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(54) **IMPEDANCE PLETHYSMOGRAPH USING CONCURRENT PROCESSING**

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A61B 5/0432	(2006.01)
A61B 5/044	(2006.01)
A61B 5/0452	(2006.01)

(52) **U.S. Cl.**
CPC ***A61B 5/0295*** (2013.01); ***A61B 5/0006*** (2013.01); ***A61B 5/044*** (2013.01); ***A61B 5/0432*** (2013.01); ***A61B 5/0452*** (2013.01)

(58) **Field of Classification Search**
CPC A61B 5/02427; A61B 5/0017; A61B 5/02154; A61B 5/0261; A61B 5/1079; A61B 5/1455
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,149,627 A		9/1964	Bagno	
3,570,474 A		3/1971	Jonson	
3,742,936 A		7/1973	Blanie et al.	
3,835,839 A		9/1974	Brown	
3,835,840 A		9/1974	Mount	
3,847,142 A		11/1974	Williams, Jr. et al.	
4,204,545 A		5/1980	Yamakoshi	
4,205,688 A		6/1980	Hauser et al.	
4,258,720 A		3/1981	Flowers	
4,432,374 A		2/1984	Osanai	
4,437,469 A		3/1984	Djordjevich et al.	
4,548,211 A	*	10/1985	Marks	A61B 5/0456 600/506
5,025,784 A	*	6/1991	Shao	A61B 5/0535 600/513
7,887,491 B2	*	2/2011	Marks	A61B 5/02141 600/485

* cited by examiner

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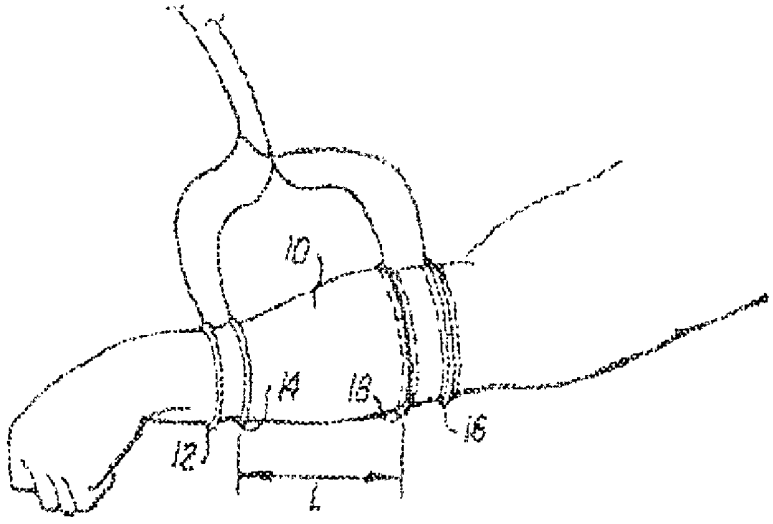
(57) **ABSTRACT**

A system and method for measuring the impedance and impedance changes in a body segment are disclosed. By utilizing an ECG buffer, at least one plethysmograph buffer, and concurrently performing at least extraction of an ECG waveform stored in the ECG buffer and extraction of impedance waveforms stored in the at least one plethysmograph buffer, enhanced signal-to-noise ratios of output signals of impedance plethysmographs are achieved. In an embodiment, improved waveform selection using template matching is also achieved. With template matching, a new candidate waveform is compared in shape to the previous average waveform and may be accepted for current averaging based on the comparison.

26 Claims, 6 Drawing Sheets



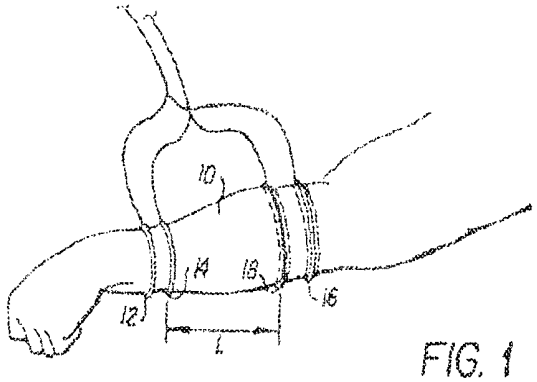


FIG. 1

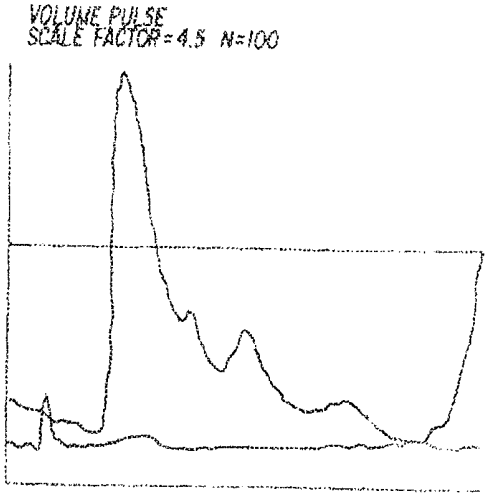


FIG. 5

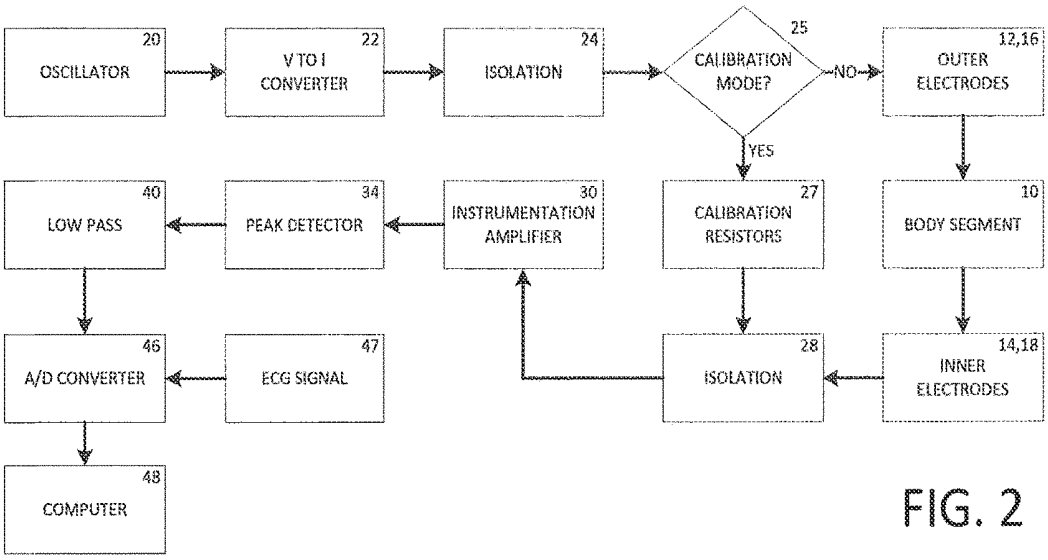

20
OSCILLATOR
22
V TO I CONVERTER
24
ISOLATION
25
CALIBRATION MODE?
NO
12,16
OUTER ELECTRODES
YES
40
LOW PASS
34
PEAK DETECTOR
30
INSTRUMENTATION AMPLIFIER
27
CALIBRATION RESISTORS
10
BODY SEGMENT
46
A/D CONVERTER
47
ECG SIGNAL
28
ISOLATION
14,18
INNER ELECTRODES
48
COMPUTER

FIG. 2

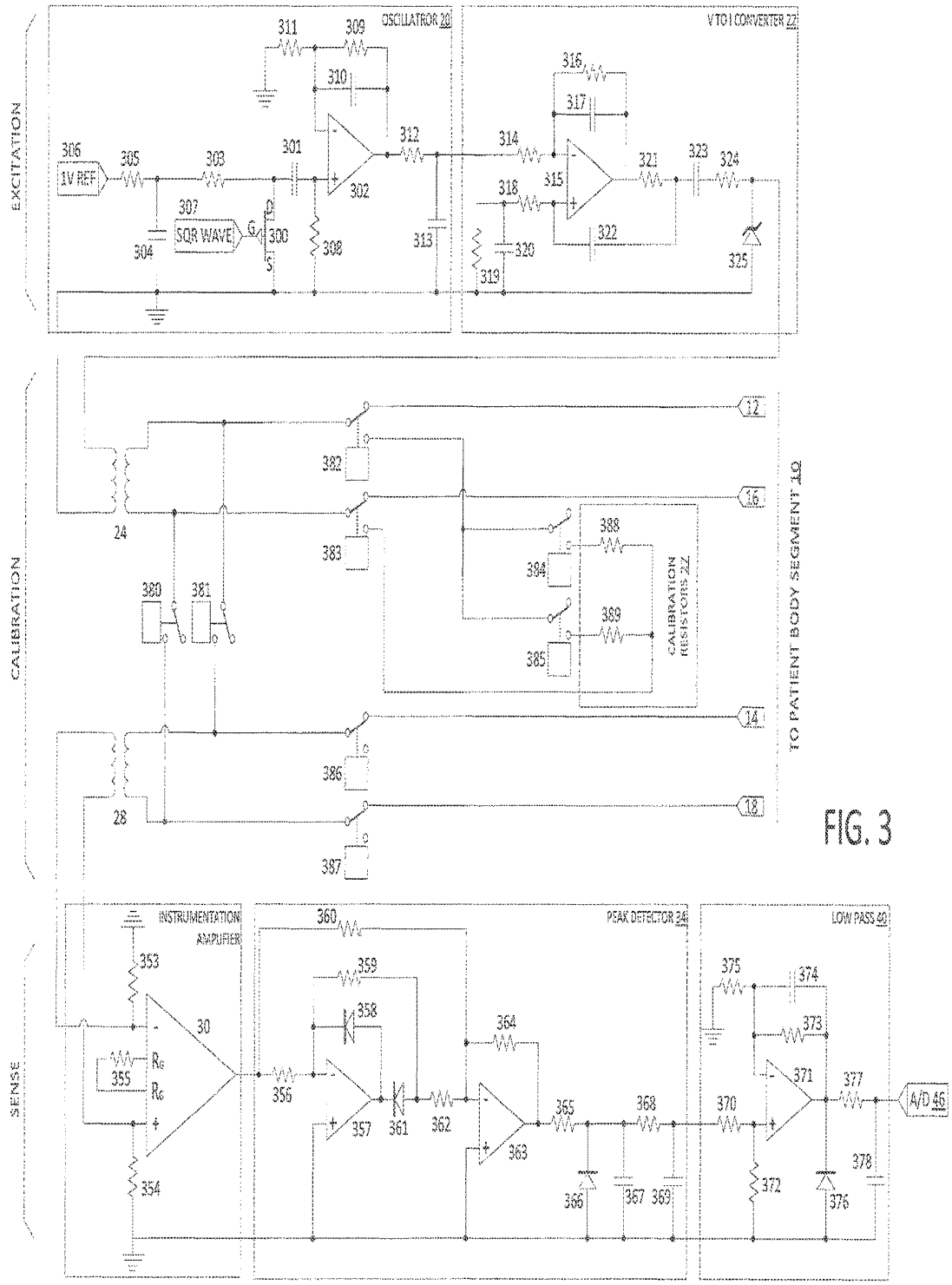

EXCITATION
OSCILLATROR 20
V TO I CONVERTER 22
1V REF
SQR WAVE
CALIBRATION
CALIBRATION RESISTORS 22
TO PATIENT BODY SEGMENT 10
SENSE
INSTRUMENTATION AMPLIFIER
PEAK DETECTOR 34
LOW PASS 40
A/D 46

FIG. 3

FIG 4

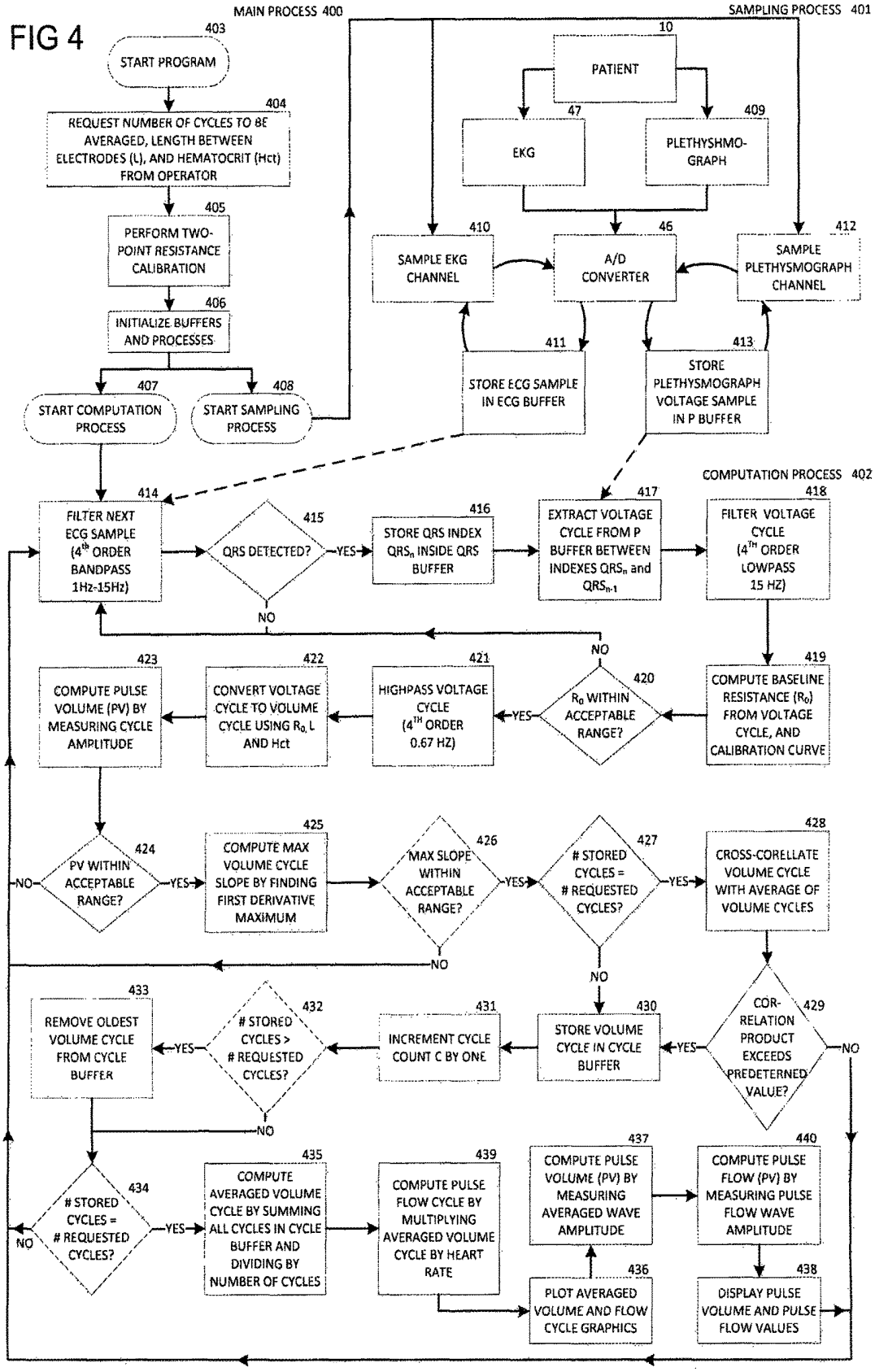
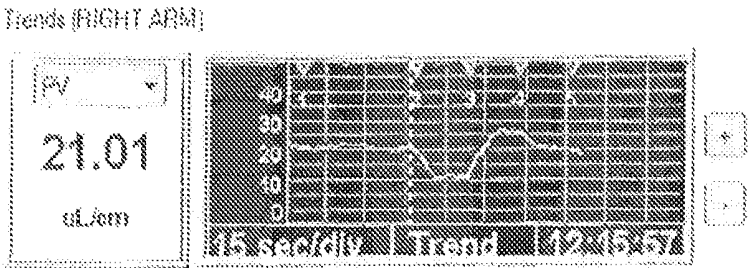

MAIN PROCESS 400
SAMPLING PROCESS 401
COMPUTATION PROCESS 402
403
START PROGRAM
404
REQUEST NUMBER OF CYCLES TO BE AVERAGED, LENGTH BETWEEN ELECTRODES (L), AND HEMATOCRIT (Hct) FROM OPERATOR
405
PERFORM TWO-POINT RESISTANCE CALIBRATION
406
INITIALIZE BUFFERS AND PROCESSES
407
START COMPUTATION PROCESS
408
START SAMPLING PROCESS
10
PATIENT
47
EKG
409
PLETHYSHMO-GRAPH
410
SAMPLE EKG CHANNEL
46
A/D CONVERTER
412
SAMPLE PLETHYSMOGRAPH CHANNEL
411
STORE ECG SAMPLE IN ECG BUFFER
413
STORE PLETHYSMOGRAPH VOLTAGE SAMPLE IN P BUFFER
414
FILTER NEXT ECG SAMPLE (4th ORDER BANDPASS 1Hz-15Hz)
415
QRS DETECTED?
YES
NO
416
STORE QRS INDEX QRSn INSIDE QRS BUFFER
417
EXTRACT VOLTAGE CYCLE FROM P BUFFER BETWEEN INDEXES QRSn and QRSn-1
418
FILTER VOLTAGE CYCLE (4TH ORDER LOWPASS 15 HZ)
419
COMPUTE BASELINE RESISTANCE (R0) FROM VOLTAGE CYCLE, AND CALIBRATION CURVE
420
R0 WITHIN ACCEPTABLE RANGE?
421
HIGHPASS VOLTAGE CYCLE (4TH ORDER 0.67 HZ)
422
CONVERT VOLTAGE CYCLE TO VOLUME CYCLE USING R0, L AND Hct
423
COMPUTE PULSE VOLUME (PV) BY MEASURING CYCLE AMPLITUDE
424
PV WITHIN ACCEPTABLE RANGE?
425
COMPUTE MAX VOLUME CYCLE SLOPE BY FINDING FIRST DERIVATIVE MAXIMUM
426
MAX SLOPE WITHIN ACCEPTABLE RANGE?
427
STORED CYCLES = # REQUESTED CYCLES?
428
CROSS-CORELLATE VOLUME CYCLE WITH AVERAGE OF VOLUME CYCLES
429
COR-RELATION PRODUCT EXCEEDS PREDETERNED VALUE?
430
STORE VOLUME CYCLE IN CYCLE BUFFER
431
INCREMENT CYCLE COUNT C BY ONE
432
STORED CYCLES > # REQUESTED CYCLES?
433
REMOVE OLDEST VOLUME CYCLE FROM CYCLE BUFFER
434
STORED CYCLES = # REQUESTED CYCLES?
435
COMPUTE AVERAGED VOLUME CYCLE BY SUMMING ALL CYCLES IN CYCLE BUFFER AND DIVIDING BY NUMBER OF CYCLES
439
COMPUTE PULSE FLOW CYCLE BY MULTIPLYING AVERAGED VOLUME CYCLE BY HEART RATE
437
COMPUTE PULSE VOLUME (PV) BY MEASURING AVERAGED WAVE AMPLITUDE
440
COMPUTE PULSE FLOW (PV) BY MEASURING PULSE FLOW WAVE AMPLITUDE
436
PLOT AVERAGED VOLUME AND FLOW CYCLE GRAPHICS
438
DISPLAY PULSE VOLUME AND PULSE FLOW VALUES

FIGURE 6



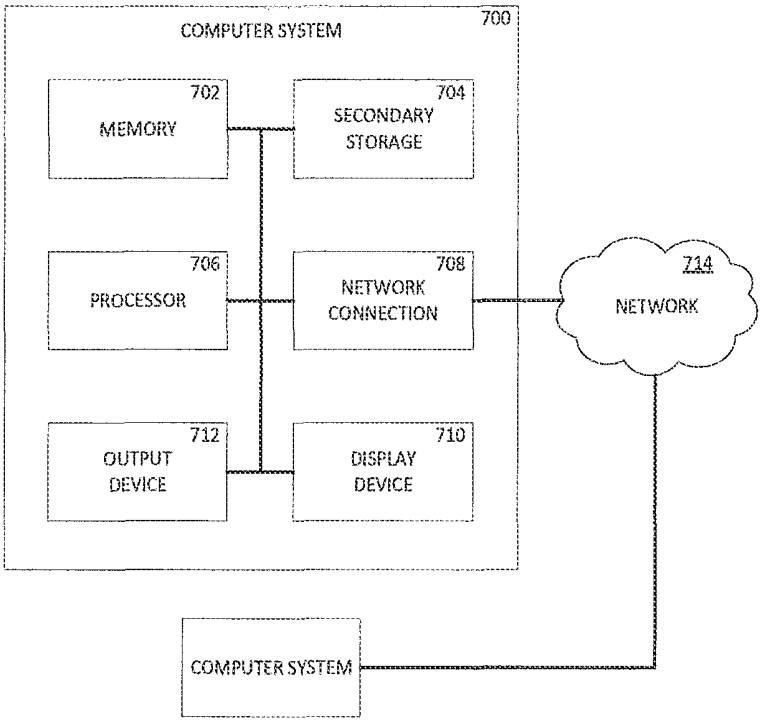

COMPUTER SYSTEM
700
702
MEMORY
704
SECONDARY STORAGE
706
PROCESSOR
708
NETWORK CONNECTION
714
NETWORK
712
OUTPUT DEVICE
710
DISPLAY DEVICE
COMPUTER SYSTEM

FIG. 7

IMPEDANCE PLETHYSMOGRAPH USING CONCURRENT PROCESSING

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a Continuation of application Ser. No. 14/836,493 filed Aug. 26, 2016, the contents of which application are incorporated herein by reference.

FIELD OF THE INVENTION

Embodiments are in the field of impedance plethysmography. More particularly, embodiments disclosed herein relate to systems and methods for enhancing output signals of impedance plethysmographs via concurrent processing which, inter alia, foster enhanced signal-to-noise ratios of output signals of impedance plethysmographs.

BACKGROUND OF THE INVENTION

Pulsatile volume and pulsatile flow (pulsatile volume times heart rate) in an extremity can be measured with an admittance (or equivalently an impedance) plethysmograph such as that described in U.S. Pat. No. 4,548,211. In that device, an admittance signal is derived from a body segment and QRS complexes of the patient's ECG are stored. Using the ECG as a gating signal, the admittance waveforms are averaged to reduce noise. In the device described in U.S. Pat. No. 4,548,211, this is accomplished in a linear sequence. First, a QRS complex is detected. Then an admittance waveform is captured. Then, it is determined if the captured waveform remains within certain bounds. This is done to eliminate noisy waveforms. If a waveform is accepted, it is then averaged with a number (determined by the user) of prior waveforms to produce an averaged composite waveform which has considerably less noise than the individual waveforms. The averaged waveform is then measured to determine its amplitude. The waveform and its amplitude are then displayed.

These operations are executed sequentially. The beat selection, averaging process, waveform measurement and display take a sufficiently long time such that only about 1 in 3 or 1 in 4 waveforms can be captured for averaging. This means that it takes a long time for the pulse volume readouts to appear and to be updated. Also, plethysmographic waveform amplitude varies with respiration. If the respiratory cycle is close to the frequency of intermittent plethysmographic waveform selection, then errors will be introduced.

Thus, it is desirable to provide a system and method for enhancing output signals of an impedance plethysmograph via concurrent processing which are able to overcome the above disadvantages.

It is the purpose of this invention to speed up the process so that all waveforms can be used. This is accomplished by storing the entire impedance waveform and the entire ECG waveform in buffers. The waveform extraction is then performed using the waveforms stored in the buffers. This is accomplished by using a concurrent processing software technique which allows all waveforms to be used. Waveform extraction, selection, averaging, measurement and display are performed concurrently.

This results in a marked increase in speed of acquisition. The specific means by which this is accomplished is described in the detailed description of the invention below.

It is another purpose of this invention to provide improved waveform selection using template matching. Currently, waveforms are rejected based on amplitude and amplitude of first derivative criteria only. This often permits distorted waveforms to be inappropriately accepted for averaging. With template matching, a new "candidate" waveform is compared in shape to the current averaged waveform. If it matches well, the new candidate waveform is accepted for averaging. If not, it is discarded. The specific means by which this is accomplished is described in the detailed description of the invention below.

In view of the foregoing, it should be apparent that there still exists a need for an improved impedance plethysmograph in which accuracy is improved because, in the state of the art impedance plethysmograph, not all cardiac cycles are used in the averaging process and because distorted waveforms are often inappropriately included in the averaged waveform.

More particularly, it is an object of an embodiment of this invention to use concurrent processing to acquire electrocardiographic waveforms, acquire impedance plethysmographic waveforms, to use these waveforms to select plethysmographic waveforms as candidates for averaging, to compute the average of these waveforms, to calculate the pulse volume changes corresponding to the impedance changes, to measure the amplitude of the waveforms, to compute the product of heart rate and plethysmographic waveform amplitude, to display the averaged waveform and to display updated trend lines showing the amplitudes of the pulse volume waveform and the pulse volume times heart rate product waveform.

Furthermore, it is an object of an embodiment of this invention to use template matching to improve the selection of new candidate plethysmographic waveforms for averaging. The shape of a new candidate waveform is compared to the current running averaged waveforms using a cross-correlation technique. If the shape is sufficiently similar to the running average, it is accepted for averaging. If not, it is rejected.

SUMMARY OF THE INVENTION

Embodiments are directed to a method for measuring the impedance and impedance changes in a body segment. The method comprises: acquiring an ECG waveform; detecting QRS complexes from the ECG waveform; storing the ECG waveform in at least one ECG buffer; acquiring a plurality of impedance waveforms; storing the plurality of impedance waveforms in at least one plethysmograph buffer; extracting the ECG waveform stored in the at least one ECG buffer; extracting the plurality of impedance waveforms stored in the at least one plethysmograph buffer, wherein extracting the ECG waveform and extracting the plurality of impedance waveforms are performed concurrently; and averaging the plurality of impedance waveforms to obtain a single waveform representative of the average of the plurality of impedance waveforms.

In an embodiment, the acquiring the ECG waveform, the detecting QRS complexes, the storing the ECG waveform, the acquiring the plurality of impedance waveforms, the storing the plurality of impedance waveforms, the extracting the ECG waveform, the extracting the plurality of impedance waveforms, and the averaging the plurality of impedance waveforms are performed concurrently.

In an embodiment, the method further comprises measuring the single waveform to determine its amplitude. The method may further comprise displaying the single waveform and its amplitude. The averaging the plurality of

impedance waveforms, the measuring the single waveform, and the displaying the single waveform may be performed concurrently.

In an embodiment, the method further comprises comparing in shape a candidate waveform to the single waveform, wherein upon acceptance for averaging of the candidate waveform, the candidate waveform is averaged with prior accepted impedance waveforms that form the single waveform to obtain a new single waveform representative of the average of the prior accepted impedance waveforms and the candidate waveform.

In an embodiment, the method further comprises determining pulse volume from the single waveform.

In an embodiment, the averaging is performed via utilizing the QRS complexes as a gating signal.

Embodiments are also directed to a system that measures the impedance and impedance changes in a body segment. The system includes similar features that correspond to the above-mentioned method.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description will refer to the following drawings, wherein like numerals refer to like elements, and wherein:

FIG. **1** is a schematic diagram illustrating an embodiment of four electrodes positioned on a human limb;

FIG. **2** is a block diagram illustrating a preferred embodiment of a peripheral limb blood flow measuring device of the present invention;

FIG. **3** is a schematic diagram of electrical circuitry of the current source, isolation, and sense circuitry utilized with the blood flow measuring device of FIG. **2**;

FIG. **4** is a flowchart illustrating a program utilized by the digital computer as used in the present invention;

FIG. **5** is a graph illustrating a volume pulse signal obtained by the present invention;

FIG. **6** is a graph illustrating pulsatile volume versus time with pulse volume measured in microliters per centimeter; and

FIG. **7** is block diagram illustrating exemplary hardware components for implementing embodiments of a system and method for impedance plethysmography using concurrent processing and template matching techniques.

DETAILED DESCRIPTION OF THE INVENTION

It is to be understood that the figures and descriptions of the present invention may have been simplified to illustrate elements that are relevant for a clear understanding of the present invention, while eliminating, for purposes of clarity, other elements found in a typical plethysmograph or typical method of using a plethysmograph. Those of ordinary skill in the art will recognize that other elements may be desirable and/or required in order to implement the present invention. However, because such elements are well known in the art, and because they do not facilitate a better understanding of the present invention, a discussion of such elements is not provided herein. It is also to be understood that the drawings included herewith only provide diagrammatic representations of the presently preferred structures of the present invention and that structures falling within the scope of the present invention may include structures different than those shown in the drawings. Reference will now be made to the drawings wherein like structures are provided with like reference designations.

The present disclosure hereby incorporates by reference herein the disclosure of U.S. Pat. No. 4,548,211 which was issued to Lloyd A. Marks, the inventor of the present application.

Embodiments overcome the problems described above. Embodiments address the above problems and improve the state of the art by speeding up the process so that all waveforms can be used. This is accomplished by storing the entire impedance waveform and the entire ECG waveform in buffers. The waveform extraction is then performed using the waveforms stored in the buffers. That is accomplished by using concurrent processing which allows all waveforms to be used. Waveform extraction, selection, averaging, measurement and display are performed at the same time.

This results in a marked increase in speed of acquisition and increased accuracy. The respiratory cycle causes the amplitude of the plethysmographic waveform to vary. With inspiration, the amplitude of the waveform decreases and with expiration it increases. If, for example, the device captures only one in three cycles, those cycles may coincide with the respiratory cycle, for example, that occurs during expiration. This would result in overestimation of the average pulse volume amplitude. The specific means by which this is accomplished is described below.

Additional embodiments provide improved waveform selection using template matching. In this method, a new "candidate" waveform is compared in shape to the current averaged waveform. If it matches well, it is accepted for averaging. If not, it is discarded. With the current embodiment, a "junk" waveform may still meet the amplitude criteria for acceptance. This results in corruption of the average. By using template matching the likelihood of accepting a "real" waveform is dramatically improved. The specific means by which this is accomplished is described below.

With reference to FIG. **1**, one of the peripheral limbs or body segments **10** of a human body is shown, for example, the forearm. An electrical signal, of, for instance, 20 kilohertz at 1 milliamp of current, is applied to the forearm via two electrodes **12** and **16**. The resultant voltage in the limb is measured between a second pair of electrodes **14** and **18** placed within the first pair of electrodes **12** and **16**. The distance L between the inner electrodes **14** and **18** may be approximately 13 centimeters. All of the electrodes **12**, **14**, **16** and **18** may be of the circumferential type, and may consist of braided stainless steel sleeve over rubber cord attached to fleece-backed neoprene. Other types of electrodes can be used such as those described in U.S. Pat. No. 8,019,401 where a variety of such electrodes is described.

Turning now to FIG. **2**, there is shown that the two outer electrodes **12** and **16** may be connected to the secondary of an isolation transformer **24**, the primary of which is driven by a current source or oscillator **20**, through a voltage-to-current converter **22**. The two inner electrodes **14** and **18** may be connected to the primary of a second isolation transformer **28**. The secondary windings of isolation transformer **28** are connected to an instrumentation amplifier **30**. Each electrode **12**, **14**, **16** and **18** may be connected directly to its respective isolation transformers **24** and **28**.

FIG. **2** illustrates in block diagram form a preferred embodiment of the impedance plethysmograph of the present invention. An oscillator **20**, which may be a field effect transistor stabilized oscillator, is provided. The output of oscillator **20** is converted from a voltage to a current by means of V to I converter **22**. The output of converter **22** may preferably be a sine wave signal of frequency 20

kilohertz and amplitude of 1 milliamp. A more detailed schematic diagram of the oscillator **20** and converter **22** is shown in FIG. **3**.

The output from the converter **22** is fed through an isolation transformer **24**. As previously set forth, the outer patient electrodes **12** and **16** are connected to the secondary of isolation transformer **24**.

The output from the inner patient electrodes **14** and **18** is connected to the primary of a second isolation transformer **28**. The secondary windings of that isolation transformer **28** are connected to an instrumentation amplifier **30** which may be, for instance, an operational amplifier manufactured by Analog Devices, model number AD521AR, of gain 25. The output from the instrumentation amplifier **30** may be fed to a peak detector **34**.

The output from the peak detector **34** is fed to a lowpass filter **40**, which in this embodiment, is a 1st order active filter at 31 Hz to eliminate high frequency noise. The output from the lowpass filter **40** is a voltage which is proportional to the total tissue impedance, including the low magnitude phasic component. The output from the lowpass filter **40** may be fed to the input of an analog-to-digital (A/D) converter **46**. The output of the A/D converter **46** may be fed to a computer **48**.

Calibration resistors **27** are substituted for the electrodes and body segment during a calibration procedure that occurs before measurements are made. The calibration procedure is described below.

In an embodiment, all of the circuitry set forth in FIG. **2**, with the exception of the computer **48**, may preferably be powered from a power supply which supplies plus and minus 15 volts DC. Such a power supply is manufactured, for example, by Mean Well, and is designated as model RS-100.

Turning now to FIG. **3**, an embodiment of a detailed circuit diagram of the oscillator **20** and voltage-to-current converter **22** is shown therein. The oscillator **20** is based upon a field effect transistor (FET) **300**, which may preferably be a model number ZVN3306A, N-channel device. The drain of the FET **300** is connected through a capacitor **301** to the non-inverting input of an operational amplifier **302**. The operational amplifier may be a model number LF353 manufactured by Texas Instruments. The source of the FET **300** is connected to ground. The drain of the FET **300** is connected to ground through resistor **303** and capacitor **304**. Resistor **303** is connected through resistor **305** to 1V voltage reference **306**, provided by a digital-to-analog converter, which may be a model number AD7804 manufactured by Analog Devices. The gate of the FET **300** is connected to a 20 KHz square wave output **307**, generated by a digital signal processor, which may be a model number TMS320VC5501PGF manufactured by Texas Instruments. The non-inverting input of an operational amplifier **302** is connected to ground through resistor **308**. The output of operational amplifier **302** is fed back to the inverting input of the operational amplifier **302** through resistor **309** and capacitor **310**. The inverting input of the operational amplifier **302** is also connected to ground through resistor **311**. The output of operational amplifier **302** is fed to ground through resistor **312** and capacitor **313**. Thus, by appropriate selection of the values of the resistors and capacitors utilized in the oscillator circuit **20**, a sine wave output of approximately 20 KHz is available at the output of the resistor **312**.

The output from resistor **312** is fed through resistor **314** to the inverting input of a second operational amplifier **315**, which functions as the primary element of the voltage-to-current converter **22**. The operational amplifier **315** may be preferably a model number LF353 manufactured by Texas Instruments. The output of the operational amplifier **315** is fed back to the inverting input of the operational amplifier **315** through resistor **316** and capacitor **317**. The non-inverting input is connected to ground through resistor **318** in series with resistor **319** and capacitor **320**. The output of operational amplifier **315** is also fed back to its non-inverting input through resistor **321** and capacitor **322**. The output of resistor **321** is connected to the cathode of a Transient Voltage Suppressor diode **325** through capacitor **323** and resistor **324**. The diode **325** may preferably be a model number SD05 manufactured by Semtech. The anode of the diode **325** is connected to ground. The output from the cathode of the diode **325** is fed to the primary coil of the isolation transformer **24**.

The secondary coil of isolation transformer **24** passes the 20 KHz excitation current through single-pole double-throw (SPDT) relays **382** and **383** onto body segment **10** via two electrodes **12** and **16**. The resulting voltage in the limb is measured between a second pair of electrodes **14** and **18**. That voltage is then passed through SPDT relays **386** and **387** into isolation transformer **28** and then instrumentation amplifier **30**. The inverting and non-inverting inputs of instrumentation amplifier **30** are grounded via resistors **353** and **354**, respectively. An appropriate resistor **355** is placed across gain inputs R_G, to ensure a voltage gain of 25.

The output of instrumentation amplifier **30** is fed into peak detector **34** based upon two operational amplifiers **357** and **363**. The operational amplifiers may be preferably a model number LM318P manufactured by Texas Instruments. The signal from instrumentation amplifier **30** is connected into inverting inputs of operational amplifiers **357** and **363** via resistors **356** and **360**, respectively. The non-inverting inputs of operational amplifiers **357** and **363** are grounded. The output of operational amplifier **357** is fed back into its inverting input via diode **358**, and also via diode **361** and resistor **359** connected in series. Diodes **358** and **361** may be a model number 1N4148 manufactured by Fairchild Semiconductor™. The anode of diode **361** is connected to inverting input of operational amplifier **363** via resistor **362**. The output of operational amplifier **363** is fed back into its inverting input via resistor **364**. The output of operational amplifier **363** is connected to ground via resistor **365** and diode **366** (also model number 1N4148). The cathode of diode **366** is connected to ground via capacitor **367**. The non-grounded terminal of capacitor **367** is connected to ground via resistor **368** and capacitor **369**. By appropriate selection of the values of the resistors and capacitors utilized in the peak detector circuit **34**, a voltage signal representing envelope of the sine wave is available at the output of the resistor **368**.

That signal is then passed into a low pass filter **40**, based upon operational amplifier **371**, which may preferably be model TLE2141 manufactured by Texas Instruments. The signal passes through resistor **370** into non-inverting input of operational amplifier **371**. The non-inverting input is connected to ground via resistor **372**. The inverting input is connected to ground via resistor **375**. The output of operational amplifier **371** is fed back into the inverting input via resistor **373** and capacitor **374** connected in parallel. The output of operational amplifier **371** is connected to ground via diode **376** (also model number 1N4148). The output of operational amplifier **371** is also connected to ground via resistor **377** and capacitor **378**. The non-grounded terminal of capacitor **378** is connected to input of analog-to-digital converter **46**. By appropriate selection of the values of the

resistors and capacitors utilized in the low pass filter circuit **40**, the voltage signal is low-pass filtered at the corner frequency of 31 Hz.

The eight single-pole double-throw (SPDT) relays (**380** through **387**) allow automated calibration and electrode check. The relays may preferably be model G5V-1 manufactured by Omron. The self-calibration is performed by first energizing relays **382** and **383**, which connect excitation circuit to the calibration resistors **27**, instead of the body segment **10**. At the same time relays **386** and **387** are energized to disconnect sense circuit from body segment **10**. Simultaneously, relays **380** and **381** are energized to connect sense circuit to the excitation circuit, so that the voltage drop across calibration resistors **27** can be measured. Two separate measurements are performed. The first measurement energizes relay **384**, so that the voltage drop across resistor **388** of value 100 Ohm is obtained. The second measurement energizes both relay **384** and **385**, so that the voltage drop is obtained across the parallel combination of resistors **388** and **389** (also 100 Ohm), which results in effective 50 Ohm resistance. The two resulting voltage points are then linearly interpolated to create a calibration curve allowing conversion between A/D converter voltage and resistance.

The automated electrode check is performed by energizing relays **380** and **381**, which shorts each outer electrode to its adjacent inner electrode. This makes it possible to perform resistance measurements with only two electrodes connected to patient body segment **10**. Four sets of measurements are then performed, with only two electrodes connected to the patient at a time, by energizing only two out of the four electrode relays **382**, **383**, **386** and **387**. A short (low resistance), or an open (high resistance) reading in any of the measurements indicates a problem with electrode hardware, or electrode preparation, which is communicated to the user via display.

As shown in FIG. **2**, the plethysmogram signal output from lowpass filter **40** and the ECG signal **47** may all be fed continuously to the analog-to-digital converter **46**. Turning now to FIG. **4**, the program contained in the computer **48** is composed of three processes: a main process **400**, a sampling process **401** and a computation process **402**. The program starts **403**, and requests the number of cycles to be averaged, the length between the electrodes (L) and the hematocrit (Hct) from the operator **404**. The program then performs a two-point resistance calibration **405** by substituting resistors **27** (FIG. **2**) for the electrodes and body segment. The buffers and processes are then initialized **406**. The main process **400** then starts a sampling process **408**, which is responsible for continuously sampling ECG **47** and plethysmograph **409** signals connected to A/D converter **46** (FIG. **2**). The ECG samples are stored inside ECG buffer **411** and the plethysmograph samples are stored inside P buffer **413**.

The main process **400** also starts a computation process **402**, which is responsible for processing the data being continuously obtained by the sampling process. Each incoming ECG sample is digitally filtered using a 4^{th} order bandpass Butterworth filter with lower and upper cutoff frequencies of 1 Hz and 15 Hz respectively (**414**). The program then determines whether a QRS complex has occurred in the ECG signal **415**. If not, the program processes the next ECG sample **414**. If the proper conditions have been met to identify a new QRS complex, the program stores the index QRS_n of the ECG sample at which the detection was made **416**. Since plethysmograph **409** and ECG **47** signals are sampled simultaneously by the A/D converter **46**, the sample indexes correspond to the same point in time for both channels. That allows the program to identify and extract a single voltage cycle **417** from voltage samples stored in P buffer **413**. The extracted samples are bound by the last two QRS indexes, starting at QRS_{n-1} and ending at QRS_n.

The extracted voltage cycle is then digitally filtered using a 4^{th} order lowpass Butterworth filter with a cutoff frequency of 15 Hz (**418**), to eliminate high frequency noise. The program then calculates baseline resistance R_0 **419** based on the filtered voltage, and the calibration curve obtained in step **405**. The program then determines whether the baseline resistance is within a predetermined acceptable range **420**. If it isn't, the program processes the next ECG sample **414**. If it is, the program then filters the voltage points using a 4^{th} order highpass Butterworth filter with a cutoff frequency of 0.67 Hz (**421**), to extract the phasic component of tissue impedance. The filtered points are converted from voltage into physiologic units of volume using baseline resistance R_0, electrode length (L) and hematocrit (Hct) values **422**. This is done using the Nyboer equation:

$$\Delta V = \rho(L/Z_o)^2 \Delta Z$$

where ΔV is the change in volume, ρ is the blood resistivity, L is the length between the inner electrodes, Z_o is the baseline impedance and ΔZ is the change in impedance.

The program then identifies and computes the peak-to-peak value (PV) of the pulsatile volume cycle **423**. The program then determines whether the PV number exceeds a predetermined acceptable range **424**. If it does, the program processes the next ECG sample **414**. If it does not, the program then calculates maximum slope of the volume cycle by finding the maximum of the absolute values of first derivative points **425**.

The program then determines whether the maximum slope is within a predetermined acceptable range **426**. If it isn't, the program processes the next ECG sample **414**. If it is, it is determined if the number of stored cycles is equal to the number of requested cycles **427**. If the number of requested cycles does not equal the number of stored cycles, then the average is not complete and the program stores the current volume cycle in the cycle buffer **430**. If the number of requested cycles equals the number of stored cycles, then an averaged waveform exists. The averaged waveform is compared to the current cycle using the cross-correlation technique **428**. In the cross-correlation technique, the two waveforms to be compared are first high pass filtered such that they have an equal area above and below the baseline. The waveforms are then sampled, for example 200 times at equal intervals. The value of the waveforms at each sampled interval is multiplied and the results of those multiplications are summed to provide a "correlation product." If the correlation product exceeds a predetermined value **429**, then the current waveform is deemed acceptable and it is stored in the cycle buffer **430**. If the correlation product does not exceed the predetermined value then the program processes the next ECG sample **414**.

After a volume cycle is stored **430**, the cycle count C is incremented by one **431**. The program then determines whether the number of stored cycles is greater than the number of cycles requested **432**. If it is, the oldest volume cycle is removed from cycle buffer **433**. The program then checks if the number of stored cycles is equal to the number of cycles requested **434**. If it isn't, the program processes the next ECG sample **414**. If it is, the program computes averaged volume cycle by summing all stored cycles and dividing them by their count **435**.

The averaged pulse flow cycle is computed by multiplying the averaged volume cycle by the heart rate **439**.

The averaged volume cycle and the averaged pulse flow cycle are then displayed on a suitable output device **436** (not shown). The program then identifies and computes the peak-to-peak value of the pulsatile volume curve **437** and the pulse flow curve **440**. These values are then displayed on a suitable output device **438** (not shown). The program then processes next ECG sample **414**.

The desired volume pulse graph is shown in FIG. **5**. The program provides continuous measurements and/or graphic representation of pulsatile volume as shown in FIG. **6**. In FIG. **6**, the x axis is time and the y-axis is the pulse volume measured in microliters per centimeter. A Valsalva maneuver (increase of intrathoracic pressure against a closed glottis), indicated at a point **2**, is shown to decrease the pulsatile volume transiently. After the Valsalva is released, the pulse volume increases as indicated at point **3**. It then overshoots the baseline as indicated at point **4** before finally returning to baseline as indicated at point **5**.

In view of the foregoing, it should be apparent that there is provided by the present invention an impedance plethysmograph in which a high signal-to-noise ratio of the output signal measured from a body segment is achieved. In addition, by means of a digital computer the outputs from the plethysmograph are analyzed and clarified such that the effects of the reduced signal-to-noise ratio are further enhanced. Furthermore, the pulsatile and ECG waveforms are stored in buffers, so that all waveforms are available for processing.

With reference now to FIG. **7**, there is shown a block diagram of exemplary hardware that may be used to provide the system and perform the method for computations and communication. Exemplary hardware implementation of the system may include multiple computing devices **700** (e.g., computing system N). Computing devices **700** may be, e.g., blade servers or other stack servers. For example, each component shown in the system may be implemented as software running on one or more computing devices **700**. Alternatively, components and functionality of each may be combined and implemented as software running on a single computing device **700**. Furthermore, steps of the method may be implemented as software modules executed on one or more computing devices **700**.

Computing device **700** may include a memory **702**, a secondary storage device **704**, a processor **706**, and a network connection **708**. Computing device **700** may be connected a display device **710** (e.g., a terminal connected to multiple computing devices **700**) and output device **712**. Memory **702** may include RAM or similar types of memory, and it may store one or more applications (e.g., software for performing functions or including software modules described herein) for execution by processor **706**. Secondary storage device **704** may include a hard disk drive, DVD-ROM drive, or other types of non-volatile data storage. Processor **706** executes the applications, which are stored in memory **702** or secondary storage **704**, or received from the Internet or other network **714**. Network connection **708** may include any device connecting computing device **700** to a network **714** and through which information is received and through which information (e.g., analysis results) is transmitted to other computing devices. Network connection **708** may include network connection providing connection to internal enterprise network, network connection provided connection to Internet or other similar connection. Network connection **708** may also include bus connections providing connections to other computing devices **700** in the system (e.g., other servers in server stack).

Display device **710** may include any type of device for presenting visual information such as, for example, a computer monitor or flat-screen display. Output device **712** may include any type of device for presenting a hard copy of information, such as a printer, and other types of output devices include speakers or any device for providing information in audio form. Computing device **700** may also include input device, such as keyboard or mouse, permitting direct input into computing device **700**.

Computing device **700** may store a database structure in secondary storage **704** for example, for storing and maintaining information needed or used by the software stored on computing device **700**. Also, processor **702** may execute one or more software applications in order to provide the functions described in this specification, specifically in the methods described above, and the processing may be implemented in software, such as software modules, for execution by computers or other machines. The processing may provide and support web pages and other user interfaces.

Although computing device **700** is depicted with various components, one skilled in the art will appreciate that the servers can contain additional or different components. In addition, although aspects of an implementation consistent with the above are described as being stored in memory, one skilled in the art will appreciate that these aspects can also be stored on or read from other types of computer program products or computer-readable media. The computer-readable media may include instructions for controlling a computer system, such as computing device **700**, to perform a particular method.

More generally, even though the present disclosure and exemplary embodiments are described above with reference to the examples according to the accompanying drawings, it is to be understood that they are not restricted thereto. Rather, it is apparent to those skilled in the art that the disclosed embodiments can be modified in many ways without departing from the scope of the disclosure herein. Moreover, the terms and descriptions used herein are set forth by way of illustration only and are not meant as limitations. Those skilled in the art will recognize that many variations are possible within the spirit and scope of the disclosure as defined in the following claims, and their equivalents, in which all terms are to be understood in their broadest possible sense unless otherwise indicated.

The invention claimed is:

1. A method for measuring the impedance and impedance changes in a body segment, the method comprising:

acquiring a new ECG waveform;

detecting QRS complexes from the new ECG waveform;

storing a previously acquired ECG waveform in at least one ECG buffer;

acquiring a plurality of new impedance waveforms;

storing the plurality of previously acquired impedance waveforms in at least one plethysmograph buffer;

extracting the previously acquired ECG waveform stored in the at least one ECG buffer;

extracting the plurality of previously acquired impedance waveforms stored in the at least one plethysmograph buffer; and

averaging the plurality of previously acquired impedance waveforms to obtain a single waveform representative of the average of the plurality of previously acquired impedance waveforms;

wherein the acquiring the new ECG waveform, the acquiring the plurality of new impedance waveforms,

the extracting the previously acquired ECG waveform, and the extracting the plurality of previously acquired impedance waveforms are performed concurrently.

2. The method of claim 1, further comprising determining an amplitude of the single waveform.

3. The method of claim 2, further comprising displaying the single waveform and its amplitude.

4. The method of claim 3, wherein the displaying the single waveform is performed concurrently with the acquiring the new ECG waveform and the acquiring the plurality of new impedance waveforms.

5. The method of claim 3, wherein the measuring the single waveform is performed concurrently with the acquiring the new ECG waveform and the acquiring the plurality of new impedance waveforms.

6. The method of claim 1, further comprising determining pulse volume from the single waveform.

7. The method of claim 1, wherein the averaging is performed via utilizing the QRS complexes as a gating signal.

8. The method of claim 1, wherein, prior to the averaging, the plurality of previously acquired impedance waveforms used to obtain the single waveform are analyzed to determine whether they are acceptable for the averaging.

9. A method for measuring the impedance and impedance changes in a body segment, the method comprising:

acquiring a new ECG waveform;

detecting QRS complexes from the new ECG waveform;

storing a previously acquired ECG waveform in at least one ECG buffer;

acquiring a plurality of new impedance waveforms;

storing the plurality of previously acquired impedance waveforms in at least one plethysmograph buffer;

extracting the previously acquired ECG waveform stored in the at least one ECG buffer;

extracting the plurality of previously acquired impedance waveforms stored in the at least one plethysmograph buffer; and

averaging the plurality of previously acquired impedance waveforms to obtain a single waveform representative of the average of the plurality of previously acquired impedance waveforms;

wherein the acquiring the new ECG waveform, the acquiring the plurality of new impedance waveforms, and the averaging the plurality of previously acquired impedance waveforms are performed concurrently.

10. The method of claim 9, further comprising determining an amplitude of the single waveform.

11. The method of claim 10, further comprising displaying the single waveform and its amplitude.

12. The method of claim 11, wherein the averaging the plurality of previously acquired impedance waveforms and the displaying the single waveform are performed concurrently.

13. The method of claim 11, wherein the measuring the single waveform is performed concurrently with the acquiring the new ECG waveform and the acquiring the plurality of new impedance waveforms.

14. The method of claim 9, further comprising determining pulse volume from the single waveform.

15. The method of claim 9, wherein the averaging is performed via utilizing the QRS complexes as a gating signal.

16. The method of claim 9, wherein, prior to the averaging, the plurality of previously acquired impedance waveforms used to obtain the single waveform are analyzed to determine whether they are acceptable for the averaging.

17. A system that measures the impedance and impedance changes in a body segment, the system comprising:

an ECG device that acquires a new ECG waveform, wherein QRS complexes are detected from the new ECG waveform;

at least one ECG buffer that stores a previously acquired ECG waveform;

a plethysmograph that acquires a plurality of new impedance waveforms;

at least one plethysmograph buffer that stores a plurality of previously acquired impedance waveforms;

wherein the previously acquired ECG waveform stored in the at least one ECG buffer is extracted;

wherein the plurality of previously acquired impedance waveforms stored in the at least one plethysmograph buffer are extracted;

wherein the plurality of previously acquired impedance waveforms are averaged to obtain a single waveform representative of the average of the plurality of previously acquired impedance waveforms; and

wherein the acquisition of the new ECG waveform, the acquisition of the plurality of new impedance waveforms, and the averaging the plurality of previously acquired impedance waveforms are performed concurrently.

18. The system of claim 17, wherein the single waveform comprises an amplitude.

19. The system of claim 18, further comprising a display device that displays the single waveform and its amplitude.

20. The system of claim 19, wherein the averaging the plurality of previously acquired impedance waveforms and the displaying the single waveform are performed concurrently.

21. The system of claim 19, wherein the measurement of the single waveform is performed concurrently with the acquisition of the new ECG waveform and the acquisition of the plurality of new impedance waveforms.

22. The system of claim 17, wherein pulse volume is determined from the single waveform.

23. The system of claim 17, wherein the QRS complexes are utilized as a gating signal to obtain the single waveform from the average of the plurality of previously acquired impedance waveforms.

24. The system of claim 17, wherein, prior to the averaging, the plurality of previously acquired impedance waveforms used to obtain the single waveform are analyzed to determine whether they are acceptable for the averaging.

25. A system that measures the impedance and impedance changes in a body segment, the system comprising:

an ECG device that acquires a new ECG waveform, wherein QRS complexes are detected from the new ECG waveform;

at least one ECG buffer that stores a previously acquired ECG waveform;

a plethysmograph that acquires a plurality of new impedance waveforms;

at least one plethysmograph buffer that stores a plurality of previously acquired impedance waveforms;

wherein the previously acquired ECG waveform stored in the at least one ECG buffer is extracted;

wherein the plurality of previously acquired impedance waveforms stored in the at least one plethysmograph buffer are extracted;

wherein the plurality of previously acquired impedance waveforms are averaged to obtain a single waveform representative of the average of the plurality of previously acquired impedance waveforms; and

wherein the acquisition of the new ECG waveform, the acquisition of the plurality of new impedance waveforms, the extraction of the previously acquired ECG waveform, and the extraction of the plurality of previously acquired impedance waveforms are performed concurrently.

26. The system of claim **25**, wherein, prior to the averaging, the plurality of previously acquired impedance waveforms used to obtain the single waveform are analyzed to determine whether they are acceptable for the averaging.

* * * * *

专利名称(译)	使用并发处理的阻抗体积描记器		
公开(公告)号	US10231635	公开(公告)日	2019-03-19
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[标]申请(专利权)人(译)	MARKS劳埃德		
申请(专利权)人(译)	MARKS，LLOYD A.		
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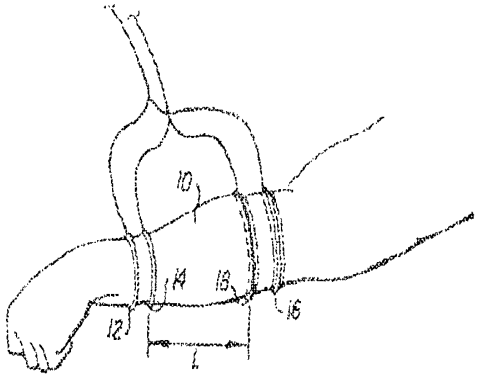
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