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(54) **HEART RATE MONITOR**

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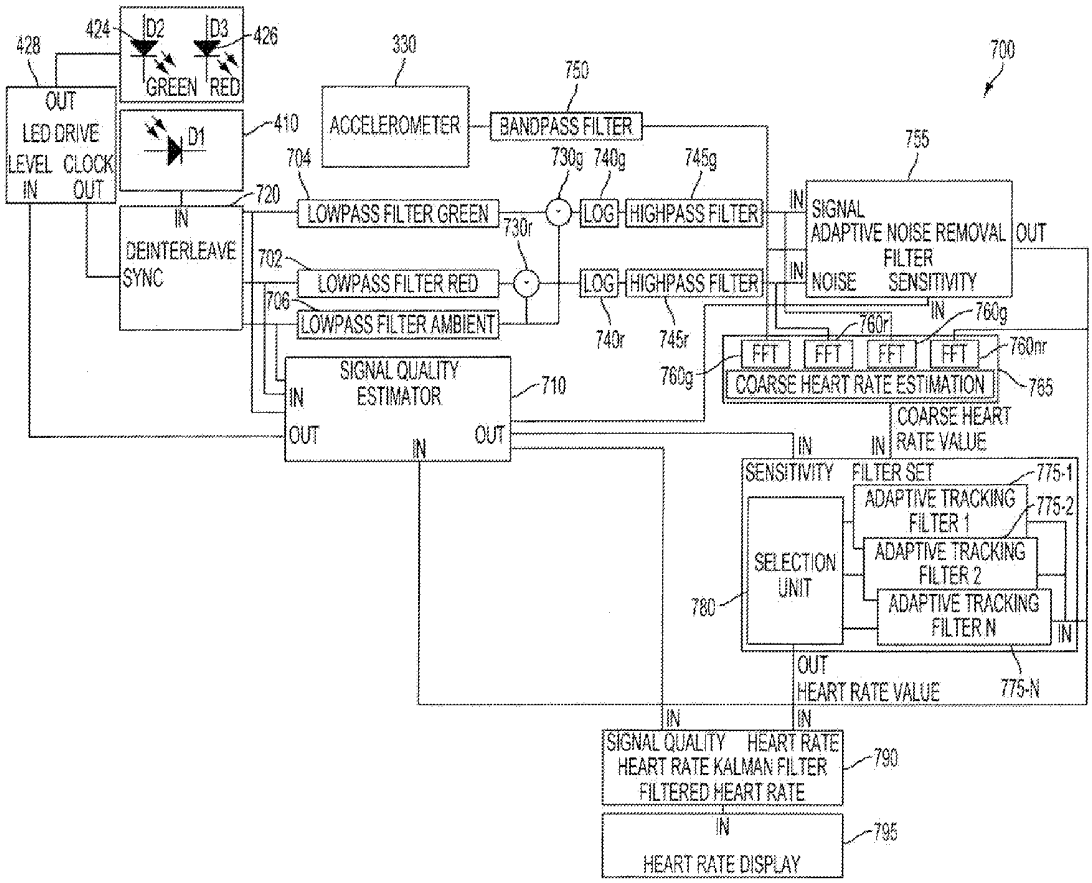
USPC **600/301**; 600/508

(57) **ABSTRACT**

A signal processing apparatus for determining a heart rate includes a plurality of sensors configured to detect changes in blood properties in a user's skin and a heart rate Kalman filter configured to compute a heart rate on the basis of signals obtained from the plurality of sensors. A method of computing a heart rate using the apparatus includes detecting changes in blood properties with a plurality of sensors, and computing with a heart rate Kalman filter the heart rate on the basis of signals obtained from the plurality of sensors.



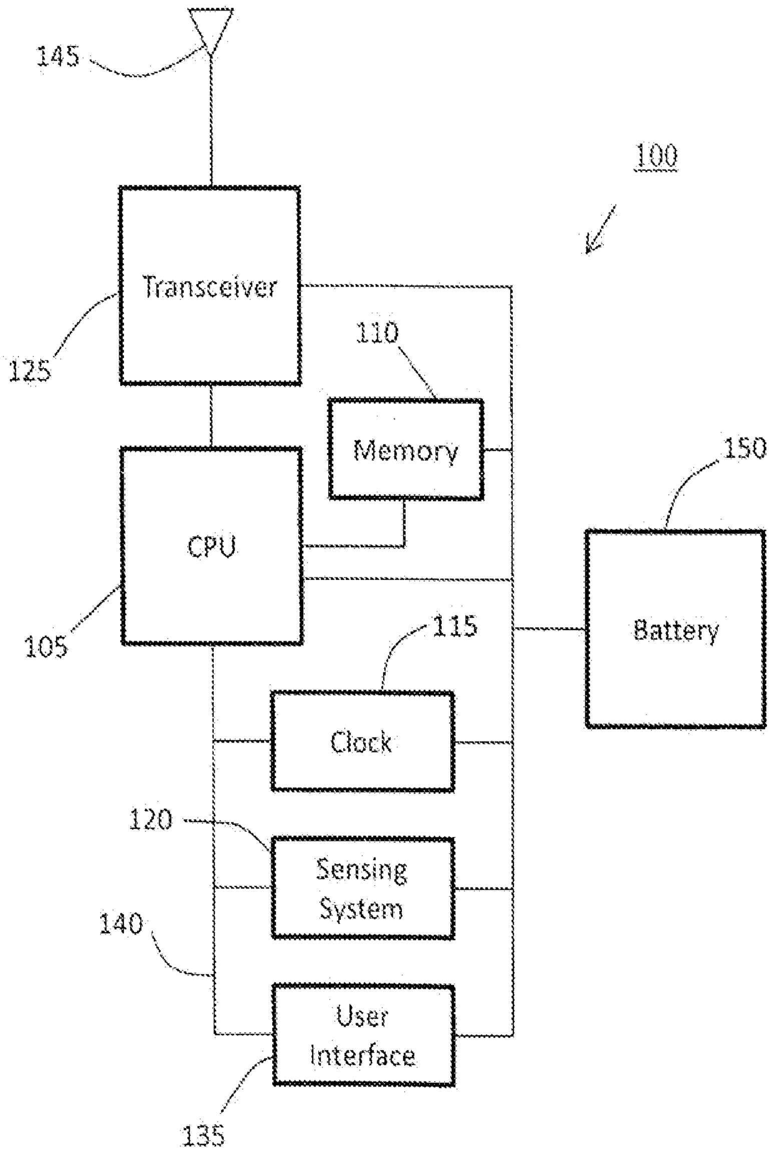

145
100
Transceiver
125
110
Memory
150
CPU
105
115
Battery
Clock
120
Sensing System
140
User Interface
135

FIG. 1

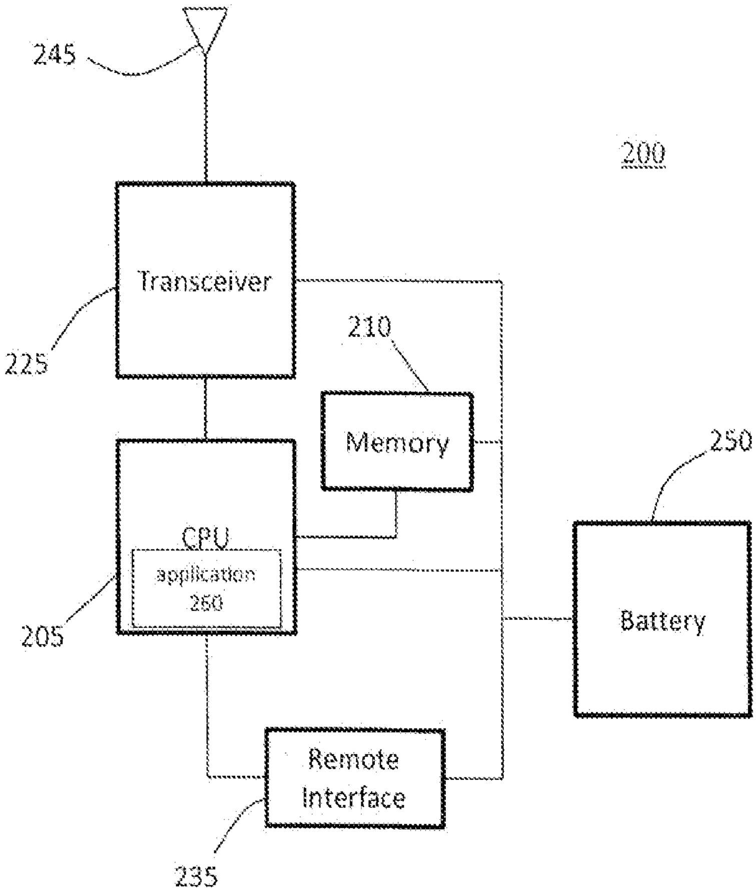

245
200
Transceiver
225
210
Memory
250
CPU
application
260
Battery
205
Remote
Interface
235

FIG. 2

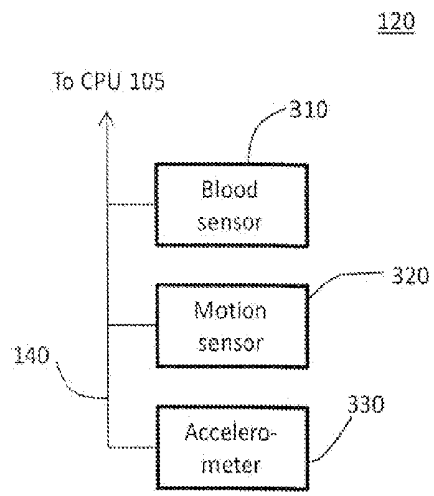


FIG. 3

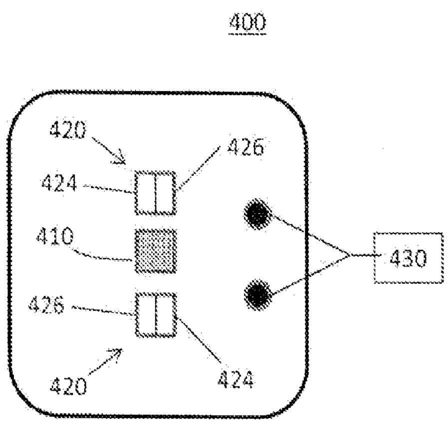


FIG. 4

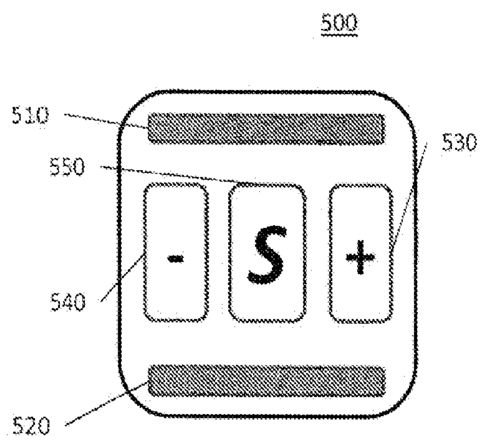


FIG. 5

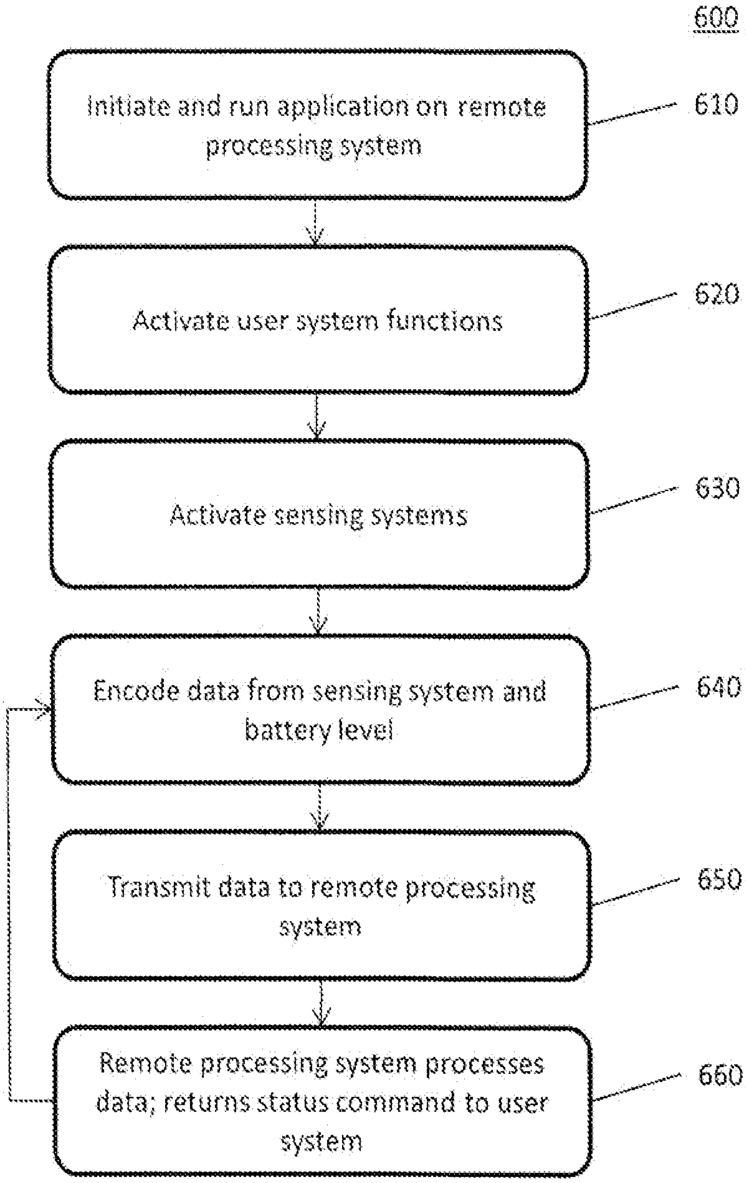

600
Initiate and run application on remote processing system
610
Activate user system functions
620
Activate sensing systems
630
Encode data from sensing system and battery level
640
Transmit data to remote processing system
650
Remote processing system processes data; returns status command to user system
660

FIG. 6

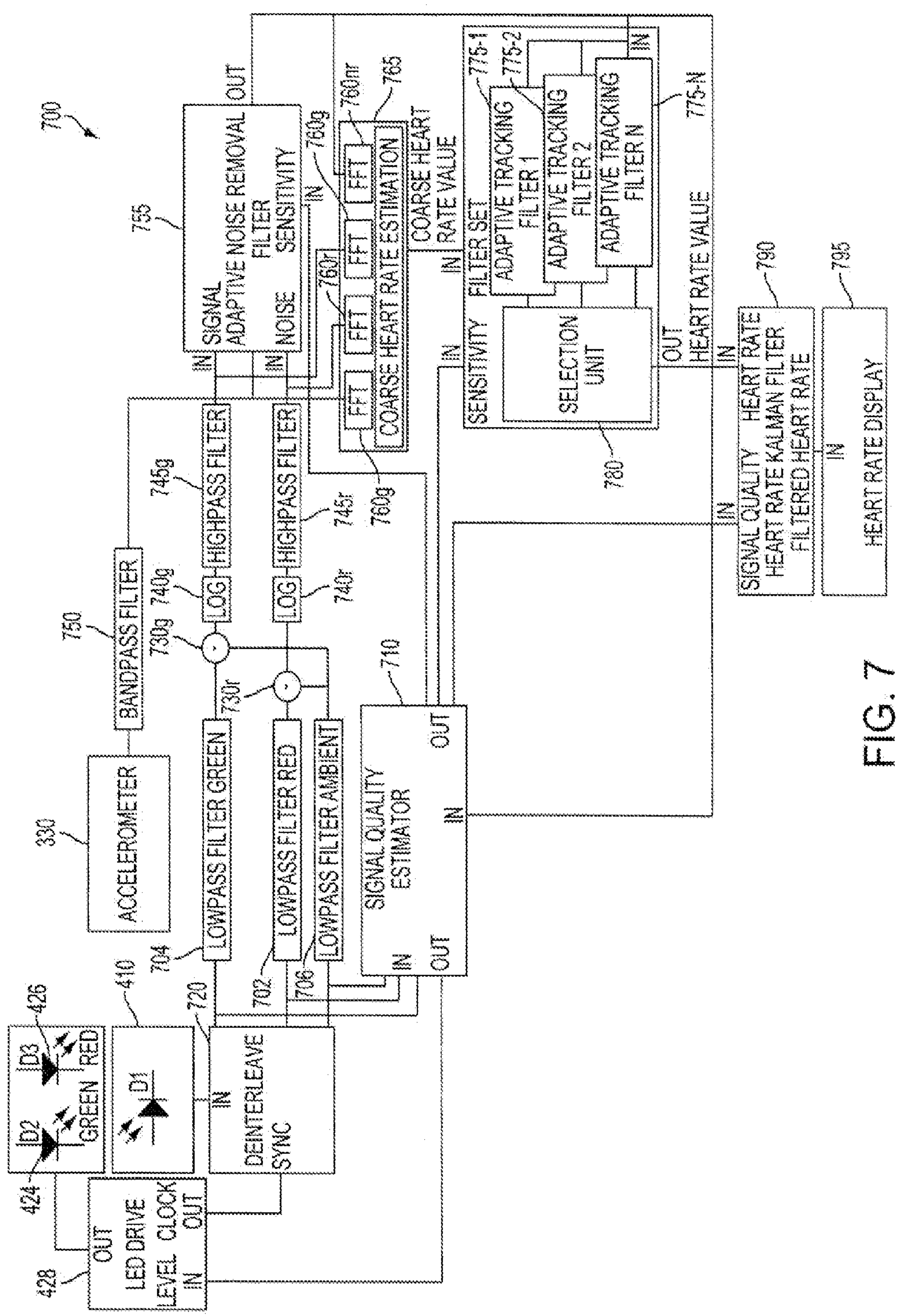

700
ACCELEROMETER
330
BANDPASS FILTER
750
LOWPASS FILTER GREEN
704
LOWPASS FILTER RED
702
LOWPASS FILTER AMBIENT
706
730g
730r
LOG
740g
LOG
740r
HIGHPASS FILTER
745g
HIGHPASS FILTER
745r
SIGNAL QUALITY ESTIMATOR
IN
OUT
IN
OUT
710
SIGNAL
ADAPTIVE NOISE REMOVAL FILTER
SENSITIVITY
NOISE
IN
IN
IN
OUT
755
FFT
FFT
FFT
FFT
760g
760r
760g
760nr
COARSE HEART RATE ESTIMATION
COARSE HEART RATE VALUE
765
IN
FILTER SET
ADAPTIVE TRACKING FILTER 1
ADAPTIVE TRACKING FILTER 2
ADAPTIVE TRACKING FILTER N
775-1
775-2
775-N
IN
SENSITIVITY
IN
SELECTION UNIT
780
OUT
HEART RATE VALUE
SIGNAL QUALITY
HEART RATE
HEART RATE KALMAN FILTER
FILTERED HEART RATE
IN
IN
790
HEART RATE DISPLAY
IN
795
D2
GREEN
D3
RED
424
426
D1
410
IN
DEINTERLEAVE
SYNC
720
OUT
LED DRIVE
LEVEL IN
CLOCK OUT
428

FIG. 7

HEART RATE MONITOR

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Application No. 61/583,532, entitled "HEART RATE MONITOR", filed on Jan. 5, 2012, which is expressly incorporated by reference herein.

BACKGROUND

[0002] 1. Field

[0003] The present disclosure relates generally to health monitoring systems and methods, and more particularly to monitoring heart rate under various exercising conditions.

[0004] 2. Background

[0005] A pulse is the rate at which the heart beats, measured in beats per minute (bpm). Basil pulse is the pulse measured at rest. The pulse measured during physical activity is generally higher than the basil pulse, and the rise in pulse during physical exertion is a measure of the efficiency of the heart in response to demand for blood supply.

[0006] A person engaging in physical activity often wishes to monitor the heart rate via pulse measurement to monitor or regulate the degree of exertion, depending on whether the exercise is intended for fitness maintenance, weight maintenance or reduction, cardiovascular training, or the like.

[0007] A standard method of measuring pulse manually is to apply gentle pressure to the skin where an artery is close to the surface, e.g., at the wrist, neck, temple area, groin, behind the knee, or top of the foot. However, measuring pulse this way during exercise is usually not feasible or accurate. Therefore, numerous devices provide pulse measurement using a variety of sensors attached to the body in some fashion. Monitors may be attached to the wrist, chest, ankle and upper arm and are preferably placed over a near-skin artery. Measuring a pulse may involve skin contact electrodes.

[0008] A wireless heart rate monitor conventionally consists of a chest strap sensor-transmitter and a wristwatch-type receiver. The chest strap sensor is worn around the chest during exercise. It has two electrodes, which are in constant contact with the skin, to detect electrical activities coming from the heart. Once the chest strap sensor-transmitter has picked up the heart signals, the information is wirelessly and continuously transmitted to the wristwatch. The number of heart beats per minute is then calculated and the value displayed on the wristwatch.

[0009] The wireless heart rate monitor can be further subdivided into digital and analog varieties, depending on the wireless technology the chest strap sensor-transmitter uses to transmit information to the wristwatch. The wireless heart rate monitor with analog chest strap sensor-transmitter is a popular type of heart rate monitor. There is, however, a possibility of signal interference (cross-talk) if other analogue heart rate monitor users are exercising nearby. If that happens, the wristwatch may not accurately display the wearer's heart rate.

[0010] One type of analog chest strap sensor-transmitter transmits coded analog wireless signals. Coded analog transmission tend to reduce (but may not eliminate entirely) the degree of cross talk while simultaneously preserving the ability to interface with remote heart rate monitor equipment.

[0011] A digital chest strap sensor-transmitter eliminates the problem of cross-talk when other heart rate monitor users are close by. By its very nature, the digital chest strap sensor transmitter is engineered to communicate only with its own receiver (e.g., wristwatch).

[0012] Strapless heart rate monitors are typically wristwatch-type devices that may be preferred by users engaged in physical training because of convenience and combined time keeping features. In some cases the user is required to press a conductive contact on the face of the device to activate a pulse measurement sequence based on electrical sensing at the finger tip. However, this may require the user to interrupt physical activity, and does not always provide an "in-process" measurement and, therefore, may not be an accurate determination of heart rate during continuous exertion.

[0013] There are 2 sub-types of strapless heart rate monitors. The first type measures heart rate by detecting electrical impulses. Some wristwatch-type devices have electrodes on the device's underside in direct contact with the skin. These monitors are accurate (often called ECG or EKG accurate) but may be more costly. The second type of monitor measures heart rate by using optical sensors to detect pulses going through small blood vessels near the skin. These monitors based on optical sensors are less accurate than ECG type monitors but may be relatively less expensive.

[0014] Optical sensing, related to pulse oximetry, may also be used. The arrangement of heart rate sensor and display may be similar to that described above. The method of measurement is based on a backscattered intensity of light that illuminates the skin's surface and is sensitive to the change of red blood cell density beneath the skin during the pulse cycle. Motion of the sensor may introduce noise that corrupts the signal. Additionally, body motion may introduce noise in the signal detected from venous blood flow.

[0015] Compensation and removal of noise due to motion of an optical pulse sensor relative to the skin during exercise imposes additional hardware and signal processing burdens on the pulse monitoring device. An apparatus and method of signal processing that compensates and removes noise corrupting the actual pulse, while providing a user friendly apparatus (such as not requiring a chest or ankle sensor, or placement over an artery) would be beneficial and more convenient for physical training.

SUMMARY

[0016] A heart rate monitor is disclosed comprising two main components. A first wristwatch type device measures three categories of sensor signal, digitizes the signals, correlates them to a generated clock signal, encodes them for transmission, and transmits the encoded data to a second device. An exemplary method of transmission may be Bluetooth, although other protocols may be employed, including hard wired signal transmission. The second device may be, for example, a smart phone (e.g., an iPhone™ or equivalent device equipped to transceive wireless data) or other device, running an application to decode the transmitted data, process the signals to obtain a noise compensated heart rate, store data, and transmit a return signal to the first device on the basis of the processed signals. Additional data may be collected by the first device, such as battery life, pulse signal strength, and the like, which may also be transmitted to the second device. In turn, the second device may return signals to the first device to alert the user with status indicator, such as low battery, pulse rate too high/low, etc. More detailed information may be provided on the display of the second device.

[0017] In addition, audio data may be transmitted from the second device to audio earphones either coupled to the first device, or by further receiving a wireless signal such as via Bluetooth™.

[0018] In an aspect of the disclosure a signal processing apparatus for determining a heart rate includes a plurality of sensors configured to detect changes in blood properties in a user's skin and a heart rate Kalman filter configured to compute a heart rate on the basis of signals obtained from the plurality of sensors.

[0019] In an aspect of the disclosure a method of computing a heart rate includes detecting changes in blood properties with a plurality of sensors, and computing with a heart rate Kalman filter the heart rate on the basis of signals obtained from the plurality of sensors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. **1** is a conceptual illustration of a heart rate sensing user system in an embodiment.

[0021] FIG. **2** is a conceptual illustration of a remote processing system for communicating with and controlling the heart rate sensing user system, according to an embodiment.

[0022] FIG. **3** is a conceptual illustration of a sensing system of the heart rate sensing user system of FIG. **1**.

[0023] FIG. **4** illustrates a conceptual view of the underside of the heart rate sensing user system, according to an embodiment.

[0024] FIG. **5** illustrates a conceptual view of the front face of the heart rate sensing user system, according to an embodiment.

[0025] FIG. **6** illustrates a method of operating a heart rate monitor comprising the heart rate sensing user system of FIG. **1** and the remote processing system of FIG. **2**, according to an embodiment.

[0026] FIG. **7** is block diagram of the signal processing system of a heart rate sensing system in an embodiment.

DETAILED DESCRIPTION

[0027] FIG. **1** illustrates a heart rate user system **100**. The user system **100** may be worn on a user's wrist, however other locations besides the wrist, such as the ankle, arm or forearm may be used. The user system **100** includes a user processing CPU **105**, a user memory **110**, a clock signal generator **115**, a sensing system **120**, a user transceiver **125**, and a user interface **135**. The CPU **105** may be coupled to the other indicated components, for example, either directly or via a bus **140**. A user antenna **145** is coupled to the user transceiver **125**. The user antenna **145** may be a wireless connection to a remote processing system (discussed in more detail below), or it may be representative of a direct wired connection to the remote processing system.

[0028] A battery **150** is coupled to the user processor CPU **105**, the user memory **110**, the clock signal generator **115**, the sensing system **120**, the user transceiver **125**, and the user interface **135** to power all functions of the indicated elements.

[0029] FIG. **2** illustrates a remote processing system **200** for receiving and analyzing signals transmitted from the user system **100**. The remote processing system **200** may operate in conjunction with a smart phone, such as the Apple iPhone™, and execute an application program to process the transmitted signals. The remote processing system **200** may alternatively be a console, such as a dedicated piece of instrumentation for communicating and interacting with the user system **100**. The remote console may be used in a hospital, a fitness facility, or the like.

[0030] In an exemplary case, the remote processing system **200** may be a smart phone, such as an iPhone™, executing a heart rate monitoring application **260** on a remote CPU **205**, where the application **260** may be stored in a remote memory **210** coupled to the remote CPU **205**. The remote processing system **200** may also include a remote antenna **245** and a remote transceiver **225**. The remote CPU **205** may execute the application commands and process the signals received from the user system **100**, and generate output signals to the user system **100** via wireless transmission such as Bluetooth™, or the like, or via a hard-wire interface.

[0031] Alternatively, all processing functions may occur on the user system **100**, where all the processing functions of remote processing system **200** may be implemented. Furthermore, the distribution of processing functions between the user system **100** and the remote processing system **200** may be split according to system design decisions and still express aspects of the invention.

[0032] FIG. **3** is a simplified block diagram of the sensing system **120** of the user system. The sensing system **120** includes a blood concentration sensing system **310**, described in more detail below. As the heart pumps blood through the arteries to microscopic blood vessels, the blood concentration varies periodically between a minimum and a maximum concentration, synchronously with a periodic variation in blood pressure. The blood concentration sensing system **310** senses this change in concentration in the blood vessels beneath the skin and transmits the signal level to the CPU **105**. The blood concentration sensing system **310** may also sense small motions of the user system **100** with respect to the user's skin, because the blood concentration sensing system **310** may be sensing information from a different area of blood vessels beneath the user's skin if the user system **100** moves relative to the skin. This component of the sensed signal may be regarded as noise, and may contaminate a true determination of the heart rate.

[0033] Signal noise may be introduced by motion of the sensor on the user's body. Compensation of this signal is enabled by a sensor that is sensitive to motion, but not to blood concentration. The sensing system **120** further includes a motion sensor **320**. The motion sensor functions in a manner analogous to a computer optical mouse, but is relatively insensitive to blood concentration near the surface of the skin. The motion sensor **320** senses changes in the position of the user system **100** with respect to the skin and sends a signal corresponding to that motion to the CPU **105**. However, this signal contains a relatively insubstantial signal due to blood concentration. The signal from the motion sensor **320** and the signal from the blood concentration sensing system **310** may be correlated in time with the signal from the clock generator **115** to provide a compensated signal in which the noise contribution due to motion is substantially reduced. The compensated signal may then be analyzed for a more accurate determination of heart rate.

[0034] The sensing system further includes an accelerometer **330**. The accelerometer **330** may be a chip-set comprising a plurality of sensing elements capable of resolving acceleration along three orthogonal axes. Microelectromechanical system (MEMS) sensors, capacitive sensors, and the like, are well known in the art of acceleration sensing. The accelerometer **330** may provide information about the motion of the user system **100** with respect to the user's heart. For example, if the user system **100** is worn on the wrist, and the nature of the exercise requires the wrists and hands to rise above the heart, the consequent elevation may cause a drop in the minimum and maximum (min/max) of the blood pressure at the point of sensing relative to that which may be measured when the user system **100** is as the same level or lower than the heart. This information may be used to qualify or disqualify the blood concentration measurements if the measured min/max values fall outside an acceptable range for determining the heart rate.

[0035] Some judgment may be used in making most effective use of the accelerometer **330**. For example, if the exercise comprises bench presses, where the user's arms and hands are constantly being raised above the chest, placement of the user system at a relatively motion neutral location, such as an ankle or upper calf may yield more accurate readings. The signal measured by the accelerometer **330** will not then indicate a shifting "baseline" for the effect of blood pressure on blood concentration measurements due to altitude change relative to the heart, and more data will qualify.

[0036] FIG. **4** illustrates a conceptual underside view **400** of the user system **100**, showing elements of the blood concentration sensing system **310** and the motion sensor **320**. In the illustration shown in FIG. **4**, a photodetector **410** is positioned between two sets, **420**, of light emitting diodes (LEDs), although other light sources may be contemplated within the scope of the invention. Only one set **420** of LEDs is required, but a plurality of such LEDs can improve the sensitivity and performance of the user system **100**. The photodetector **410** and the LED set **420** are positioned in close proximity, e.g., adjacent, to the user's skin and close to each other. Light emanating from an LED in the set **420** will penetrate to a limited skin depth and a portion of the penetrating light will backscatter and be detected by the photodetector **310**. As will be described below, the photodetector **410** has a spectral sensitivity that spans at least from green to red, or at least spanning the spectral bandwidths of the two LEDs.

[0037] For operation of the blood concentration sensing system **310**, the LED set **420** includes a green LED **424**. Green light is preferentially absorbed by red blood cells in the skin. Therefore, a systolic increase in blood pressure and vascular blood concentration during the course of a pulse may result in a decreased backscattered green light intensity. During the diastolic interval, blood concentration is lower, leading to an increased backscattered green light. The sensed signal level provided by the photodetector **410**, when synchronized with the clock signal generator **115**, may be analyzed under the control of a computer program stored in the user memory **110** and executable on the CPU **105** to determine a periodicity of the minimum/maximum signals, and thus determine a heart rate. Alternatively, signal may be exported to the remote user system **200**, where the remote processing system **200** performs substantially the same functions.

[0038] During exercise, a degree of motion of the user system **100** along the skin may occur. Because this changes the detailed microvascular network illuminated by the green LED **424**, a motion signal, which may be regarded as noise, may be included in the backscattered green light. Therefore, a motion sensor independent of blood concentration is beneficial.

[0039] For operation of the motion sensor **320**, the LED set **420** includes a red LED **426**. Red light backscattered from vascular tissue in the skin is not substantially affected changes in blood concentration, and is not substantially sensitive to the pulsing of blood near the skin surface. However, the red LED **426** and photodetector **410** may function in a manner similar to an optical mouse, which is sensitive to motion relative to a surface, which in the present case happens to be the user's skin. The red LED **426** is used to sense small motion of the sensor with respect to the microvascular structure just beneath the skin. In an embodiment of the implementation of the motion sensor **320**, the photodetector **410** may be a special purpose image processing chip that measures pixel-to-pixel changes in light intensity to compute motion of the user system relative to the user's skin. Such motion is typical during exercise. This may result in a variation in signal levels having a temporal spectrum consistent with the periodicity of physical motion and which corrupts the primary heart rate signal of interest.

[0040] Operation of both the blood concentration sensing system **310** and the motion sensor **320** with a common photodetector **410** is achieved by alternately firing the green LED **424** and the red LED **426** under control of the CPU **105**, synchronized with the clock signal generator **115**. Thus, the photodetector **410** must have sensitivity to spectral bands including both LED colors. The clock signal rate may be high enough, e.g., typically a kilohertz or more, so that the two signals, one for blood concentration and one for and motion, may appear to be quasi-continuous, with enough granularity to extract sufficient detail from each signal. Blood concentration and motion are extracted from the green LED **424** and motion only from the red LED **426**. Additionally, there may be included a time interval between red and green pulses when neither LED is fired, enabling the photodetector to acquire an ambient "background" signal that may include fluorescent lighting and wireless or other circuitry generated signals that constitute noise added to the system user **100** signal in addition to the signal detected by the concentration sensing system **310**, motion sensor **320** and accelerometer **330**.

[0041] One of the functions of the user CPU **105** may further include reading the battery level to the CPU **205** of the remote processing system **200** as transmitted, for example, via Bluetooth™, and returning a command to the user system **100** to display an indication that the battery level is normal or low.

[0042] Another function of the remote CPU **205** may be to determine, on the basis of the received sensor signals, whether the pulse signal peak values are too large (causing saturation) or two weak (causing poor signal-to-noise ratio (SNR)). If the detected pulse is two weak, the remote CPU **205** may provide feedback to the user CPU **105** instructing it increase the intensity of the LEDs by increasing the pulse peak power or pulse width, or reducing the intensity of the LEDs by reducing the pulse peak power or pulse width if the signal is saturating. This is especially valuable because normative values of blood pressure may differ for different people, e.g., different skin pigment and light absorption properties, and may also change significantly as the course of a variable exercise regimen progresses through different levels of activity. For example, when the user is engaged in a sports activity, blood pressure and blood concentration is usually higher, so less light may be required to pick up a signal. Therefore, the pulse driven fluctuation of the green LED light is affected by blood pressure, and the current to the green LED may be controlled to conserve power and prevent signal saturation.

[0043] Alternatively, this function may be performed locally on the user system **100**. In this alternate embodiment, the user CPU **105** may determine, on the basis of the sensor signals output from the photodetector **410**, or the power applied to the LEDs, whether the pulse signal peak values are too large (causing saturation) or two weak (causing poor signal-to-noise ratio (SNR)). If the detected pulse is too weak, the user CPU **205** may increase the pulse peak power or pulse width, or reduce the pulse peak power or pulse width if the signal is saturating.

[0044] As described above, the operation of the blood concentration sensing system **310** and the motion sensor **320** with a common photodetector **410** may be achieved by alternately firing the green LED **424** and the red LED **426** under control of the CPU **105**. In an alternative embodiment of the sensing system, the firing sequence may include a blanking period after the green and red LEDs are fired. In this embodiment, the user CPU **105** will cause the green LED **424** to fire, followed by the red LED **426**, and then followed by a blanking period before the sequence repeats. The remote CPU **205** may then determine, on the basis of the received sensor signal for the blanking period, the effect that sunlight, fluorescent light or stray electronic emissions are having on the measurements. The remote CPU **205** may then compensate the received sensor signals for the green and red LEDs when computing the heart rate of the user, or may provide this information to the user CPU **105** in the form of feedback to allow adjustment of the intensity of the green and red LEDs.

[0045] The user system **100** as shown in the underside view **400**, may also include recharging ports **430** for recharging the user battery **150**.

[0046] An exercise schedule may be created using the remote interface **235** of the remote processing system **200**. The remote interface **235** may be, for example, a touch screen, such as found on an APPLE iPhone™, a smart phone keyboard and screen, and a screen, keyboard and mouse of a computer console. A maximum estimated heart rate may be determined based on various factors, including the user's age. A maximum estimated heart rate may correspond to an extreme level of performance, and different levels of performance may correspond to different ranges spanning a maximum estimated heart rate down to a range corresponding to a resting heart rate, so that a range of heart rates may be established for each range of exercise performance. Typical ranges of performance may correspond to resting, moderate exercise (e.g., walking), up to an extreme range reflecting a maximum recommended level of activity, keeping in mind that such levels are only guidelines, and subject to appropriate modification. Having chosen a level of exercise, the remote processing system **200** CPU **205** may communicate via the transceivers **145** and **245** to the user system CPU **105** to signal when the received sensor signals indicate the heart rate is below, within, or above the selected exercise performance range. In this manner, the user may control and monitor his/her level of activity.

[0047] FIG. **5**, illustrates a conceptual view of the front face **500** of the user system **100**, the user CPU **105**; on the basis of performance range information received from the remote system **200**, the user CPU **105** may control display features on the front face **500**, away from the user's skin, which is readable by the user. In one embodiment, a red light indicator **510** on the display face may indicate that the heart rate is above a prescribed range for a selected exercise performance, and the user should exercise more slowly. Conversely, a green light indicator **520** may indicate that the performance level is below the prescribed range, and the user should exercise harder. At an appropriate level of exercise, neither light may be on, indicating an appropriate level of exercise is obtained. Other combinations of light indicators and colors may be contemplated within the scope of the invention.

[0048] Additional functionality may be included in the user system **100** in conjunction with functionality available in the remote processing system **200**. The remote processing system **200** may also serve as an audio player (MP3, iPod™, etc.) storing a number of music tracks, or accessing a number of radio stations, made available by an appropriate entertainment software application running on the remote processing system **200**. Referring to FIG. **5**, a set of buttons ("+"=volume up/track forward **530**, "–"=volume down/track backward **540**, and "select" S **550**) on the user system **100** front face **500** enable the user to select an audio file or channel and volume. The select button S **550** may provide entertainment selection functions, such as pause, play, etc.

[0049] Additionally, the select button S **550** may also serve as an emergency alert button. Repeated or continuously pressing S **550** may initiate a signal from the user system **100** to the remote processing system **200** to activate an alarm, such as an emergency alert phone message (**911**, private physician, or the like). If the remote processing system **200** is also equipped with GPS, the emergency alert message may also contain the location of the user, and vital statistics, such as the heart rate and/or high or low blood concentration level, which may indicate a high or low blood pressure, together with the identity of the user.

[0050] The remote system **200** may be worn by the user, for example, on a wrist, arm or waist strap, with viewing access easily available. The remote system **200** may therefore provide on its display (not shown) more detailed information, such as heart rate, calories burned, distance run, and the like, as determined by the application.

[0051] FIG. **6** illustrates a method **600** of operating the heart rate monitor comprising the user system **100** and the remote processing system **200**. In block **610**, the user initiates and runs the heart rate monitoring application **260** on the remote processing system **200**. In block **620** the remote processing system **200** communicates with and activates the user system **100** heart monitor functions stored in the user memory **110** executable on the user CPU **105**. The user system CPU **105** turns on operation routines controlling the sensing system **120** comprising the green LED **424**, the red LED **426** and photodetector **410** as well as the accelerometer operation routines in block **630**. The routines control the operation of the LEDs, i.e., the repetition rate, alternating timing of the green and red LEDs, pulse widths of the LED output, and photodetector circuitry. The routines may also control the operation of the accelerometer **330** and associated circuitry. In block **640** the CPU **105** converts the analog signal from the photodetector, the accelerometer and the battery voltage to a digital signal that is then encoded for transmission as a data packet. In block **650**, a signal is transmitted by the user system **100** CPU via the transceivers **225**, **245**, such as a Bluetooth™, and antennas **245**, **345** to the remote processing system **200** including the blood concentration data, motion data accelerometer data, battery voltage, and clock signal. Alternatively, transmission may be via a hard wire link. In block **660**, the remote processing system **200** CPU **205** processes the received data and may transmit various commands back to the user system **100** CPU **105**. These commands include direction to turn on red or green LEDs on the front face of the user system to indicate to the user to exercise faster (green LED), exercise slower (red LED), and maintain the same level of exercise (no front LED lit).

[0052] The method functions continuously by returning, for example, to block **640**, to obtain and encode the next packet of data.

[0053] The battery level may be indicated during charging. For example, when the user system is being charged through the charging ports **430**, the green LED **510** may blink intermittently once for 25% charged, twice for 50% charged, three times for 75% charged, and steady on for 100% charged, or the like.

[0054] All operation conditions and exercise parameters may be visually presented on the user interface of the remote processing device **200**, e.g., the touch screen of an iPhone™ or computer screen.

[0055] The remote processing device **200** display (not shown) may show a variety of data. Exemplary information that may be displayed include a numeric value of the measured (corrected) heart rate, a workout time indicator, a calorie counter, a level of performance indicator, exercise, pause and stop soft keys, and a music function soft key, all accessible using the multifunction key.

[0056] FIG. **7** illustrates a conceptual diagram of an apparatus **700** for controlling sensors, processing data and detecting heart rate accurately. As indicated above, the system **700** includes green LEDs **424**, red LEDs **426**, photodector **410**, and accelerometer **330**. The LEDs are driven by an LED driver **428**. The LED drive levels and timing are provided by a Signal Quality Estimator **710**, described in more detail below. Signals received by the detector **410** (including red pulses, green pulses and "off" pulses) are separated in time according to a clock output of the LED driver **428**, by a signal de-interleaver synched to the LED driver clock, which outputs in separate channels the detected red, green and ambient signals. The detector **410** may be coupled to the signal de-interleaver **720** via a fixed analog amplifier and a voltage level adjustment circuit (not shown) to provide a desired level of detected red and green signal in a satisfactory range for signal processing. However, other means of signal amplification and adjustment may be used and are considered within the scope of the disclosure.

[0057] Each of the red green and ambient signals are separately passed through corresponding lowpass filters **702**, **704**, **706**, respectively, to remove high frequency noise not associated with blood flow rates consistent with the possible ranges of physical activity such as, for example, ac ambient light. The filtered ambient signal is subtracted from the red and green signals to remove ambient artifacts by subtractors **730***r* and **730***g*, respectively.

[0058] The separate red green and ambient signals (before lowpass filtering) are also input to a Signal Quality Estimator **710**, which determines if the red and green detected signals are too weak or saturating. Based on the results, the Signal Quality Estimator **710** provides level control instructions to the LED Driver **428** to adjust the output of the LEDs accordingly.

[0059] Returning to the lowpass filtering section, the ambient adjusted red and green lowpass filtered signals are each separately converted to a logarithm scale output by LOG converters **740***r*, **740***g*, respectively, and passed through corresponding highpass filters **745***r*, **745***g*, respectively. Conversion of the light signals to log scale enables signal normalization to maintain the heart rate AC component of amplitude in the same range. The filtering step removes, at least, any DC offsets and drift caused by skin or sensor-to-skin changes in the signal and any low frequency noise not associated with the frequencies related to heart rate and rhythmic physical motion.

[0060] The accelerometer **330** outputs a signal in response to acceleration due to physical motion. This signal may be a source of noise that is imposed on the red and green signals. The accelerometer signal is passed through a bandpass filter **750** to remove DC offsets and high frequency noise similar to that discussed above for the red and green signals.

[0061] The highpass filtered log scale red and green signals are input to an adaptive noise removal filter **755**. The noise signal is supplied by the bandpass filtered accelerometer signal. The adaptive noise removal filter **755** digitizes the input filtered red, green, and accelerometer signals and self-adjusts its transfer function according to an optimization algorithm driven by an error signal. The output is an adaptively filtered noise removal green light signal, the color sensitive to changes in blood concentration. This output also serves as the error signal. The sensitivity of the adaptive noise removal filter is controlled by the Signal Quality Estimator **710**.

[0062] The filtered red, green, and accelerometer signals (prior to entering the adaptive noise removal filter **755**), and the adaptively filtered noise removal signal are each input into separate Fast Fourier Transform (FFT) processor channels **760***r*, **760***g* and **760***nr* in a coarse heart rate estimator **765**. An output of a coarse heart rate value is an estimate of the actual heart rate, computed by selecting the frequency out of the fit spectrum that is most probably the heart rate, and taking into account the amount of noise on the other channels.

[0063] The coarse heart rate value, in the form of the four FFT spectra is input to a filter set **770** of adaptive tracking filters **775-1** to **775**-N that actively adjust their frequency response to minimize the signal from the adaptive noise removal filter **755**. Initially, all tracking filters are disabled. The accelerometer, red and green FFT spectra are used to initialize the tracking filters using a rough heart rate estimation. The signals from the FFT spectra are used to pick candidates for a possible heart rate using the adaptive tracking filters **775-1** to **775**-N. The adaptive tracking filters **775-1** to **775**-N actively adjust the weight of how much of the accelerometer FFT spectrum to subtract from the red and green spectra on the basis of the filtered red FFT, filtered green FFT, filtered accelerometer FFT and the adaptively filtered noise removal signal FFT. The fundamental frequency output of each of the adaptive tracking filter is heart rate value determined on the basis of the optimization algorithm of each of the adaptive tracking filters. If there is no noise, there will be only one frequency to track, and only one of the adaptive tracking filters **775-1** to **775**-N will be initialized to track the frequency. If the signal is noisy, there may be multiple frequencies as candidates for the heart rate signal. If there is no tracking filter already tracking a frequency in the FFT spectrum, then a disabled adaptive filter will be initialized to track that signal. If all adaptive filters are already tracking other frequencies, the one with the lowest signal quality may be reset to track the new frequency. As the signal from the adaptive noise removal filter **755** may still contain residual noise the adaptive tracking filters may lose their tracking.

[0064] The output from the Signal Quality Estimator **710** is used to disable filters that lost their tracking. A selection unit **780** selects which adaptive tracking filter output has the best quality to provide as the heart rate value on the basis of the output from the Signal Quality Estimator **710**.

[0065] The heart rate value output from the selection unit **780** of the filter set **770** and the error signal from the Signal Quality Estimator **710** may be input to a Kalman filtering unit **790** to provide a filtered heart rate. The filtered heart rate may then be output, for example, to a display **795** for a user to read.

[0066] The distribution of processing functions between a user system and a remote system may vary according to design and functional requirements. For example, the user system may include only the LEDs, LED driver, de-interleaver and accelerometer, where the acquired analog signals are digitized and transmitted to a remote system for processing and determination of the filtered heart rate. The filtered heart rate may then be transmitted back to the user system for display to the user. At the other extreme, all processing functions may be executed on the user system, and the filtered heart rate displayed to the user. Data may be temporarily stored on the user system and then transmitted (periodically or on demand) for download to a remote system for archiving or further processing. Alternatively, an intermediate level of signal processing may be performed on the user system and the balance performed on the remote system.

[0067] It is to be understood that such a system may be applied beyond the example given of a heart rate monitor, such as, for example, gaming, social networking, emergency alarming, etc.

[0068] It is to be understood that the specific order or hierarchy of steps in the methods disclosed is an illustration of exemplary processes. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the methods may be rearranged. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented unless specifically recited therein.

[0069] The claims are not intended to be limited to the various aspects of this disclosure, but are to be accorded the full scope consistent with the language of the claims. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited using the phrase "step for."

What is claimed is:

1. A signal processing apparatus to determine a heart rate comprising:

a plurality of sensors configured to detect changes in blood properties in a user's skin; and

a heart rate Kalman filter configured to compute a heart rate on the basis of signals obtained from the plurality of sensors;

a communication link between the sensors and the heart rate Kalman filter to transmit the signals; and

a housing to contain at least the plurality of sensors to maintain them in proximity to the user's skin.

2. The apparatus of claim **1**, wherein the plurality of sensors comprise:

an optical sensor comprising a plurality of light emitting devices and at least one photodetector, wherein the photodetector is configured to detect optical signals from the light emitting devices and ambient light; and

an accelerometer configured to detect motion adding a noise signal to the optical signals.

3. The apparatus of claim **2**, further comprising a driver to control a periodic emission level and timing of light output from the light emitting devices and a period of off state of the light emitting devices.

4. The apparatus of claim **3**, further comprising a signal quality estimator to determine the emission level of the light emitting devices on the basis of the detected optical signals.

5. The apparatus of claim **4**, wherein a one or more of a plurality of filters is configured to filter noise outside specified frequency bands from the optical signals, and wherein filtered noise from an ambient signal when the light emitting devices are off is subtracted from the optical signals when the light emitting devices are on.

6. The apparatus of claim **5**, further comprising an adaptive noise removal filter configured to remove from the noise filtered optical signals noise on the basis of the accelerometer noise signal and provide a noise removal filtered signal.

7. The apparatus of claim **6**, further comprising a spectrum analyzer to provide spectra of the optical signals, accelerometer noise signal, and noise removal filtered signal, wherein the spectra are used to provide a coarse rate heart estimation.

8. The apparatus of claim **7**, further comprising a plurality of adaptive tracking filters to determine a heart rate value on the basis of the coarse heart rate estimation, the error signal from the signal quality estimator and the noise removal filtered signal.

9. The apparatus of claim **8**, wherein the heart rate Kalman filter is configured to compute a heart rate on the basis of an error signal from the signal quality estimator and the heart rate value from the plurality of adaptive tracking filters.

10. A signal processing apparatus comprising:

means for generating a plurality of sensor signals corresponding to changes in blood properties; and

means for filtering with a Kalman filter and one or more of a plurality of other filters to compute a heart rate on the basis of the sensor signals.

11. The apparatus of claim **10**, wherein the sensor means comprises:

means for optical sensing comprising a plurality of light emitting devices and one or more photodetectors, wherein the photodetector is configured to detect optical signals from the light emitting devices and ambient light;

means for acceleration sensing configured to detect motion adding a noise signal to the optical signals;

means for processing the optical and noise signals to compute a heart rate; and

means for outputting from the from the processor means processor a one or more status commands on the basis of the computed heart rate.

12. The apparatus of claim **11**, further comprising a controlling means to control a periodic emission level and timing of light output from the light emitting devices and a period of off state of the light emitting devices.

13. The apparatus of claim **12**, further comprising a signal quality estimation means to determine a drive level on the basis of the detected optical signals.

14. The apparatus of claim **12**, wherein one or more of the filters is configured to filter noise outside specified frequency bands from the optical signals, comprising subtracting filtered noise from an ambient signal when the light emitting devices are off from the optical signals when the light emitting devices are on.

15. The apparatus of claim **14**, further comprising adaptive noise filtering means to remove noise on the basis of the acceleration sensing means noise signal from the noise filtered optical signals and provide a signal filtered to remove motion noise.

16. The apparatus of claim **15**, further comprising:

a spectral analysis means to provide spectra of the optical signals, accelerometer noise signal, and noise removal filtered; and

an estimation means for determining a coarse rate heart on the basis of the spectra.

17. The apparatus of claim **16**, further comprising a plurality of adaptive tracking filters to determine a heart rate value on the basis of the coarse heart rate estimation, the error signal from the signal quality estimation means and the noise removal filtered signal.

18. The apparatus of claim **17**, further comprising a heart rate Kalman filter to compute the heart rate on the basis of an error signal from the signal quality estimation means and the heart rate value from the plurality of adaptive tracking filters.

19. The apparatus of claim **18**, further comprising means for removing an optical signal noise at least due at least to the ambient light and the motion noise signal to compute a heart rate.

20. A method of computing a user's heart rate, comprising:

detecting changes in blood properties with a plurality of sensors; and

computing with at least one of a heart rate Kalman filter and one or more of a plurality of other filters a heart rate on the basis of signals obtained from the plurality of sensors.

21. The method of claim **20**, wherein the plurality of sensors comprise an optical sensor comprising a plurality of light emitting devices and one or more photodetectors, the method further comprising;

detecting with the photodetectors optical signals from the light emitting devices and ambient light;

detecting with an accelerometer a motion that adds a noise signal to the optical signals;

providing the optical and noise signals to a processor for computing the heart rate; and

outputting from the processor a one or more status commands on the basis of the computed heart rate.

22. The method of claim **21**, further comprising controlling with a driver a periodic emission level and timing of light output from the light emitting devices and a period of off state of the light emitting devices.

23. The method of claim **22**, further comprising determining with a signal quality estimator a drive level of the light emitting devices on the basis of the detected optical signals.

24. The method of claim **23**, wherein a one or more of the filters is configured to filter noise outside specified frequency bands from the optical signals, comprising subtracting filtered noise from an ambient signal when the light emitting devices are off from the optical signals when the light emitting devices are on.

25. The method of claim **24** further comprising removing, with an adaptive noise removal filter, noise on the basis of the accelerometer noise signal from the noise filtered optical signals and provide a noise removal filtered signal.

26. The method of claim **25**, further comprising:

providing, with a spectrum analyzer, spectra of the optical signals, accelerometer noise signal, and noise removal filtered signal; and

determining a coarse rate heart estimation on the basis of the spectra.

27. The method of claim **26**, further comprising determining, with a plurality of adaptive tracking filters, a heart rate value on the basis of the coarse heart rate estimation, the error signal from the signal quality estimator and the noise removal filtered signal.

28. The method of claim **27**, further comprising computing a heart rate with the heart rate Kalman filter to compute the heart rate on the basis of an error signal from the signal quality estimator and the heart rate value from the plurality of adaptive tracking filters.

29. A computer readable media including program instructions which when executed by a processor cause the processor to perform the method comprising:

detecting changes in blood properties with a plurality of sensors; and

computing with at least one of a heart rate Kalman filter and one or more of a plurality of other filters a heart rate on the basis of signals obtained from the plurality of sensors.

30. The computer readable media program instructions of claim **29** further causing the processor to execute the method of:

detect optical signals including ambient light and light from an optical sensor comprising a plurality of light emitting devices and one or more photodetectors;

detecting with an accelerometer a motion that adds a noise signal to the optical signals;

providing the optical and noise signals to a processor for computing the heart rate; and

outputting from the processor a one or more status commands on the basis of the computed heart rate.

31. The computer readable media program instructions of claim **30**, the method further comprising controlling with a driver a periodic emission level and timing of light output from the light emitting devices and a period of off state of the light emitting devices.

32. The computer readable media program instructions of claim **31**, the method further comprising determining with a signal quality estimator a drive level of the light emitting devices on the basis of the detected optical signals.

33. The computer readable media program instructions of claim **32**, wherein a one or more of the filters is configured to filter noise outside specified frequency bands from the optical signals, comprising subtracting filtered noise from an ambient signal when the light emitting devices are off from the optical signals when the light emitting devices are on.

34. The computer readable media program instructions of claim **33**, the method further comprising removing, with an adaptive noise removal filter, noise on the basis of the accelerometer noise signal from the noise filtered optical signals and provide a noise removal filtered signal.

35. The computer readable media program instructions of claim **34**, the method further comprising:

providing, with a spectrum analyzer, spectra of the optical signals, accelerometer noise signal, and noise removal filtered signal; and determining a coarse rate heart estimation on the basis of the spectra.

36. The computer readable media program instructions of claim **35**, the method further comprising:

controlling a spectrum analyzer to provide spectra of the optical signals, accelerometer noise signal, and noise removal filtered signal; and

determining a coarse rate heart estimation on the basis of the spectra.

37. The computer readable media program instructions of claim **36**, the method further comprising determining, with a plurality of adaptive tracking filters, a heart rate value on the basis of the coarse heart rate estimation, the error signal from the signal quality estimator and the noise removal filtered signal.

38. The computer readable media program instructions of claim **367**, the method further comprising computing a heart rate with the heart rate Kalman filter to compute the heart rate on the basis of an error signal from the signal quality estimator and the heart rate value from the plurality of adaptive tracking filters.

* * * * *

patsnap

专利名称(译)	心率监测器		
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申请(专利权)人(译)	Scosche产品INDUSTRIES，INC.		
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摘要(译)

一种用于确定心率的信号处理装置包括：多个传感器，被配置为检测用户皮肤中的血液特性的变化;以及心率卡尔曼滤波器，被配置为基于从多个传感器获得的信号来计算心率。使用该装置计算心率的方法包括利用多个传感器检测血液特性的变化，并且基于从多个传感器获得的信号利用心率卡尔曼滤波计算心率。