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Narimatsu et al.

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(54) **AUGMENTATION-INDEX MEASURING APPARATUS**

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(52) **U.S. Cl.** **600/485**; 600/500
(58) **Field of Search** 600/485, 490, 600/493–6, 500–503

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(57) **ABSTRACT**

An augmentation-index measuring apparatus including a cuff which is adapted to be worn on a portion of a living subject to press the portion, a fourth-order-differentiating device for subjecting a cuff pulse wave obtained from the cuff, to a fourth-order differentiation, and thereby obtaining a fourth-order-differentiated waveform, a peak-point determining device for determining, based on the fourth-order-differentiated waveform obtained by the fourth-order-differentiating device, a peak point of an incident-wave component contained in the cuff pulse wave and a peak point of a reflected-wave component contained in the cuff pulse wave, and an augmentation-index determining device for determining an augmentation index of the subject that indicates a proportion of one of a first magnitude of the cuff pulse wave at a time of occurrence of the peak point of the incident-wave component and a second magnitude of the cuff pulse wave at a time of occurrence of the peak point of the reflected-wave component, to the other of the first and second magnitudes.

8 Claims, 6 Drawing Sheets

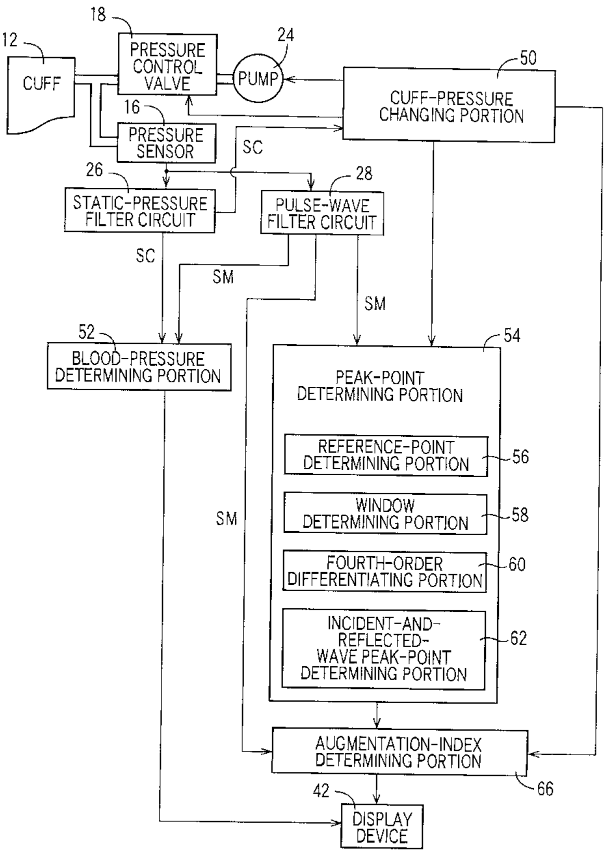


FIG. 1

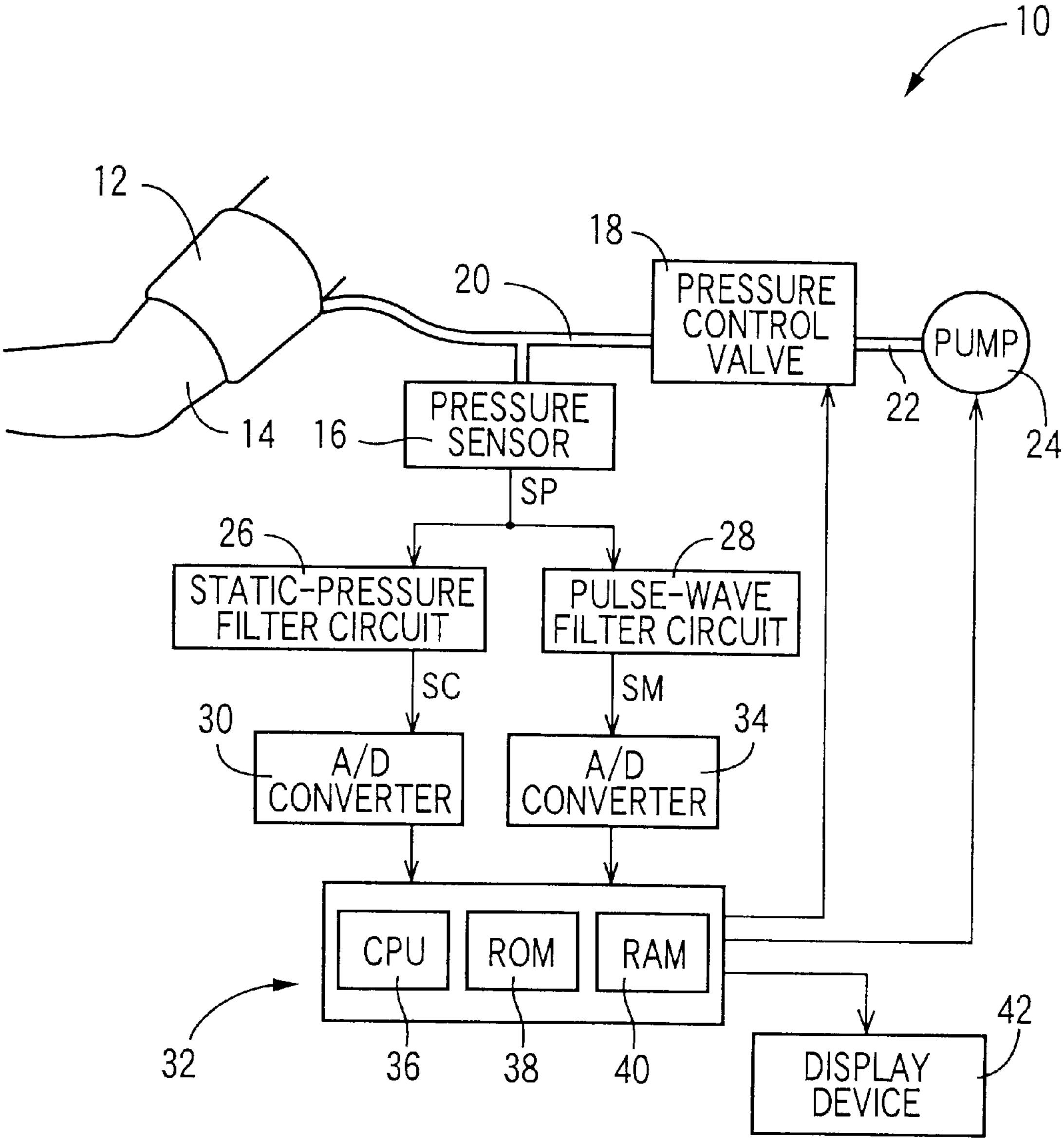
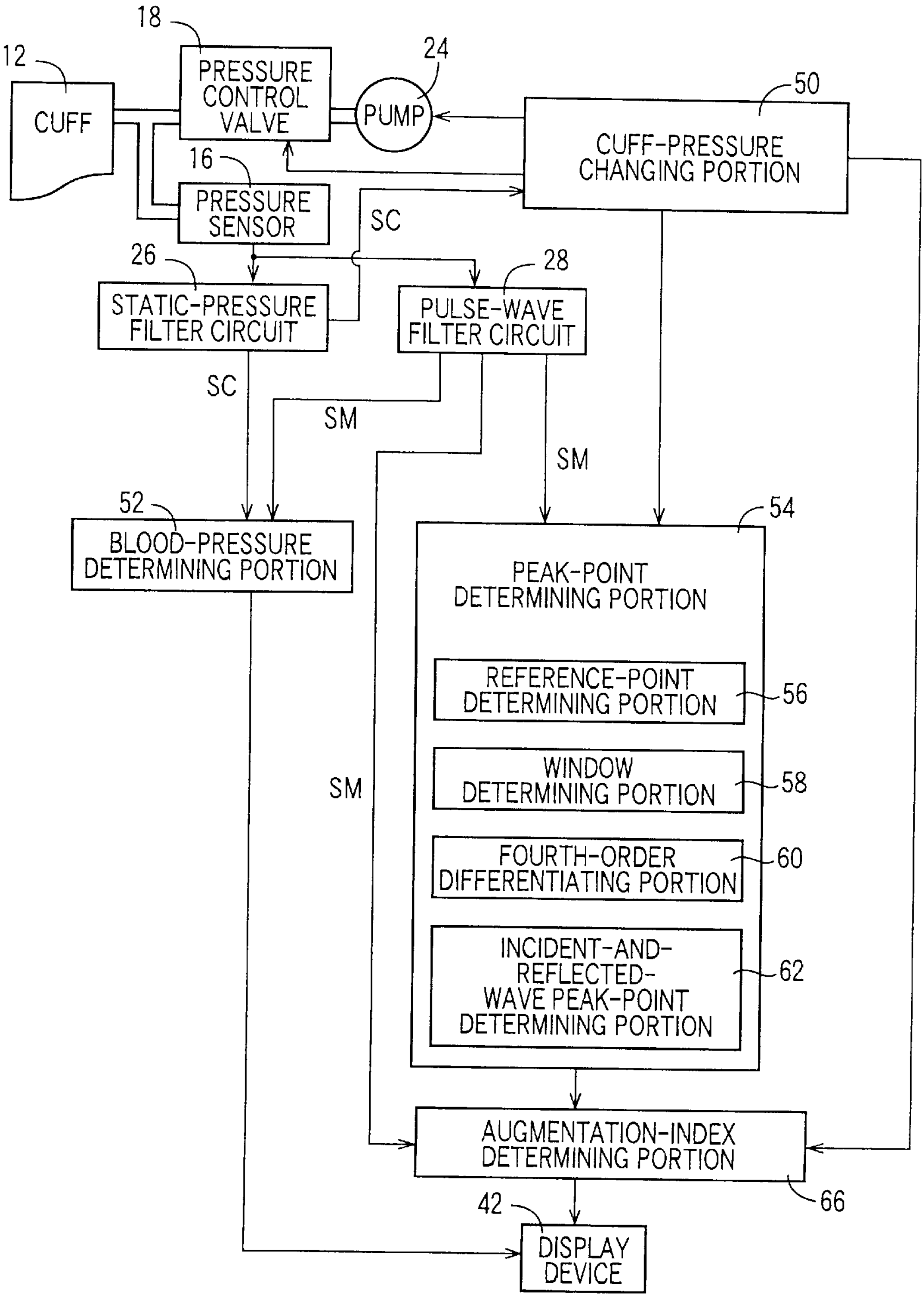

10
12
14
16
18
20
22
24
PRESSURE CONTROL VALVE
PUMP
PRESSURE SENSOR
SP
26
28
STATIC-PRESSURE FILTER CIRCUIT
PULSE-WAVE FILTER CIRCUIT
SC
SM
30
34
A/D CONVERTER
A/D CONVERTER
CPU
ROM
RAM
32
36
38
40
42
DISPLAY DEVICE

FIG. 2



12
CUFF
18
PRESSURE CONTROL VALVE
24
PUMP
50
CUFF-PRESSURE CHANGING PORTION
16
PRESSURE SENSOR
SC
26
STATIC-PRESSURE FILTER CIRCUIT
28
PULSE-WAVE FILTER CIRCUIT
SC
SM
SM
52
BLOOD-PRESSURE DETERMINING PORTION
54
PEAK-POINT DETERMINING PORTION
REFERENCE-POINT DETERMINING PORTION
56
WINDOW DETERMINING PORTION
58
FOURTH-ORDER DIFFERENTIATING PORTION
60
INCIDENT-AND-REFLECTED-WAVE PEAK-POINT DETERMINING PORTION
62
SM
AUGMENTATION-INDEX DETERMINING PORTION
66
42
DISPLAY DEVICE

FIG. 3

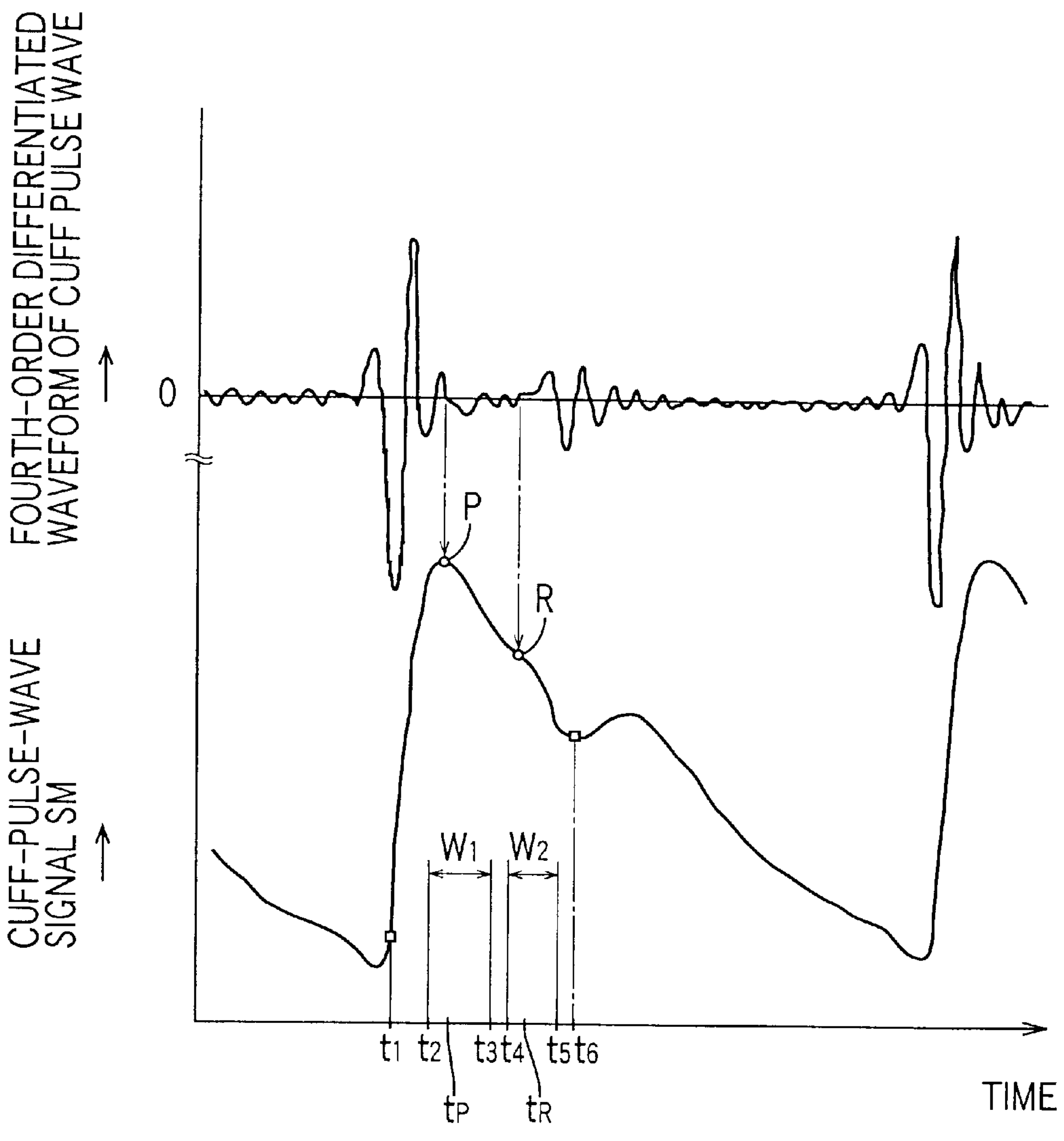

FOURTH-ORDER DIFFERENTIATED WAVEFORM OF CUFF PULSE WAVE
0
CUFF-PULSE-WAVE SIGNAL SM
P
R
W1
W2
t1
t2
t3
t4
t5
t6
tP
tR
TIME

FIG. 4

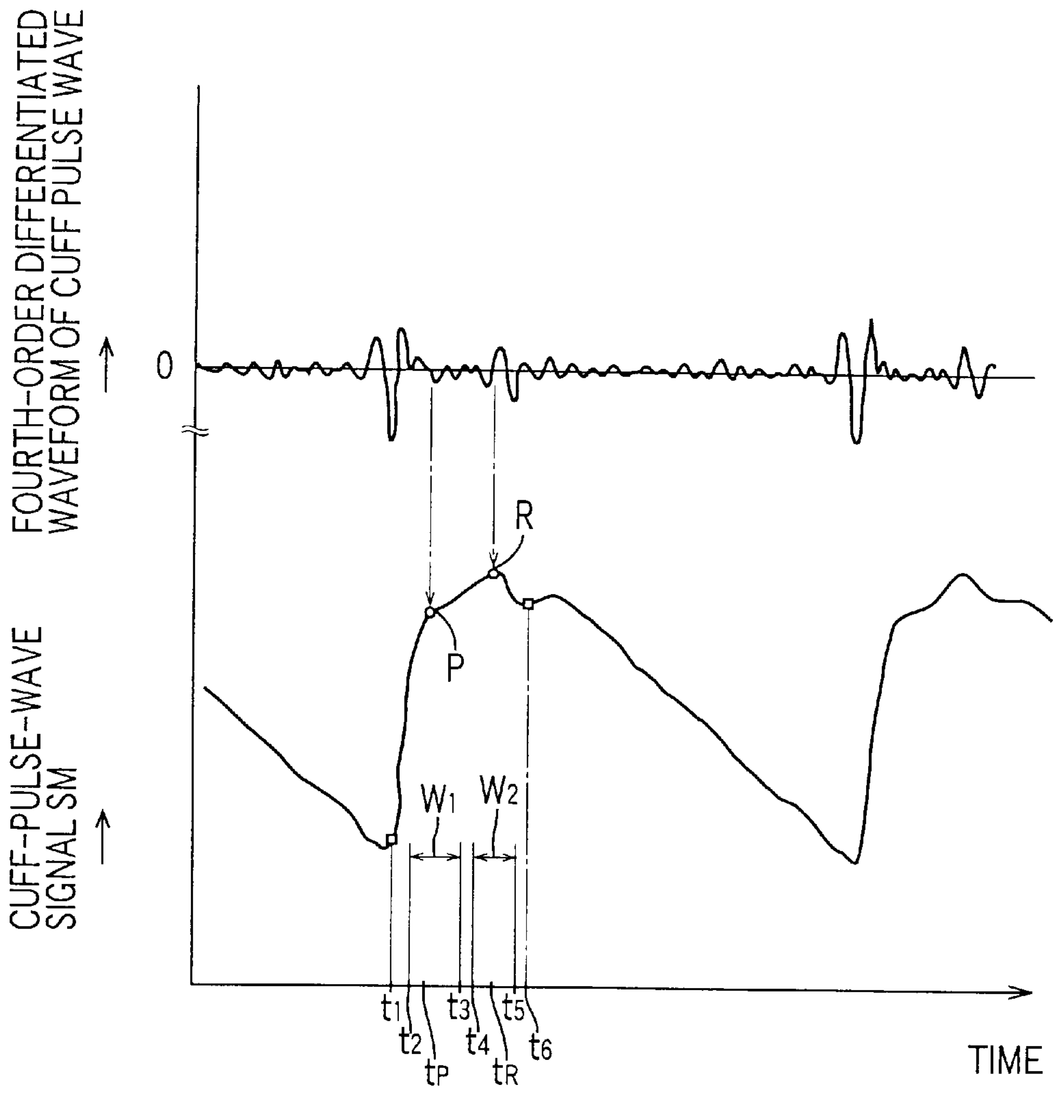

FOURTH-ORDER DIFFERENTIATED WAVEFORM OF CUFF PULSE WAVE
0
CUFF-PULSE-WAVE SIGNAL SM
R
P
W1
W2
t1
t2
tP
t3
t4
tR
t5
t6
TIME

FIG. 5

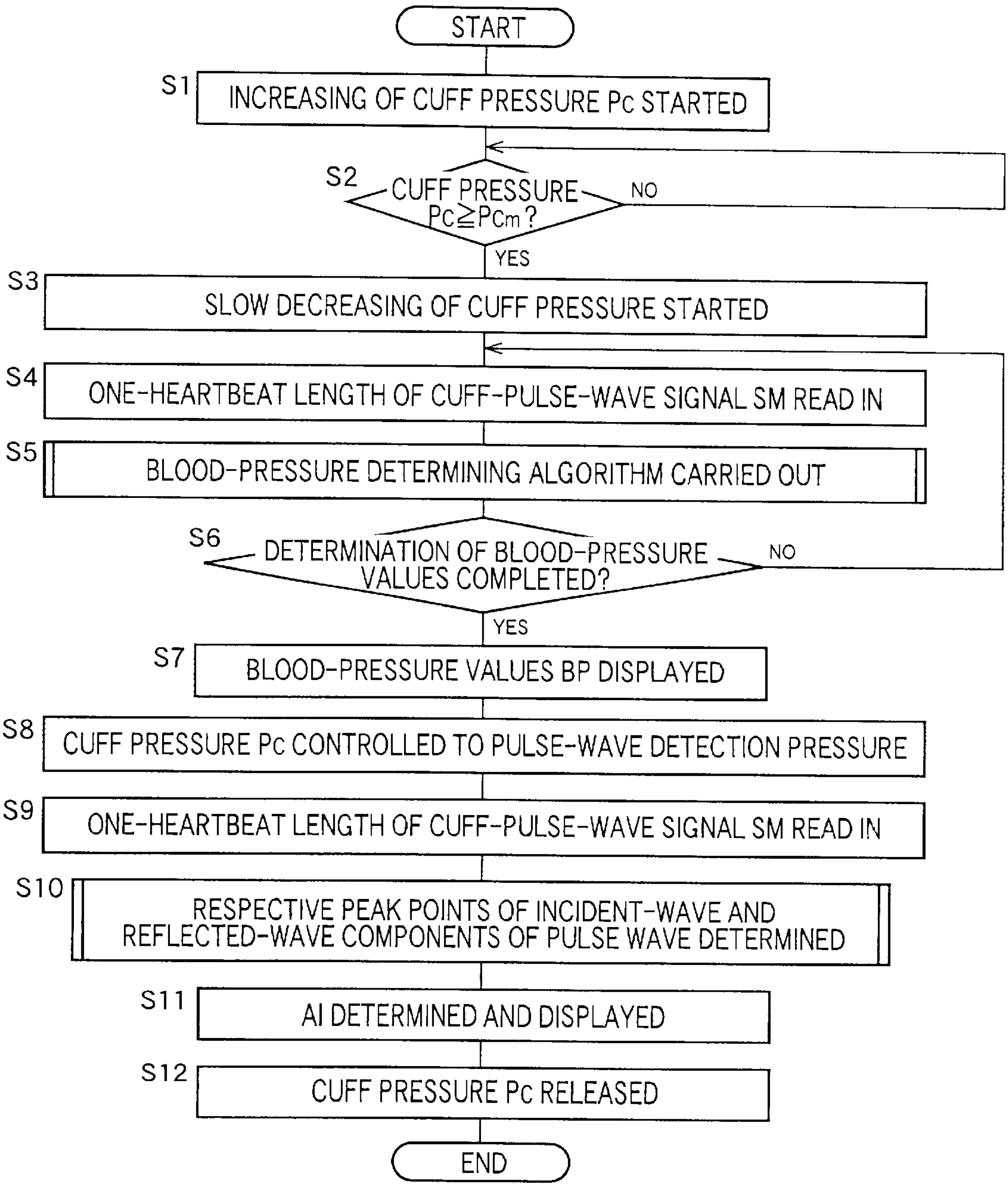
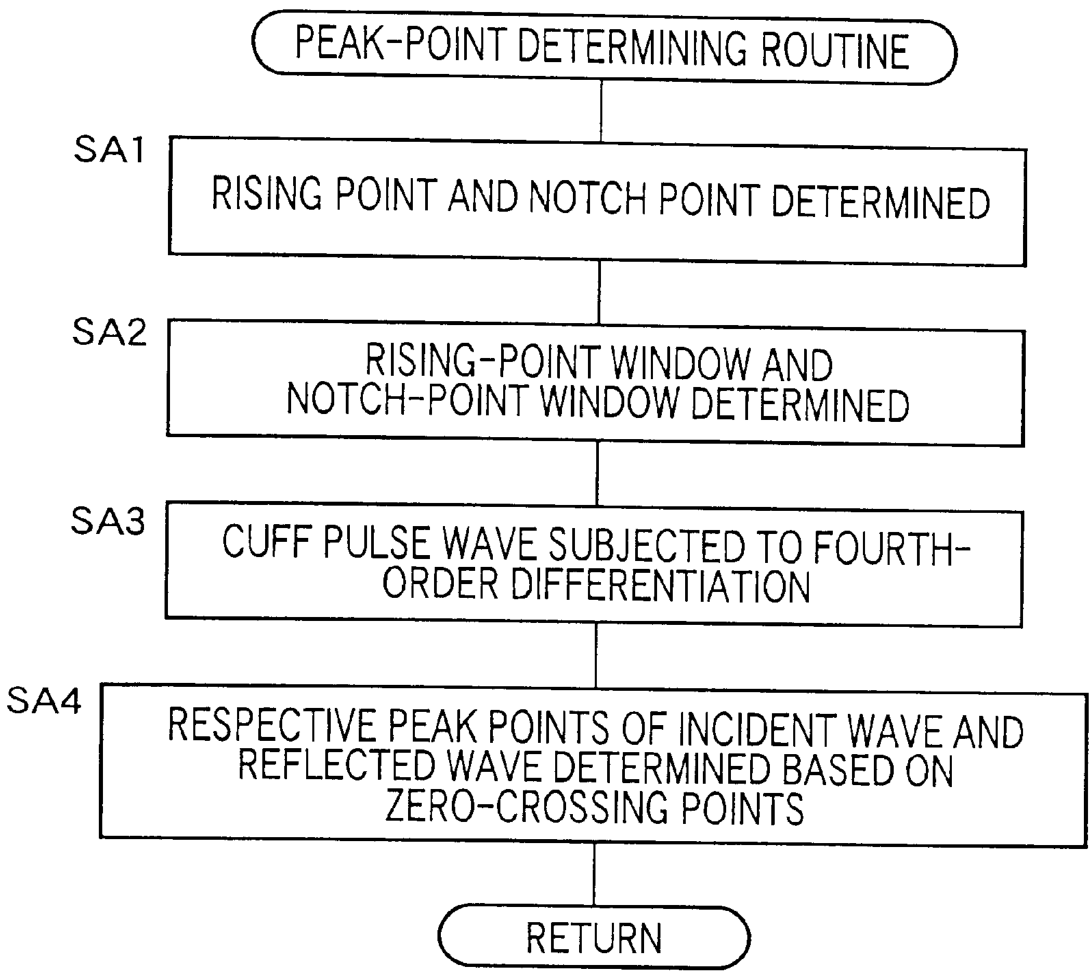

START
S1
INCREASING OF CUFF PRESSURE Pc STARTED
S2
CUFF PRESSURE Pc≧Pcm?
NO
YES
S3
SLOW DECREASING OF CUFF PRESSURE STARTED
S4
ONE-HEARTBEAT LENGTH OF CUFF-PULSE-WAVE SIGNAL SM READ IN
S5
BLOOD-PRESSURE DETERMINING ALGORITHM CARRIED OUT
S6
DETERMINATION OF BLOOD-PRESSURE VALUES COMPLETED?
NO
YES
S7
BLOOD-PRESSURE VALUES BP DISPLAYED
S8
CUFF PRESSURE Pc CONTROLLED TO PULSE-WAVE DETECTION PRESSURE
S9
ONE-HEARTBEAT LENGTH OF CUFF-PULSE-WAVE SIGNAL SM READ IN
S10
RESPECTIVE PEAK POINTS OF INCIDENT-WAVE AND REFLECTED-WAVE COMPONENTS OF PULSE WAVE DETERMINED
S11
AI DETERMINED AND DISPLAYED
S12
CUFF PRESSURE Pc RELEASED
END

FIG. 6


PEAK-POINT DETERMINING ROUTINE
SA1
RISING POINT AND NOTCH POINT DETERMINED
SA2
RISING-POINT WINDOW AND NOTCH-POINT WINDOW DETERMINED
SA3
CUFF PULSE WAVE SUBJECTED TO FOURTH-ORDER DIFFERENTIATION
SA4
RESPECTIVE PEAK POINTS OF INCIDENT WAVE AND REFLECTED WAVE DETERMINED BASED ON ZERO-CROSSING POINTS
RETURN

AUGMENTATION-INDEX MEASURING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an augmentation-index measuring apparatus that measures an augmentation index of a living subject, based on a cuff pulse wave obtained from a cuff that is worn on a portion of the subject's body to press the body portion.

2. Related Art Statement

Augmentation index, generally known as AI, indicates, e.g., a proportion of a reflected-wave component of a pulse wave to an incident-wave component of the same, and is used to evaluate compliance of aorta. As the compliance of aorta increases, the reflected-wave component decreases and, as the compliance of aorta decreases, the reflected-wave component increases. More specifically described, as wall of aorta hardens, a reflected-wave component contained in waveform of pulse wave obtained from the aorta increases. Thus, augmentation index reflects arteriosclerosis, and can be used as an index for inspecting arteriosclerosis.

As described above, augmentation index indicates a proportion of a reflected-wave component of a pulse wave to an incident-wave component of the same, but it is difficult to separate a pulse wave detected (hereinafter, referred to as a detected pulse wave) into its incident-wave and reflected-wave components. Hence, an augmentation index may be determined as follows: First, a detected pulse wave is analyzed to identify respective peak points of incident-wave and reflected-wave components of the pulse wave. Then, the augmentation index is calculated by dividing a difference between a magnitude of the detected pulse wave at the time of occurrence of the peak of the incident-wave component and a magnitude of the pulse wave at the time of occurrence of the peak of the reflected-wave component, by a pulse pressure of the pulse wave. In addition, the peak of the incident-wave component may be determined as an inflection point or a local-maximum point between a rising point of the detected pulse wave and a peak of the same; and the peak of the reflected-wave component may be determined as the first local maximum point following the peak of the incident-wave component.

Since augmentation index is used to evaluate compliance of aorta as described above, it is a clinical practice to non-invasively detect a pulse wave from a carotid artery that is, of arteries located in the vicinity of body surface, the nearest to the aorta, and determine an augmentation index based on the carotid pulse wave. However, first, it needs adequate skill to wear, at an appropriate position, a carotid-pulse-wave sensor for detecting a carotid pulse wave and, second, it is needed to use or employ the carotid-pulse-wave sensor. Thus, there has been a need to easily measure an augmentation index using a cuff pulse wave detected from a cuff that is worn on, e.g., an upper arm of a living subject for measuring a blood pressure of the subject.

However, since a cuff pulse wave is detected as an oscillation of pressure in a cuff, change of the cuff pulse wave is considerably moderate, and accordingly there are many cases where it is difficult to identify respective peak points of incident-wave and reflected-wave components contained in the cuff pulse wave. In addition, there are some cases where the peak of the reflected-wave component is not the first local maximum point following the peak of the incident-wave component. In those cases, an accurate augmentation index cannot be determined based on respective magnitudes of the cuff pulse wave at the respective times of occurrence of the respective peaks of the incident-wave and reflected-wave components.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an augmentation-index measuring apparatus that can measure an accurate augmentation index based on a cuff pulse wave.

The Inventors have carried out extensive studies and found that though respective peak points of incident-wave and reflected-wave components contained in a cuff pulse wave may not be clearly identified from the waveform of cuff pulse wave, there is a phenomenon that zero-crossing points of a fourth-order-differentiated waveform of the cuff pulse wave advantageously correspond to the respective peak points of incident-wave and reflected-wave components, and that an accurate augmentation index can be determined as a ratio of one of respective magnitudes of the cuff pulse wave at the respective peak points of the incident-wave and reflected-wave components determined based on the zero-crossing points of the fourth-order-differentiated waveform, to the other. The present invention has been developed based on this finding.

The above object has been achieved by the present invention. According to the present invention, there is provided an augmentation-index measuring apparatus comprising a cuff which is adapted to be worn on a portion of a living subject to press the portion; a fourth-order-differentiating device or means for subjecting a cuff pulse wave obtained from the cuff, to a fourth-order differentiation, and thereby obtaining a fourth-order-differentiated waveform; a peak-point determining device or means for determining, based on the fourth-order-differentiated waveform obtained by the fourth-order-differentiating device, a peak point of an incident-wave component contained in the cuff pulse wave and a peak point of a reflected-wave component contained in the cuff pulse wave; and an augmentation-index determining device or means for determining an augmentation index of the subject that indicates a proportion of one of a first magnitude of the cuff pulse wave at a time of occurrence of the peak point of the incident-wave component and a second magnitude of the cuff pulse wave at a time of occurrence of the peak point of the reflected-wave component, to the other of the first and second magnitudes.

According to the present invention, the peak-point determining device determines, based on the fourth-order-differentiated waveform obtained by the fourth-order-differentiating device, the peak point of the incident-wave component contained in the cuff pulse wave and the peak point of the reflected-wave component contained in the cuff pulse wave, and the augmentation-index determining device accurately determines the augmentation index indicating the proportion of one of the magnitude of the cuff pulse wave at the time of occurrence of the peak point of the incident-wave component and the magnitude of the cuff pulse wave at the time of occurrence of the peak point of the reflected-wave component, to the other.

According to a preferred feature of the present invention, the augmentation-index measuring apparatus further comprises a reference-point determining device or means for determining, as a reference point, a rising point of the cuff pulse wave; and a window determining device or means for determining a rising-point window based on the rising point determined by the reference-point determining device, and the peak-point determining device determines the peak point of the incident-wave component, based on a zero-crossing point of the fourth-order-differentiated waveform that falls in the rising-point window determined by the window determining device. Thus, the peak point of the incident-wave component is more accurately determined and the augmentation index is more accurately determined based on the peak point, as compared with a case where a peak point is determined on a moderate waveform.

According to another feature of the present invention, the peak-point determining device selects, as the peak point of the incident-wave component, one of a plurality of zero-crossing points of the fourth-order-differentiated waveform that fall in the rising-point window, such that the selected one zero-crossing has a predetermined relationship with respect to a starting point or an ending point of the rising-point window. According to this feature, since the zero-crossing point having the predetermined position is determined as the peak point of the incident-wave component, the peak point of the incident-wave component is more accurately determined and the augmentation index is more accurately determined based on the peak point.

According to another feature of the present invention, the augmentation-index measuring apparatus further comprises a reference-point determining device or means for determining, as a reference point, a notch point of the cuff pulse wave; and a window determining device or means for determining a notch-point window based on the notch point determined by the reference-point determining device, and the peak-point determining device determines the peak point of the reflected-wave component, based on a zero-crossing point of the fourth-order-differentiated waveform that falls in the notch-point window determined by the window determining device. Thus, the peak point of the reflected-wave component is more accurately determined and the augmentation index is more accurately determined based on the peak point, as compared with a case where a peak point is determined on a moderate waveform.

According to another feature of the present invention, the peak-point determining device selects, as the peak point of the incident-wave component, one of a plurality of zero-crossing points of the fourth-order-differentiated waveform that falls in the notch-point window, such that the selected one zero-crossing has a predetermined relationship with respect to a starting point or an ending point of the notch-point window. According to this feature, since the zero-crossing point having the predetermined position is determined as the peak point of the reflected-wave component, the peak point of the reflected-wave component is more accurately determined and the augmentation index is more accurately determined based on the peak point.

According to another feature of the present invention, the augmentation-index measuring apparatus further comprises a cuff-pressure changing device which changes, for a blood-pressure measurement, a pressure in the cuff from a pressure higher than a systolic blood pressure of said portion of the subject to a pressure lower than a diastolic blood pressure of said portion of the subject, and the cuff pulse wave is obtained, before or after the blood-pressure measurement, from the cuff having a pressure lower than the diastolic blood pressure of the subject obtained from the blood-pressure measurement. According to this feature, the augmentation index can be obtained simultaneously with the blood-pressure measurement.

According to another feature of the present invention, the augmentation-index measuring apparatus is used as an arteriosclerosis inspecting apparatus. That is, the arteriosclerosis inspecting apparatus is used for inspecting arteriosclerosis of the subject based on the augmentation index determined by the augmentation-index determining device.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and optional objects, features, and advantages of the present invention will be better understood by reading the following detailed description of the preferred embodiments of the invention when considered in conjunction with the accompanying drawings, in which:

FIG. **1** is a diagrammatic view showing a circuitry of a blood-pressure measuring apparatus having an augmentation-index determining function, to which the present invention is applied;

FIG. **2** is a block diagram for explaining essential control functions of an electronic control device of the blood-pressure measuring apparatus having the augmentation-index determining function, shown in FIG. **1**;

FIG. **3** is a time chart showing a relationship among a cuff pulse wave, a fourth-order-differentiated waveform, a rising-point window W_1, a notch-point window W_2, an incident-wave peak point P, and a reflected-wave peak point R that are obtained or determined by the control device shown in FIG. **2**;

FIG. **4** is a time chart showing a relationship among a cuff pulse wave having a different waveform than that of the cuff pulse wave shown in FIG. **3**, a fourth-order-differentiated waveform, a rising-point window W_1, a notch-point window W_2, an incident-wave peak point P, and a reflected-wave peak point R;

FIG. **5** is a flow chart for explaining the essential control functions of the electronic control device of the blood-pressure measuring apparatus having the augmentation-index determining function, shown in FIG. **1**; and

FIG. **6** is a flow chart for explaining a peak-point determining routine employed in the flow chart shown in FIG. **5**.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Hereinafter, there will be described an embodiment of the present invention in detail by reference to the drawings. FIG. **1** is a diagrammatic view showing a circuitry of a blood-pressure measuring apparatus **10** to which the present invention is applied and which has an augmentation-index measuring function. The present blood-pressure measuring apparatus **10** can also be used as an arteriosclerosis inspecting apparatus.

In FIG. **1**, reference numeral **12** designates an inflatable cuff which includes a belt-like cloth bag and a rubber bag accommodated in the cloth bag and which is adapted to be wound around an upper arm (i.e., brachium) of a living subject. The cuff **12** is connected via a piping **20** to a pressure sensor **16** and a pressure control valve **18**. The pressure control valve **18** is connected via a piping **22** to an air pump **24**. The pressure control valve **18** adjusts a pressure of a pressurized air supplied from the air pump **24**, and supplies the pressure-adjusted air to the cuff **12**, or discharges the pressurized air from the cuff **12**, so as to control an air pressure in the cuff **12**.

The pressure sensor **16** detects the air pressure in the cuff **12**, and supplies a pressure signal, SP, representing the detected air pressure, to a static-pressure filter circuit **26** and a pulse-wave filter circuit (i.e., a pulse-wave filter device) **28**. The static-pressure filter circuit **26** includes a low-pass filter that extracts, from the pressure signal SP, a cuff-pressure signal, SC, representing a static component of the detected air pressure, i.e., a pressing pressure of the cuff **12** (hereinafter, referred to as the cuff pressure, Pc). The filter circuit **26** supplies the cuff-pressure signal SC to an electronic control device **32** via an A/D (analog-to-digital) converter **30**. The pulse-wave filter circuit **28** includes a band-pass filter that permits passing of signals having frequencies of from 1 to 30 Hz and thereby extracts, from the pressure signal SP, a cuff-pulse-wave signal, SM, representing a cuff pulse wave as an oscillatory component of the detected air pressure. The filter circuit **28** supplies the cuff-pulse-wave signal SM to the control device **32** via an A/D converter **34**. The cuff pulse wave represented by the cuff-pulse-wave signal SM is a pressure oscillation transmitted from an artery of the upper arm **14** of the subject to the cuff **12** and, since this artery is a brachial artery, the cuff pulse wave is called a brachial pulse wave.

The control device **32** is provided by a so-called microcomputer including a CPU (central processing unit) **36**, a ROM (read only memory) **38**, a RAM (random access memory) **40**, and an I/O (input-and-output) port, not shown. The CPU **36** processes signals according to the control programs pre-stored in the ROM **38** by utilizing the temporary-storage function of the RAM **40**, and supplies drive signals via the I/O port to the air pump **24** and the pressure control valve **18** so as to control the cuff pressure Pc. Moreover, the CPU **36** has various functions shown in detail in FIG. **2** for determining an augmentation index AI of the subject, and controls what is displayed by a display device **42**.

FIG. **2** is a block diagram for explaining essential control functions of the control device **32** of the blood-pressure measuring apparatus **10**.

A cuff-pressure changing portion or means **50** operates, based on the cuff-pressure signal SC supplied from the static-pressure filter circuit **26**, the pressure control valve **18** and the air pump **24** so as to change the cuff pressure Pc. Thus, the static-pressure filter circuit **26**, the pressure control valve **18**, the air pump **24**, and the cuff-pressure changing portion **50** cooperate with one another to provide a cuff-pressure changing device. The cuff-pressure changing portion **50** controls the pressure control valve **18** and the air pump **24** so as to carry out the following blood-pressure-measurement-related pressure control: First, the cuff-pressure changing portion **50** quickly increases the cuff pressure Pc to a target pressure value (e.g., 180 mmHg) pre-determined to be higher than a systolic blood pressure BP_{SYS} of the upper arm **14** of the subject, and then slowly decreases the cuff pressure Pc at a prescribed rate of from 2 to 3 mmHg/sec. Finally, after a blood-pressure determining portion or means **52**, described later, determines a diastolic blood pressure BP_{DIA} of the subject, the cuff-pressure changing portion **50** changes the cuff pressure Pc to a pulse-wave detection pressure that is determined, for detecting a cuff pulse wave, based on a mean blood pressure BP_{MEAN} or the diastolic blood pressure BP_{DIA} of the subject, and keeps the cuff pressure Pc at the pulse-wave detection pressure for a time period corresponding to one or more heartbeats of the subject. If the above-indicated pulse-wave detection pressure is higher than the diastolic blood pressure BP_{DIA} of the subject, the cuff or brachial pulse wave extracted by the pulse-wave filter circuit **28** is deformed. In particular, if the pulse-wave detection pressure is higher than the mean blood pressure BP_{MEAN} of the subject, the brachial pulse wave is so largely deformed that an accurate augmentation index AI cannot be determined based thereon. Thus, the pulse-wave detection pressure is preferably lower than the mean blood pressure BP_{MEAN} of the subject, more preferably lower than the diastolic blood pressure BP_{DIA} of the subject, and is equal to, for example, a pressure of from 50 mmHg to 60 mmHg. However, if the cuff pressure Pc is too low, the brachial pulse wave detected is too small to determine an accurate augmentation index AI. Thus, the pulse-wave detection pressure is pre-determined at a value that assures that a brachial pulse wave having a sufficiently great magnitude is detected.

The blood-pressure determining portion or means **52** determines, based on change of respective amplitudes of a plurality of heartbeat-synchronous pulses of the brachial pulse wave represented by the cuff-pulse-wave signal SM continuously obtained during the slow-decreasing of the cuff pressure Pc under the control of the cuff-pressure changing portion **50**, a systolic blood pressure BP_{SYS}, a mean blood pressure BP_{MEAN}, and a diastolic blood pressure BP_{DIA} of the subject, according to well-known oscillometric method. In addition, the determining portion **52** operates the display device **42** to display the thus determined systolic blood pressure BP_{SYS}, etc.

A peak-point determining portion or means **54** subjects, to fourth-order differentiation, the cuff-pulse-wave signal SM obtained from the cuff **12** in the state in which the cuff pressure Pc is kept at the pulse-wave detection pressure, and determines, based on the thus obtained fourth-order-differentiated waveform of the signal SM, more specifically, zero-crossing points of the differentiated waveform, a peak point P of an incident-wave component contained in the signal SM, a time t_P of occurrence of the peak point P, a peak point R of a reflected-wave component of the signal SM, and a time t_R of occurrence of the peak point R. FIGS. **3** and **4** show two cuff-pulse-wave signals SM having respective different waveforms, and their respective fourth-order-differentiated waveforms, and each of the FIGS. **3** and **4** shows the corresponding one signal SM and its differentiated waveform along a common time axis, and additionally shows a peak point P of an incident-wave component of the one signal SM, a time t_P of occurrence of the peak point P, a peak point R of a reflected-wave component of the one signal SM, and a time t_R of occurrence of the peak point R.

The peak-point determining portion **54** includes a reference-point determining portion or means **56** for determining, based on waveform of the cuff pulse wave represented by the cuff-pulse-wave signal SM obtained from the cuff **12** whose pressure is kept at the pulse-wave detection pressure, reference points on the cuff pulse wave, i.e., a rising point t_1 and a notch point t_6; a window determining portion or means **58** for determining a rising-point window (i.e., a time gate) W_1 that starts and ends at a time t_2 and a time t_3, respectively, that are subsequent by respective prescribed times to the rising point t_1, and additionally determining a notch-point window (a time gate) W_2 that starts and ends at a time t_4 and a time t_5, respectively, that are prior by respective prescribed times to the notch point t_6; a fourth-order differentiating portion or means **60** for fourth-order differentiating, i.e., four times differentiating the cuff-pulse-wave signal SM obtained from the cuff **12** whose pressure is kept at the pulse-wave detection pressure; and an incident-and-reflected-wave peak-point determining portion or means **62** for determining, based on two zero-crossing points of the thus obtained fourth-order differentiated waveform that fall within the rising-point window W_1 and the notch-point window W_2, respectively, a peak point P of an incident-wave component of the cuff pulse wave, a time t_P of occurrence of the peak point P, a peak point R of a reflected-wave component of the cuff pulse wave, and a time t_R of occurrence of the peak point R. The reference-point determining portion **56** determines, as a rising point t_1, a point that is subsequent to a local minimum point of a heartbeat-synchronous pulse of the cuff pulse wave and has a magnitude equal to a predetermined proportion, e.g., one tenth, of an amplitude between the minimum point and a maximum point of the heartbeat-synchronous pulse, and additionally determines, as a notch point t_6, the first local minimum point, or the first inflection point, subsequent to the maximum point. The incident-and-reflected-wave peak-point determining portion **62** determines, as a peak point t_P of an incident-wave component, a zero-crossing point that has a pre-determined position as counted from the start point of the rising-point window W_1, e.g., the first zero-crossing point falling in the rising-point window W_1, and crosses zero in a direction from a positive area to a negative area; and additionally determines, as a peak point t_R of a reflected-wave component, a zero-crossing point that has a pre-determined position as counted from the start point of the notch-point window W_2, e.g., the first zero-crossing point falling in the notch-point window W_2, and crosses zero in a direction from the negative area to the positive area. The respective times from the rising point t_1 to the start and end points of the rising-point window W_1 and the respective times from the notch point t_6 to the start and end points of the notch-point window W_2, employed by the window determining portion **58**, are experimentally determined in advance so that the peak points t_P, t_R can fall in the widows W_1, W_2, respectively.

An augmentation-index determining portion or means **66** first determines a maximum magnitude and a minimum magnitude of a heartbeat-synchronous pulse of the cuff-pulse-wave signal SM obtained from the cuff **12** whose pressure Pc is kept at the pulse-wave detection pressure, and additionally determines, as a pulse pressure (i.e., a maximum amplitude) PP of the cuff pulse wave, a difference between the maximum and minimum magnitudes. Moreover, the augmentation-index determining portion **66** determines, according to a relationship represented by the following Expression 1, an augmentation index AI based on the pulse pressure PP and a difference ΔP (=b−a) obtained by subtracting a magnitude, a, of the cuff pulse wave at the time of occurrence of the peak point t_P of the incident-wave component from a magnitude, b, of the cuff pulse wave at the time of occurrence of the peak point t_R of the reflected-wave component, and operates the display device **42** to display the thus determined augmentation index AI.

$$AI=(\Delta P/PP)\times 100\ (\%) \qquad \text{(Expression 1)}$$

FIG. **5** is a flow chart representing the control functions of the CPU **36**, shown in the block diagram of FIG. **2**; and FIG. **6** is a flow chart representing a sub-routine corresponding to an incident-and-reflected-wave peak-point determining operation carried out according to FIG. **5**.

In FIG. **5**, when a measurement starting operation, not shown, is carried out, the control of the CPU starts with Step **S1** (hereinafter, the term "Step" is omitted). At **S1**, the CPU actuates the air pump **24** and operates the pressure control valve **18** and, for a blood pressure measurement, the CPU starts quick increasing of the cuff pressure Pc to the predetermined target pressure value Pcm, e.g., 180 mmHg. Then, the control goes to **S2** to judge whether the cuff pressure Pc has reached the target pressure Pcm. **S2** is repeated until a positive judgment is made, while the cuff pressure Pc is quickly increased. Meanwhile, if a positive judgment is made at **S2**, the control goes to **S3** to stop the air pump **24** and operate the pressure control valve **18** to slowly decrease the cuff pressure Pc at a low rate of, e.g., from 3 to 5 mmHg/sec.

Then, at **S4**, the CPU reads in a one-heartbeat length of the cuff-pulse-wave signal SM supplied from the pulse-wave filter circuit **28**. Subsequently, the control goes to **S5** corresponding to the blood-pressure determining portion **52**. At **S5**, the CPU determines, based on change of respective amplitudes of a plurality of heartbeat-synchronous pulses of the brachial pulse wave continuously obtained at **S5** during the slow decreasing of the cuff pressure Pc, a systolic blood pressure BP_{SYS}, a mean blood pressure BP_{MEAN}, and a diastolic blood pressure BP_{DIA} of the subject, according to well-known oscillometric method. Then, at **S6**, the CPU judges whether all blood-pressure values BP have been determined at **S5**. **S4** through **S6** are repeated until a positive judgment is made at **S6**, while the current blood-pressure measuring operation is continued. Meanwhile, if a positive judgment is made at **S6**, the control goes to **S7** to operate the display device **42** to display the thus determined systolic blood pressure BP_{SYS}, mean blood pressure BP_{MEAN}, and diastolic blood pressure BP_{DIA}, each determined at **S5**.

Then, the control goes to **S8** corresponding to the cuff-pressure changing portion **50**. At **S8**, the CPU changes and keeps, for obtaining a cuff pulse wave, the cuff pressure Pc to the pulse-wave detection pressure determined and set in advance. Subsequently, the control goes to **S9** to read in a length of the cuff-pulse-wave signal SM that corresponds to at least one heartbeat of the subject. Then, the control goes to **S10** corresponding to the peak-point determining portion **54**. At **S10**, the CPU carries out the peak-point determining routine shown in FIG. **6**.

In FIG. **6**, the control of the CPU starts with **SA1** corresponding to the reference-point determining portion **56**. At **SA1**, the CPU determines, based on the waveform of the cuff pulse wave represented by the cuff-pulse-wave signal SM obtained from the cuff **12** the pressure of which is kept at the pulse-wave detection pressure, reference points on the cuff pulse wave, i.e., a rising point t_1 and a notch point t_6. For example, the reference-point determining portion **56** determines, as the rising point t_1, a point that is subsequent to a minimum point of a heartbeat-synchronous pulse of the cuff pulse wave and has a magnitude equal to a predetermined proportion, e.g., one tenth, of an amplitude between the minimum point and a maximum point of the heartbeat-synchronous pulse, and additionally determines, as the notch point t_6, the first local minimum point, or the first inflection point, subsequent to the maximum point. Subsequently, the control goes to **SA2** corresponding to the window determining portion **58**. At **SA2**, the CPU determines a rising-point window (i.e., a time gate) W_1 that starts and ends at a time t_2 and a time t_3, respectively, that are subsequent by respective prescribed times to the rising point t_1, and additionally determines a notch-point window (a time gate) W_2 that starts and ends at a time t_4 and a time t_5, respectively, that are prior by respective prescribed times to the notch point t_6. Subsequently, the control goes to **SA3** corresponding to the fourth-order differentiating portion **60**. At **SA3**, the CPU subjects, to fourth-order differentiation, the cuff-pulse-wave signal SM obtained from the cuff **12** the pressure of which is kept at the pulse-wave detection pressure. Then, the control goes to **SA4** corresponding to the incident-and-reflected-wave peak-point determining portion **62**. At **SA4**, the CPU determines, based on two zero-crossing points of the thus obtained fourth-order differentiated waveform that fall within the rising-point window W_1 and the notch-point window W_2, respectively, a peak point P of an incident-wave component of the cuff-pulse-wave signal SM, a time t_P of occurrence of the peak point P, a peak point R of a reflected-wave component of the signal SM, and a time t_R of occurrence of the peak point R.

Back to FIG. **5**, after the peak point P of the incident-wave component of the cuff-pulse-wave signal SM, the time t_P of occurrence of the peak point P, the peak point R of the reflected-wave component of the signal SM, and the time t_R of occurrence of the peak point R are thus determined, the control goes to **S10** corresponding to the augmentation-index determining portion **66**. At **S10**, the CPU first determines a pulse pressure (a maximum amplitude) PP of the cuff-pulse-wave signal SM obtained from the cuff **12** the pressure of which is kept at the pulse-wave detection pressure, and then determines a difference ΔP (=b−a) by subtracting a magnitude, a, of the cuff-pulse-wave signal SM at the time of occurrence of the peak point t_P of the incident-wave component from a magnitude, b, of the signal SM at the time of occurrence of the peak point t_R of the reflected-wave component. Moreover, the CPU determines, according to the relationship represented by the above-indicated Expression 1, an augmentation index AI based on the pulse pressure PP and the difference ΔP. Then, at **S11**, the CPU operates the display device **42** to display the thus determined augmentation index AI. Finally, at **S12**, the CPU operates the pressure-control valve **18** to release the cuff pressure Pc down to atmospheric pressure.

As is apparent from the foregoing description of the present embodiment, the peak-point determining portion **54** **(S10)** determines, based on the fourth-order differentiated waveform of the cuff-pulse-wave signal SM, provided by the fourth-order differentiating portion **60** **(SA3)**, the respective peak points P, R of the incident-wave and reflected-wave components of the signal SM; and the augmentation-index determining portion **66** **(S11)** accurately determines, as the augmentation index AI, the proportion of the difference ΔP between the amplitude of the cuff pulse wave at the thus determined peak point P of the incident-wave component and the amplitude of the cuff pulse wave at the thus determined peak point R of the reflected-wave component, to the pulse pressure PP.

Also, in the present embodiment, the reference-point determining portion **56** **(SA1)** determines the rising point of the cuff-pulse-wave signal SM, and the window determining portion **58** **(SA2)** determines the rising-point window W_1 based on the rising point of the cuff-pulse-wave signal SM determined by the reference-point determining portion **56**. In addition, the peak-point determining portion **54** determines, based on the zero-crossing point of the fourth-order differentiated waveform that falls in the rising-point window W_1, the peak point P of the incident-wave component. Thus, as compared with a case in which a peak point is determined on a moderate waveform, the peak point P of the incident-wave component is more accurately determined and accordingly the augmentation index AI is more accurately determined based on the peak point P.

Also, in the present embodiment, the peak-point determining portion **54** selects, as the peak point P of the incident-wave component, one of the zero-crossing points of the fourth-order differentiated waveform that fall in the rising-point window W_1, such that the selected one zero-crossing point has prescribed crossing direction and position as seen from the start or end point of the rising-point window W_1. Therefore, the peak point P of the incident-wave component is more accurately determined and accordingly the augmentation index AI is more accurately determined based on the peak point P.

Also, in the present embodiment, the reference-point determining portion **56** (SA1) determines the notch point of the cuff-pulse-wave signal SM, and the window determining portion **58** (SA2) determines the notch-point window W_2 based on the notch point of the cuff-pulse-wave signal SM, determined by the reference-point determining portion **56**. In addition, the peak-point determining portion **54** determines, based on the zero-crossing point of the fourth-order differentiated waveform that falls in the notch-point window W_2, the peak point R of the reflected-wave component. Thus, as compared with a case in which a peak point is determined on a moderate waveform, the peak point R of the reflected-wave component is more accurately determined and accordingly the augmentation index AI is more accurately determined based on the peak point R.

Also, in the present embodiment, the peak-point determining portion **54** selects, as the peak point R of the reflected-wave component, one of the zero-crossing points of the fourth-order differentiated waveform that fall in the notch-point window W_2, such that the selected one zero-crossing point has prescribed crossing direction and position as seen from the start or end point of the notch-point window W_2. Therefore, the peak point R of the reflected-wave component is more accurately determined and accordingly the augmentation index AI is more accurately determined based on the peak point R.

Also, in the present embodiment, the cuff-pressure changing portion slowly decreases, for each blood-pressure measurement, the pressing pressure of the cuff **12** from a pressure higher than a systolic blood pressure BP_{SYS} of a body portion of the subject where the cuff **12** is worn, to a pressure lower than a diastolic blood pressure BP_{DIA} of the body portion of the subject, and the cuff-pulse-wave signal SM is obtained, immediately after the blood-pressure measurement, from the cuff **12** whose pressure is sufficiently lower than the diastolic blood pressure of the subject obtained from the blood-pressure measurement. Thus, the augmentation index AI is obtained simultaneously with the blood-pressure measurement.

Also, in the present embodiment, the blood-pressure measuring apparatus **10** having the augmentation-index determining function can be used as an arteriosclerosis inspecting apparatus. In this case, the arteriosclerosis inspecting apparatus inspects a degree of arteriosclerosis of a living subject based on an augmentation index AI determined by the augmentation-index determining portion **66**.

While the present invention has been described in its preferred embodiment by reference to the drawings, it is to be understood that the invention may otherwise be embodied.

For example, in the illustrated blood pressure measuring apparatus **10** having the augmentation-index determining function, the cuff **12** is worn on the upper arm **14**. However, the cuff **12** may be worn on a different body portion of the subject, such as a femoral portion or an ankle.

Also, in the illustrated blood pressure measuring apparatus **10** having the augmentation-index determining function, the cuff-pressure changing portion **50** first quickly increases the cuff pressure Pc to the target pressure higher than the systolic blood pressure BP_{SYS} of the subject, subsequently slowly decreases the cuff pressure Pc from the target pressure, and then changes the cuff pressure Pc to the pulse-wave detection pressure for detecting the cuff pulse wave. However, the cuff-pressure changing portion **50** may be modified such that the portion **50** changes the cuff pressure Pc to the pulse-wave detection pressure for detecting the cuff pulse wave, before the portion **50** quickly increases the cuff pressure Pc for measuring blood-pressure values of the subject. In this case, an augmentation index AI is measured before the blood-pressure-measurement.

In the illustrated blood pressure measuring apparatuses **10** having the augmentation-index determining function, the cuff pulse wave is obtained in the state in which the cuff pressure Pc is kept at the pulse-wave detection pressure. However, a cuff pulse wave may be obtained during the slow decreasing of the cuff pressure Pc, because it is possible to obtain, using a high-performance filter, a cuff pulse wave that is not so largely deformed.

In addition, generally, augmentation index AI is calculated according to the mathematical expression (Expression 1) where the denominator is pulse pressure PP. However, even in the case where the denominator is replaced with an amplitude of low-pressure-cuff pulse wave at the time of occurrence of peak point of the incident-wave component or at the time of occurrence of peak point of the reflected-wave component, a value calculated according to the thus modified expression reflects a degree of arteriosclerosis. Therefore, in Expression 1, pulse pressure PP may be replaced with amplitude of low-pressure-cuff pulse wave at the time of occurrence of peak point of the incident-wave component or at the time of occurrence of peak point of the reflected-wave component. In short, augmentation index may be defined as any value that indicates a proportion of a reflected-wave component of a cuff pulse wave to an incident-wave component of the same.

In the illustrated embodiment, the incident-and-reflected-wave peak-point determining portion **62** determines, as the peak point P of the incident wave, the first zero-crossing point of the fourth-order differentiated waveform that falls in the rising-point window W_1 and where the waveform crosses zero in the direction from the positive area to the negative area, and additionally determines, as the peak point R of the reflected wave, the first zero-crossing point that falls in the notch-point window W_2 and where the waveform crosses zero in the direction from the negative area to the positive area. However, the position and direction of each zero crossing may be changed depending upon the manner in which the rising-point window W_1 and the notch-point window W_2 are determined and the manner in which the fourth-order differentiation is applied to the cuff pulse wave.

It is to be understood that the present invention may be embodied with other changes, improvements, and modifications that may occur to a person skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An augmentation-index measuring apparatus comprising:

a cuff which is adapted to be worn on a portion of a living subject to press said portion;

a fourth-order-differentiating device which subjects a cuff pulse wave obtained from the cuff, to a fourth-order differentiation, and thereby obtaining a fourth-order-differentiated waveform;

a peak-point determining device which determines, based on the fourth-order-differentiated waveform obtained by the fourth-order-differentiating device, a peak point of an incident-wave component contained in the cuff pulse wave and a peak point of a reflected-wave component contained in the cuff pulse wave; and

an augmentation-index determining device which determines an augmentation index of the subject that indicates a proportion of one of a first magnitude of the cuff pulse wave at a time of occurrence of the peak point of the incident-wave component and a second magnitude of the cuff pulse wave at a time of occurrence of the peak point of the reflected-wave component, to the other of the first and second magnitudes.

2. An apparatus according to claim **1**, further comprising:

a reference-point determining device which determines, as a reference point, a rising point of the cuff pulse wave; and

a window determining device which determines a rising-point window based on the rising point determined by the reference-point determining device,

wherein the peak-point determining device determines the peak point of the incident-wave component, based on a zero-crossing point of the fourth-order-differentiated waveform that falls in the rising-point window determined by the window determining device.

3. An apparatus according to claim **2**, wherein the peak-point determining device selects, as the peak point of the incident-wave component, one of a plurality of zero-crossing points of the fourth-order-differentiated waveform that fall in the rising-point window, such that the selected one zero-crossing has a predetermined relationship with respect to a starting point or an ending point of the rising-point window.

4. An apparatus according to claim **1**, further comprising:

a reference-point determining device which determines, as a reference point, a notch point of the cuff pulse wave; and

a window determining device which determines a notch-point window based on the notch point determined by the reference-point determining device,

wherein the peak-point determining device determines the peak point of the reflected-wave component, based on a zero-crossing point of the fourth-order-differentiated waveform that falls in the notch-point window determined by the window determining device.

5. An apparatus according to claim **4**, wherein the peak-point determining device selects, as the peak point of the incident-wave component, one of a plurality of zero-crossing points of the fourth-order-differentiated waveform that falls in the notch-point window, such that the selected one zero-crossing has a predetermined relationship with respect to a starting point or an ending point of the notch-point window.

6. An apparatus according to claim **1**, further comprising a cuff-pressure changing device which changes, for a blood-pressure measurement, a pressure in the cuff from a pressure higher than a systolic blood pressure of said portion of the subject to a pressure lower than a diastolic blood pressure of said portion of the subject, wherein the cuff pulse wave is obtained, before or after the blood-pressure measurement, from the cuff having a pressure lower than the diastolic blood pressure of the subject obtained from the blood-pressure measurement.

7. An augmentation-index measuring apparatus comprising:

a cuff which is adapted to be worn on a portion of a living subject to press said portion;

a fourth-order-differentiating means for subjecting a cuff pulse wave obtained from the cuff, to a fourth-order differentiation, and thereby obtaining a fourth-order-differentiated waveform;

a peak-point determining means for determining, based on the fourth-order-differentiated waveform obtained by the fourth-order-differentiating device, a peak point of an incident-wave component contained in the cuff pulse wave and a peak point of a reflected-wave component contained in the cuff pulse wave; and an augmentation-index determining means for determining an augmentation index of the subject that indicates a proportion of one of a first magnitude of the cuff pulse wave at a time of occurrence of the peak point of the incident-wave component and a second magnitude of the cuff pulse wave at a time of occurrence of the peak point of the reflected-wave component, to the other of the first and second magnitudes.

8. A method of inspecting arteriosclerosis of a subject comprising:

Measuring an augmentation index with the measuring apparatus of claim **1**; and

inspecting arteriosclerosis of the subject based on the augmentation index.

* * * * *

patsnap

专利名称(译)	增强指数测量装置		
公开(公告)号	US6659958	公开(公告)日	2003-12-09
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[标]申请(专利权)人(译)	日本柯林股份有限公司		
申请(专利权)人(译)	COLIN CORPORATION		
当前申请(专利权)人(译)	福田DENSHI CO.，LTD.		
[标]发明人	NARIMATSU KIYOYUKI TAMPO AKIRA		
发明人	NARIMATSU, KIYOYUKI TAMPO, AKIRA		
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摘要(译)

一种增强指标测量装置，包括：袖带，其适于佩戴在生活对象的一部分上以按压该部分;四阶微分装置，用于对从袖带获得的袖带脉冲波进行四阶分割，到四阶区分，从而获得四阶微分波形，峰值确定装置，用于根据由四阶微分装置获得的四阶微分波形，确定入射波分量的峰值点包含在袖带脉冲波中的袖带脉冲波和包含在袖带脉冲波中的反射波分量的峰值点，以及用于确定对象的增强指数的增强指标确定装置，其指示第一幅度的一个的比例。在入射波分量的峰值出现时的袖带脉冲波和在反射波的峰值点出现时的袖带脉冲波的第二大小ve分量，到第一和第二大小的另一个。