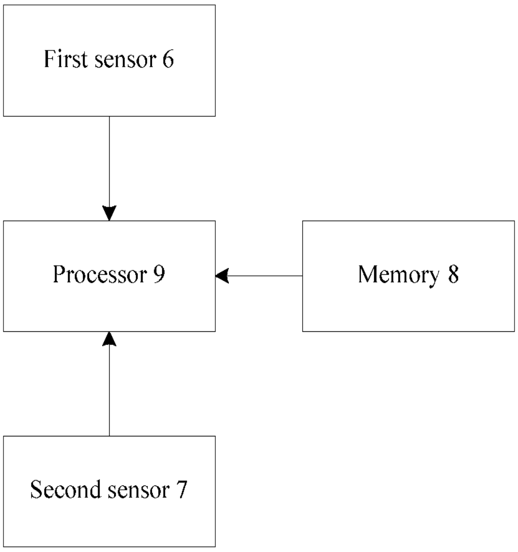

First sensor 6
Processor 9
Memory 8
Second sensor 7

FIG. 6

WEARABLE DEVICE, METHOD AND APPARATUS FOR ELIMINATING MOTION INTERFERENCE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present disclosure is a continuation of international application No. PCT/CN2017/083846, filed on May 10, 2017, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of signal processing technology, and more particularly to a wearable device, a method and apparatus for eliminating motion interference.

BACKGROUND

[0003] With the improvement of living standards, people pay more and more attention to their own health. Heart rate is the speed of the heartbeat measured by the number of contractions of the heart per minute, and it is a very important physiological indicator in clinical diagnosis. Traditional medical devices require users to be at rest while measuring heart rate, and are not convenient to be carried. Therefore, many manufacturers have already produced wearable devices capable of performing heart rate measurement, so that users can measure heart rate in daily life occasions.

[0004] The existing most commonly used method for measuring heart rate is Photoplethysmogram (PPG) method. In this method, a LED is used to emit light of a specific wavelength, the light is propagated, scattered, diffracted, and reflected via human tissue, then returned, and a returned optical signal is converted into an electrical signal, so as to obtain a corresponding PPG signal. When light beams are propagated through human tissues, intensity of light beams is attenuated due to the property of light absorbing by human tissues. For example, a value of light absorbing by static tissues such as skin, fat, muscle, etc. is a constant value. However, light absorbing by blood undergoes periodic volume changes due to contraction and diastole of the heart, thus the PPG signal shows a periodic waveform that is consistent with the heartbeat. Accordingly, the heartbeat frequency can be measured with the PPG signal. Further, the PPG method is a non-invasive measurement method for measuring heart rate.

[0005] The inventor has found that there are at least the following problems: heart rate measurement on the wearable device is more demanding on the PPG method because users need to measure the heart rate in a motion state. However, muscle and pressure will change in a motion state, which results in that a propagation path of light beams changes. Besides a pulse wave signal, a motion interference signal is also superimposed on the PPG signal. Different motion states produce different motion interference frequencies, and a value of the motion frequency cannot be guaranteed to be a constant value. For example, the motion frequency is in a range of 0 Hz to 4 Hz in the state of walking, climbing and running, and the human heart rate is also in a range of 0.5 Hz to 4 Hz. Therefore, motion interference with unknown frequencies cannot be filtered by traditional FIR (finite impulse response), IIR (infinite impulse response) or wavelet filtering.

[0006] There are two existing technical solutions for measuring heart rate in a motion state: one is an adaptive noise cancellation method based on an adaptive filter; and the other is an oxygen saturation discrete saturation transform (DST) method. However, a precondition for implementing the adaptive noise cancellation method is that the motion state has statistical stability, in this way, the adaptive filter is continuously in a convergent state. But the motion state cannot be kept stable in reality, such as up and down stairs. A precondition for the DST method is that blood oxygen saturation is relatively high, usually higher than 85%, thus this method is not suitable for users with dyspnea (whose blood oxygen saturation is relatively low). In addition, the DST method is computationally intensive and difficult to be implemented on wearable devices.

SUMMARY

[0007] The objective of some embodiments of the present disclosure is to provide a wearable device, a method and apparatus for eliminating motion interference, with which interference in motion can be effectively eliminated, and detection of signals with motion interference being eliminated is suitable in various motion states, meanwhile computational complexity is less, and implementation is easily performed on the wearable device.

[0008] An embodiment of the present disclosure provides a method for eliminating motion interference. The method is applied to a wearable device capable of acquiring a multi-dimensional acceleration signal and a measurement signal to be processed of the wearable device, and the measurement signal to be processed includes a first signal and a second signal having different wavelengths. The method comprises: performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference; mixing the first signal and the second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients; calculating a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal; obtaining a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients; calculating a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.

[0009] An embodiment of the present disclosure further provides an apparatus for eliminating motion interference. The apparatus is applied to the method for eliminating motion interference as described above. The apparatus comprises: a dimensionality reduction module configured to perform dimensionality reduction on a multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference; a first calculation module configured to mix a first signal and a second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients; a second calculation module configured to calculate a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal; an identification module configured to obtain a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients; and a third calculation module configured to calculate a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.

[0010] An embodiment of the present disclosure further provides a wearable device. The wearable device comprises a first sensor, a second sensor, a memory, and a processor connected to the first sensor and the second sensor. The first sensor is configured to acquire a multi-dimensional acceleration signal of the wearable device. The second sensor is configured to obtain a measurement signal to be processed, and the measurement signal to be processed includes a first signal and a second signal having different wavelengths. The memory is configured to store a plurality of instructions. The processor is configured to load the plurality of instructions and perform the function of the apparatus for eliminating motion interference as described above.

[0011] In the embodiments of the present disclosure, dimensionality reduction is performed on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference; the first signal and the second signal are mixed through a plurality of preset coefficients respectively, and a plurality of mixed signals corresponding to the plurality of preset coefficients are calculated; a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal is calculated accordingly; then a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients are obtained; so that a signal with motion interference being eliminated from the measurement signal to be processed is calculated according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient. That is, interference in motion is eliminated by using the correlation between motion interference and the multi-dimensional acceleration signal, and detection of signals with motion interference being eliminated is suitable in various motion states, meanwhile computational complexity is less, and implementation is easily be performed on the wearable device.

[0012] Further, in the method for eliminating motion interference, the mixed signal $D_{r_i}(t)$ is: $D_{r_i}(t)=S_{\lambda_a}(t)-r_i S_{\lambda_b}$, i=1, 2, 3, . . . ; $S_{\lambda_a}(t)$ represents the first signal; S_{λ_b} represents the second signal; r_i represents an i-th preset coefficient, and a traversal range of r_i is $[r_{slow}, r_{high}]$, r_{slow}, r_{high} are a lower limit and an upper limit of the traversal range, respectively. This embodiment provides a specific method for calculating the mixed signal $D_{r_i}(t)$.

[0013] Further, in the method for eliminating motion interference, the signal with motion interference being eliminated is expressed as:

$$ppg_{\lambda_a}(t) = \frac{r_a(S_{\lambda_a}(t) - r_v \cdot S_{\lambda_b})}{(r_a - r_v)}, \text{ or } ppg_{\lambda_b}(t) = \frac{S_{\lambda_a}(t) - r_v \cdot S_{\lambda_b}}{(r_a - r_v)},$$

in which $g_{\lambda_a}(t)=r_a \cdot ppg_{\lambda_b}(t)$, and $ppg_{\lambda_a}(t)$ and $ppg_{\lambda_b}(t)$ represents the signal with motion interference being eliminated; r_a represents the preset coefficient corresponding to the maximum correlation coefficient, r_v represents the preset coefficient corresponding to the minimum correlation coefficient. This embodiment provides a specific formula for calculating the signal with motion interference being eliminated.

[0014] Further, in the method for eliminating motion interference, the correlation coefficient is a Pearson correlation coefficient. This embodiment provides a method for calculating the correlation coefficient.

[0015] Further, in the method for eliminating motion interference, performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference specifically comprises: calculating a covariance matrix of a multi-dimensional acceleration matrix formed by the multi-dimensional acceleration signal; calculating a plurality of eigenvalues and a plurality of eigenvectors of the covariance matrix, the plurality of eigenvalues corresponding to the plurality of eigenvectors respectively; identifying, according to the plurality of eigenvalues, an eigenvector that includes a preset information weight from the plurality of eigenvectors; and multiplying the eigenvector with the multi-dimensional acceleration signal to obtain the one-dimensional acceleration signal. This embodiment provides a specific method of implementing dimensionality reduction processing on the multi-dimensional acceleration signal.

[0016] Further, in the method for eliminating motion interference, the value of the plurality of preset coefficients is increased in an arithmetic progression manner.

[0017] Further, in the method for eliminating motion interference, the signal with motion interference being eliminated is a PPG signal.

[0018] Further, in the wearable device, the second sensor is a heart rate sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] One or more embodiments are exemplified by the corresponding figures in the accompanying drawings, these illustrative explanations are not intended to limit these embodiments, elements with the same reference numbers in the drawings indicate similar elements. The figures in the accompany drawings do not present a proportional limit unless specifically declared.

[0020] FIG. **1** is a detailed flowchart of a method for eliminating motion interference according to a first embodiment of the present disclosure;

[0021] FIG. **2** is a schematic diagram of calculating a mixed signal according to the first embodiment of the present disclosure;

[0022] FIG. **3** is a curve diagram of a correlation coefficient and a preset coefficient according to the first embodiment of the present disclosure;

[0023] FIG. **4** is a detailed flowchart of a method for eliminating motion interference according to a second embodiment of the present disclosure;

[0024] FIG. **5** is a schematic block diagram of an apparatus for eliminating motion interference according to a third embodiment of the present disclosure; and

[0025] FIG. **6** is a schematic block diagram of a wearable device according to a fourth embodiment of the present disclosure.

DETAILED DESCRIPTION

[0026] In order to make a purpose, a technical solution, and advantages of the present disclosure clearer, some embodiments of the present disclosure will be described in detail in accordance with the accompanying drawings. It should be understood that, the specific embodiments described herein are only used to explain the present disclosure, rather than to limit the present disclosure.

[0027] A first embodiment of the present disclosure provides a method for eliminating motion interference. The method is applied to a wearable device, such as a watch, a ring, a headband, an earphone, etc. The wearable device can acquire a multi-dimensional acceleration signal and a measurement signal to be processed of the wearable device. The multi-dimensional acceleration signal represents an acceleration signal in different directions (that is, different dimensions) generated in motion state of the wearable device.

[0028] A light-emitting diode in the wearable device emits light of two different wavelengths, and an optical sensor capable of collecting optical signals of different wavelengths is disposed in the wearable device, therefore measurement signals to be processed that includes a first signal and a second signal having different wavelengths can be obtained. A signal with motion interference being eliminated can be obtained after eliminating motion interference in the measurement signal to be processed. Frequencies of the signals with motion interference being eliminated that are obtained from the first signal or the second signal are the same, that is, the wavelengths are the same. The signal with motion interference being eliminated is, for example, a PPG signal, and the measurement signal to be processed is actually a PPG signal including motion interference, thus the signal with motion interference being eliminated is obtained after motion interference in the measurement signal to be processed is eliminated.

[0029] This embodiment takes the measurement signal to be processed that is a PPG signal with motion interference as an example. The detailed process of the method for eliminating motion interference is shown in FIG. **1**.

[0030] Step **101**, dimensionality reduction is performed on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference.

[0031] Specifically, a multi-dimensional acceleration signal of a wearable device usually is a three-axis acceleration signal G(t), that includes acceleration signals in three directions of X-axis, Y-axis, and Z-axis (X-axis, Y-axis, and Z-axis are a coordinate system determined by a current direction of the wearable device). Dimensionality reduction processing is performed on the three-axis acceleration signal G(t), so that a one-dimensional acceleration signal Acc(t) can be extracted from the three-axis acceleration signal G(t). There is a strong correlation between the one-dimensional acceleration signal Acc(t) and a motion interference component in the measurement signal to be processed and there is no correlation between the one-dimensional acceleration signal Acc(t) and a pulse signal component in the measurement signal to be processed, thus the one-dimensional acceleration signal Acc(t) can be used to represent the motion interference.

[0032] Step **102**, the first signal and the second signal are mixed through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients.

[0033] Specifically, the first signal is a photoelectric signal $S_{\lambda_a}(t)$ with a wavelength of λ_a, the second signal is a photoelectric signal $S_{\lambda_b}(t)$ with a wavelength of λ_b. t is a time window with a length of T, $t=[t_0, t_0+T]$, the first signal $S_{\lambda_a}(t)$ and the second signal $S_{\lambda_b}(t)$ satisfy the following expressions:

$$S_{\lambda_a}(t)=\mathrm{ppg}_{\lambda_a}(t)+M_{\lambda_a}(t)+N_{\lambda_a}(t)$$

$$S_{\lambda_b}(t)=\mathrm{ppg}_{\lambda_b}(t)+M_{\lambda_b}(t)+N_{\lambda_b}(t)$$

[0034] Herein, $\mathrm{ppg}_{\lambda_a}(t)$ and $\mathrm{ppg}_{\lambda_b}(t)$ are pulse signal components (that is, the signal with motion interference being eliminated) in the first signal and the second signal, respectively. $M_{\lambda_a}(t)$ and $M_{\lambda_b}(t)$ are motion interference components in the first signal and the second signal, respectively. $N_{\lambda_a}(t)$ and $N_{\lambda_b}(t)$ are noise components in the first signal and the second signal, respectively. The pulse signal component, the motion interference component, and the noise component in each of the first signal and the second signal are independent of each other.

[0035] The first signal and the second signal are mixed through a preset coefficient r_i, as shown in FIG. **2**, so that a mixed signal $D_{r_i}(t)$ can be obtained. The mixed signal $D_{r_i}(t)$ may be represented as:

$$D_{r_i}(t)=S_{\lambda_a}(t)-r_i\cdot S_{\lambda_b},\ i=1, 2, 3, \ldots ;$$

[0036] Herein, r_i represents an i-th preset coefficient, and a traversal range of r_i is $[r_{slow}, r_{high}]$, r_{slow} and r_{high} are a lower limit and an upper limit of the traversal range, respectively. Preferably, the value of the plurality of preset coefficients r_i is increased in an arithmetic progression manner.

[0037] It needs to be noted that, FIG. **2** merely schematically provides a method for calculating the mixed signal, this embodiment makes no limitations thereto, and specific setting may be made according to a practical design scheme.

[0038] The pulse signal component and the motion interference component in the first signal are correlated to the pulse signal component and the motion interference component in the second signal, respectively, so that the following expressions are satisfied:

$$\mathrm{ppg}_{\lambda_a}(t)=r_a\cdot \mathrm{ppg}_{\lambda_b}(t)$$

$$M_{\lambda_a}(t)=r_v\cdot M_{\lambda_b}(t)$$

[0039] Herein, the mixed signal $D_{r_i}(t)$ is correlated to the one-dimensional acceleration signal Acc(t), and there is a correlation coefficient. r_a represents an a-th preset coefficient, that is the preset coefficient corresponding to the correlation coefficient that takes a maximum. r_v represents a v-th preset coefficient, that is the preset coefficient corresponding to the correlation coefficient that takes a minimum. $r_a \neq r_v$.

[0040] In view of the above, the mixed signal $D_{r_i}(t)$ may be further represented as:

$$\begin{aligned} D_{r_i}(t) &= S_{\lambda_a}(t) - r_i \cdot S_{\lambda_b} \\ &= (r_a - r_i) \cdot ppg_{\lambda_b}(t) + (r_v - r_i) \cdot \\ &\quad M_{\lambda_b}(t) + N(t) \end{aligned}$$

[0041] Herein, $N(t)=N_{\lambda_a}(t)-r_iN_{\lambda_b}(t)$, it is the noise component, and it is uncorrelated to $ppg_{\lambda_b}(t)$ and $M_{\lambda_b}(t)$.

[0042] According to the above expression of the mixed signal $D_{r_i}(t)$, the plurality of preset coefficients r_i are traversed within the traversal range $[r_{slow}, r_{high}]$, so as to calculate a plurality of mixed signals $D_{r_i}(t)$ corresponding to the plurality of preset coefficients. That is, each preset coefficient r_i corresponds to one mixed signal $D_{r_i}(t)$.

[0043] Step **103**, a correlation coefficient between each mixed signal and the one-dimensional acceleration signal is calculated.

[0044] Specifically, the existing correlation coefficient calculation methods include the Pearson correlation coefficient calculation method and the cosine similarity calculation method. This embodiment adopts the Pearson correlation coefficient calculation method, the correlation coefficient is a Pearson correlation coefficient. The Pearson correlation coefficient is irrelevant to amplitudes and baselines of the mixed signal $D_{r_i}(t)$ and the one-dimensional acceleration signal, and is only related to shapes of the mixed signal $D_{r_i}(t)$ and the one-dimensional acceleration signal, thus a shape similarity of the mixed signal $D_{r_i}(t)$ and the one-dimensional acceleration signal can be measured accurately.

[0045] The Pearson correlation coefficient calculation method calculates a Pearson correlation coefficient (that is, correlation coefficient) ρ_{ri} of each mixed signal $D_{r_i}(t)$ and the one-dimensional acceleration signal Acc(t):

$$\begin{aligned} \rho_{r_i} &= \left| \frac{\operatorname{cov}(D_{r_i}, Acc)}{\sigma_{D_{r_i}} \sigma_{Acc}} \right| \\ &= \left| \frac{E\left(\left(D_{r_i} - \mu_{D_{r_i}}\right) \cdot (Acc - \mu_{Acc})\right)}{\sigma_D \sigma_A} \right| \\ &= \frac{|E(D_{r_i} \cdot Acc) - E(D_{r_i}) \cdot E(Acc)|}{\sqrt{E(D_{r_i}^2) - E^2(D_{r_i})} \cdot \sqrt{E(Acc^2) - E^2(Acc)}} \end{aligned}$$

[0046] Herein, ρ_{ri} represents a Pearson correlation coefficient of the mixed signal $D_{r_i}(t)$ corresponding to the i-th preset coefficient and the one-dimensional acceleration signal Acc(t). Since each mixed signal $D_{r_i}(t)$ has one Pearson correlation coefficient (that is, correlation coefficient) ρ_{ri}, and each mixed signal $D_{r_i}(t)$ corresponds to one preset coefficient r_i, each Pearson correlation coefficient ρ_{ri} corresponds to one preset coefficient r_i.

[0047] In this embodiment, Pearson correlation coefficients (that is, correlation coefficients) ρ_{ri} of i mixed signals $D_{r_i}(t)$ and the one-dimensional acceleration signal Acc(t) are calculated respectively, that is, the i mixed signals $D_{r_i}(t)$ are sequentially substituted into the above Pearson correlation coefficient (that is, correlation coefficient) calculation formula, then i Pearson correlation coefficients (that is, correlation coefficients) ρ_{ri} can be obtained. Referring to FIG. **3**, a curve of the correlation coefficient ρ_{ri} and the preset coefficient r_i is shown.

[0048] Step **104**, a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients are obtained.

[0049] Specifically, the maximum correlation coefficient and the minimum correlation coefficient are identified from among the plurality of correlation coefficients ρ_{ri}, and it can be known from the curve of the correlation coefficient ρ_{ri} and the preset coefficient r_i in FIG. **3**, the maximum correlation coefficient is close to 1, and the minimum correlation coefficient is close to 0.

[0050] In addition, the mixed signal $D_{r_i}(t)=(r_a-r_i)\cdot ppg_{\lambda_b}(t)+(r_v-r_i)\cdot M_{\lambda_b}(t)+N(t)$, from which the following can be known:

[0051] When $r_i=r_a$, the mixed signal $D_{r_i}(t)=(r_v-r_a)\cdot M_{\lambda_b}(t)+N(t)$. In this case, the mixed signal $D_{r_i}(t)$ and the one-dimensional acceleration signal Acc(t) have a strong correlation, and the correlation coefficient ρ_{ri} takes a maximum value which is close to 1;

[0052] When $r_i=r_v$, the mixed signal $D_{r_i}(t)=(r_a-r_v)\cdot ppg_{\lambda_b}(t)+N(t)$. In this case, the mixed signal $D_{r_i}(t)$ and the one-dimensional acceleration signal Acc(t) have a weak correlation, and the correlation coefficient ρ_{ri} takes a minimum value which is close to 0.

[0053] Therefore, when the correlation coefficient ρ_{ri} takes a maximum value which is close to 1, the correlation coefficient is r_a, and when the correlation coefficient ρ_{ri} takes a minimum value which is close to 0, the correlation coefficient is r_v; that is, as shown in FIG. **3**, the preset coefficient corresponding to the maximum correlation coefficient is r_a, which is 0.5, and a preset coefficient corresponding to the minimum correlation coefficient is r_v, which is 0.9.

[0054] Step **105**, a signal with motion interference being eliminated from the measurement signal to be processed is calculated according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.

[0055] Specifically, when $r_i=r_v$, the mixed signal $D_{r_i}(t)$ and the one-dimensional acceleration signal Acc(t) have a weak correlation. In this case, the mixed signal $D_{r_i}(t)$ is:

$$D_{rv}(t)=S_{\lambda_a}(t)-r_v\cdot S_{\lambda_b}=(r_a-r_v)\cdot ppg_{\lambda_b}(t)+N(t)$$

[0056] The $D_{rv}(t)$ signal only includes the pulse signal (that is, the signal with motion interface being eliminated) and other small amount of noise, and the motion interference component has been eliminated. However, the noise signal is small and negligible, so:

$$D_{rv}(t)=S_{\lambda_a}(t)-r_v\cdot S_{\lambda_b}=(r_a-r_v)\cdot ppg_{\lambda_b}(t)$$

[0057] Accordingly, the signal $ppg_{\lambda_b}(t)$ with motion interference being eliminated from the measurement signal to be processed can be calculated as:

$$ppg_{\lambda_b}(t) = \frac{S_{\lambda_a}(t) - r_v \cdot S_{\lambda_b}}{(r_a - r_v)}$$

[0058] Herein, $ppg_{\lambda_b}(t)$ represents the signal with motion interference being eliminated, r_a represents the preset coefficient corresponding to the maximum correlation coefficient, r_v represents the preset coefficient corresponding to the minimum correlation coefficient.

[0059] Accordingly, the signal with motion interference being eliminated may be represented by $ppg_{\lambda_b}(t)$ or $ppg_{\lambda_a}(t)$:

$$ppg_{\lambda_b}(t) = \frac{S_{\lambda_a}(t) - r_v \cdot S_{\lambda_b}}{(r_a - r_v)}$$

$$ppg_{\lambda_a}(t) = r_a \cdot ppg_{\lambda_b}(t) = \frac{r_a(S_{\lambda_a}(t) - r_v \cdot S_{\lambda_b})}{(r_a - r_v)}$$

[0060] Herein, $ppg_{\lambda_a}(t)$ and $ppg_{\lambda_b}(t)$ both represent the signal with motion interference being eliminated; r_a represents the preset coefficient corresponding to the maximum correlation coefficient, r_v represents the preset coefficient corresponding to the minimum correlation coefficient.

[0061] Subsequently, the pulse and other physiological parameters can be accurately calculated by using the signal $ppg_{\lambda_a}(t)$ or $ppg_{\lambda_b}(t)$ with motion interference being eliminated and adopting the time domain waveform algorithm or the frequency domain algorithm, according to needs.

[0062] It needs to be noted that, although $ppg_{\lambda_a}(t)$ and $ppg_{\lambda_b}(t)$ are the pulse signals extracted from the first signal and the second signal with different wavelengths, frequencies of the pulse signals (that is, the signals with motion interference being eliminated) $ppg_{\lambda_a}(t)$ and $ppg_{\lambda_b}(t)$ are the same, that is, they have the same wavelengths, thus, the pulse and other physiological parameters calculated according to the pulse signals (that is, the signals with motion interference being eliminated) $ppg_{\lambda_a}(t)$ and $ppg_{\lambda_b}(t)$ are the same.

[0063] In this embodiment, dimensionality reduction is performed on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference; the first signal and the second signal are mixed through a plurality of preset coefficients respectively, and a plurality of mixed signals corresponding to the plurality of preset coefficients are calculated; a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal is calculated accordingly; then a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients are obtained; so that a signal with motion interference being eliminated from the measurement signal to be processed is calculated according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient. That is, interference in motion is eliminated by using the correlation between motion interference and the multi-dimensional acceleration signal, and detection of signals with motion interference being eliminated is suitable in various motion states, meanwhile computational complexity is less, and implementation is easily be performed on the wearable device.

[0064] A second embodiment of the present disclosure provides a method for eliminating motion interference. This embodiment is a refinement of the first embodiment, and the main refinement lies in: detailed introduction is provided to step **101** of performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference.

[0065] A specific flow of the method for eliminating motion interference in this embodiment is shown in FIG. **2**.

[0066] Herein, steps **202** to **205** are roughly the same as steps **102** to **105**, no more details are repeated here. The main difference lies in: in this embodiment, step **201** of performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference comprises the following sub-steps in details:

[0067] Sub-step **2011**, a covariance matrix of a multi-dimensional acceleration matrix formed by the multi-dimensional acceleration signal is calculated.

[0068] Specifically, a multi-dimensional acceleration signal usually is a three-axis acceleration signal G(t). The three-axis acceleration signal G(t) indicates the acceleration signals in different directions in a three-dimensional space. The three-dimensional data G(t)=[x(t), y(t), z(t)], x(t), y(t), z(t) indicate the accelerations in three directions, respectively, thus the covariance matrix C of the three-dimensional data G(t) may be calculated as:

$$C = \begin{bmatrix} \mathrm{cov}(x, x) & \mathrm{cov}(x, y) & \mathrm{cov}(x, z) \\ \mathrm{cov}(y, x) & \mathrm{cov}(y, y) & \mathrm{cov}(y, z) \\ \mathrm{cov}(z, x) & \mathrm{cov}(z, y) & \mathrm{cov}(z, z) \end{bmatrix}$$

[0069] Herein, coy represents calculating a covariance.

[0070] Sub-step **2012**, a plurality of eigenvalues and a plurality of eigenvectors of the covariance matrix are calculated.

[0071] Specifically, the eigenvalues of the covariance matrix C are λ_i, and the eigenvectors corresponding to the eigenvalues λ_i are v_i, herein i=1, 2, 3; thus, the following formula is satisfied:

$$Cv_i = \lambda_i v_i$$

[0072] Accordingly, the eigenvalues λ_i and the eigenvectors v_i corresponding thereto can be obtained, that is, the plurality of eigenvalues correspond to the plurality of eigenvectors respectively.

[0073] Sub-step **2013**, an eigenvector that includes a preset information weight is identified from the plurality of eigenvectors according to the plurality of eigenvalues.

[0074] Specifically, the plurality of eigenvalues λ_i are sorted form maximum to minimum, and sequences of the eigenvectors v_i corresponding to the eigenvalues λ_i are adjusted accordingly, the adjusted eigenvalues are represented by λ_I, and the corresponding eigenvectors are represented by v_I; herein I=1, 2, 3.

[0075] The preset information weight represents a percentage of each eigenvector in all eigenvectors, expressed as p %;

[0076] When

$$\frac{\sum_{i=1}^{i=I-1} \lambda_I}{\sum_{i=1}^{i=3} \lambda_I} < p\%, \text{ and } \frac{\sum_{i=1}^{i=I} \lambda_I}{\sum_{i=1}^{i=3} \lambda_I} \geq p\%,$$

it indicates that the eigenvector v_I corresponding to the eigenvalues λ_I includes a preset information weight; herein I=1, 2, 3.

[0077] Accordingly, an eigenvector $V=[v_1, \ldots v_I]$ that includes a preset information weight can be identified from the plurality of eigenvectors.

[0078] Sub-step **2014**, the eigenvector is multiplied with the multi-dimensional acceleration signal, so as to obtain the one-dimensional acceleration signal.

[0079] Specifically, the eigenvector V that includes a preset information weight is multiplied with the three-axis acceleration signal G(t) (that is, the multi-dimensional acceleration signal), to obtain the dimensionality-reduced three-axis acceleration signal G'(t):

$$G'(t)=G(t)V$$

[0080] Herein, G'(t) represents the dimensionality-reduced three-axis acceleration signal.

[0081] The dimensionality-reduced three-axis acceleration signal G'(t) is a T*I-dimensional matrix, I=1, 2, 3, and it may be further represented as:

$$G'(t)=[g_1(t), \ldots g_I(t)]$$

[0082] Accordingly, the one-dimensional acceleration signal Acc(t) can be obtained,

$$Acc(t)=\sum_{i=1}^{i=I} g_i(t)$$

[0083] In comparison to the first embodiment, this embodiment provides a specific mode of implementing dimensionality reduction processing on the multi-dimensional acceleration signal.

[0084] A third embodiment of the present disclosure provides an apparatus for eliminating motion interference, which is applied to the method for eliminating motion interference in any one of the first embodiment and the second embodiment. In this embodiment, as shown in FIG. **5**, the apparatus for eliminating motion interference includes a dimensionality reduction module **1**, a first calculation module **2**, a second calculation module **3**, an identification module **4**, and a third calculation module **5**.

[0085] The dimensionality reduction module **1** is configured to perform dimensionality reduction on a multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference.

[0086] The first calculation module **2** is configured to mix a first signal and a second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients.

[0087] The second calculation module **3** is configured to calculate a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal.

[0088] The identification module **4** is configured to obtain a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients.

[0089] The third calculation module **5** is configured to calculate a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.

[0090] In this embodiment, dimensionality reduction is performed on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference; the first signal and the second signal are mixed through a plurality of preset coefficients respectively, and a plurality of mixed signals corresponding to the plurality of preset coefficients are calculated; a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal is calculated accordingly; then a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients are obtained; so that a signal with motion interference being eliminated from the measurement signal to be processed is calculated according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient. That is, interference in motion is eliminated by using the correlation between motion interference and the multi-dimensional acceleration signal, and detection of signals with motion interference being eliminated is suitable in various motion states, meanwhile computational complexity is less, and implementation is easily be performed on the wearable device.

[0091] A fourth embodiment of the present disclosure provides a wearable device, which is any one of a watch, a ring, a headband and an earphone. In this embodiment, as shown in FIG. **6**, the wearable device comprises a first sensor **6**, a second sensor **7**, a memory **8**, and a processor **9**.

[0092] In this embodiment, the processor **9** is connected to the first sensor **6** and the second sensor **7**.

[0093] The first sensor **6** is configured to acquire a multi-dimensional acceleration signal of the wearable device.

[0094] The second sensor **7** is configured to obtain a measurement signal to be processed; and the measurement signal to be processed includes a first signal and a second signal having different wavelengths. Herein the second sensor **7** may be a heart rate sensor.

[0095] The memory **8** is configured to store a plurality of instructions.

[0096] The processor **9** is configured to load the plurality of instructions and perform the function of the apparatus for eliminating motion interference in the third embodiment.

[0097] This embodiment provides a wearable device capable of eliminating motion interference.

[0098] It is understandable to those ordinary skilled in the art that the above embodiments are specific examples in the present disclosure, and in practical applications, various changes can be made in form and in detail without deviating from the spirit and scope of the present disclosure.

1. A method for eliminating motion interference, which is applied to a wearable device capable of acquiring a multi-dimensional acceleration signal and a measurement signal to be processed of the wearable device, and the measurement signal to be processed includes a first signal and a second signal having different wavelengths; the method comprising:

performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference;

mixing the first signal and the second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients;

calculating a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal;

obtaining a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients; and

calculating a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.

2. The method according to claim **1**, wherein the mixed signal $D_{r_i}(t)$ is:

$$D_{r_i}(t)=S_{\lambda_a}(t)-r_i\cdot S_{\lambda_b},\ i=1,2,3,\ldots;$$

$S_{\lambda_a}(t)$ represents the first signal; S_{λ_b} represents the second signal; r_i represents an i-th preset coefficient, and a traversal range of r_i is $[r_{slow}, r_{high}]$, wherein r_{slow}, r_{high} are a lower limit and an upper limit of the traversal range, respectively.

3. The method according to claim **2**, wherein the signal with motion interference being eliminated is expressed as:

$$ppg_{\lambda_a}(t)=\frac{r_a(S_{\lambda_a}(t)-r_v\cdot S_{\lambda_b})}{(r_a-r_v)},\text{ or }ppg_{\lambda_b}(t)=\frac{S_{\lambda_a}(t)-r_v\cdot S_{\lambda_b}}{(r_a-r_v)};$$

wherein $g_{\lambda_a}(t)=r_a\cdot ppg_{\lambda_b}(t)$, and $ppg_{\lambda_a}(t)$ and $ppg_{\lambda_b}(t)$ both represent the signal with motion interference being eliminated; r_a represents the preset coefficient corresponding to the maximum correlation coefficient, r_v represents the preset coefficient corresponding to the minimum correlation coefficient.

4. The method according to claim **1**, wherein the correlation coefficient comprises a Pearson correlation coefficient.

5. The method according to claim **1**, wherein performing dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference specifically comprises:

calculating a covariance matrix of a multi-dimensional acceleration matrix formed by the multi-dimensional acceleration signal;

calculating a plurality of eigenvalues and a plurality of eigenvectors of the covariance matrix; the plurality of eigenvalues corresponding to the plurality of eigenvectors respectively;

identifying, according to the plurality of eigenvalues, an eigenvector that includes a preset information weight from the plurality of eigenvectors; and

multiplying the eigenvector with the multi-dimensional acceleration signal to obtain the one-dimensional acceleration signal.

6. The method according to claim **1**, wherein the value of the plurality of preset coefficients is increased in an arithmetic progression manner.

7. The method according to claim **1**, wherein the signal with motion interference being eliminated comprises a PPG signal.

8. An apparatus for eliminating motion interference, which is applied to a wearable device capable of acquiring a multi-dimensional acceleration signal and a measurement signal to be processed of the wearable device, and the measurement signal to be processed includes a first signal and a second signal having different wavelengths, the apparatus comprising:

a dimensionality reduction module configured to perform dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference;

a first calculation module configured to mix the first signal and the second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients;

a second calculation module configured to calculate a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal;

an identification module configured to obtain a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients; and

a third calculation module configured to calculate a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.

9. A wearable device comprising a first sensor, a second sensor, a memory, and a processor connected to the first sensor and the second sensor;

wherein the first sensor is configured to acquire a multi-dimensional acceleration signal of the wearable device;

the second sensor is configured to obtain a measurement signal to be processed; and the measurement signal to be processed includes a first signal and a second signal having different wavelengths;

the memory is configured to store a plurality of instructions; and

the processor is configured to load the plurality of instructions and perform the function of an apparatus for eliminating motion interference, the apparatus comprises:

a dimensionality reduction module configured to perform dimensionality reduction on the multi-dimensional acceleration signal to obtain a one-dimensional acceleration signal that represents motion interference;

a first calculation module configured to mix the first signal and the second signal through a plurality of preset coefficients respectively, so as to calculate a plurality of mixed signals corresponding to the plurality of preset coefficients;

a second calculation module configured to calculate a correlation coefficient between each of the mixed signals and the one-dimensional acceleration signal;

an identification module configured to obtain a preset coefficient corresponding to the maximum correlation coefficient among the correlation coefficients and a preset coefficient corresponding to the minimum correlation coefficient among the correlation coefficients; and

a third calculation module configured to calculate a signal with motion interference being eliminated from the measurement signal to be processed, according to the first signal, the second signal, the preset coefficient corresponding to the maximum correlation coefficient, and the preset coefficient corresponding to the minimum correlation coefficient.

10. The wearable device according claim **9**, wherein the second sensor comprises a heart rate sensor.

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专利名称(译)	用于消除运动干扰的可穿戴设备，方法和设备		
公开(公告)号	US20180338728A1	公开(公告)日	2018-11-29
申请号	US16/049075	申请日	2017-05-10
[标]申请(专利权)人(译)	深圳市汇顶科技股份有限公司		
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IPC分类号	A61B5/00 A61B5/024		
CPC分类号	A61B5/721 A61B5/02416 A61B5/02438 A61B5/7225 A61B5/7246 A61B2562/0219		
外部链接	Espacenet USPTO		

摘要(译)

一种消除运动干扰的方法，包括：对多维加速度信号进行降维，得到表示运动干扰的一维加速度信号;分别通过多个预设系数r i 混合第一信号和第二信号，以计算与多个预设系数对应的多个混合信号;计算每个混合信号和一维加速度信号之间的相关系数;获得相关系数中对应于最大相关系数的预设系数和相关系数中与最小相关系数对应的预设系数;根据第一信号，第二信号，与最大相关系数对应的预设系数，以及与最小相关系数对应的预设系数，计算从待处理测量信号中消除运动干扰的信号。