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(54) INTERFACE BETWEEN VITAL-SIGNS SENSORS AND PATIENT MONITOR

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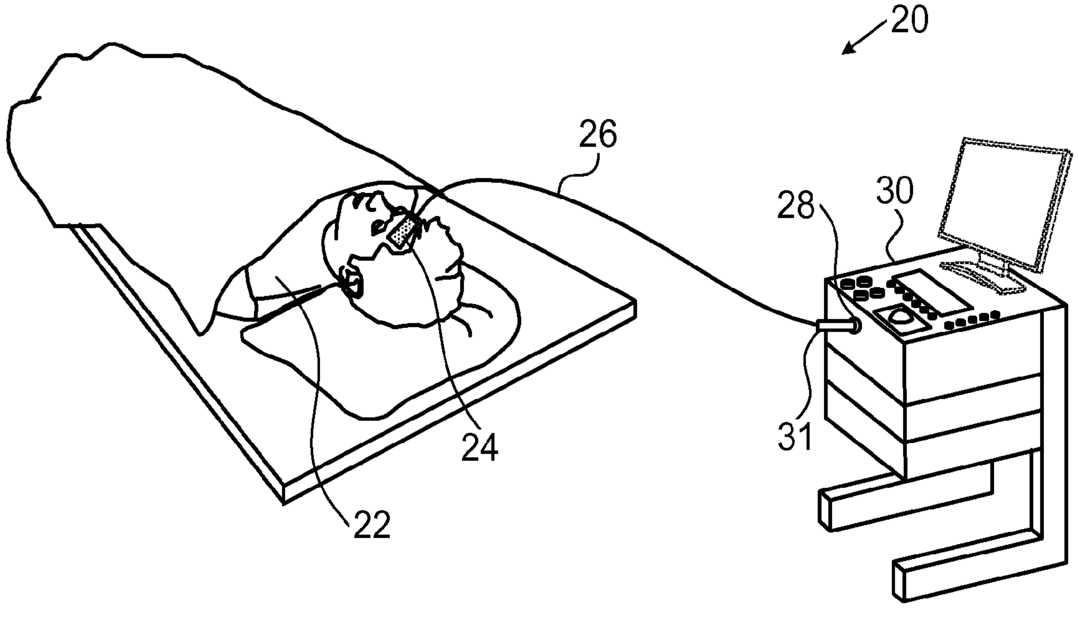
(57) ABSTRACT

An apparatus includes at least one sensor, a connector and a conversion unit. The sensor is coupled to a patient body so as to measure a physiological parameter of the body. The connector coupled to a patient monitor, which measures a value of the physiological parameter by applying a test signal via the connector and measuring a response signal on the connector in response to the test signal. The conversion unit is coupled between the at least one sensor and the connector, and is configured to determine a corrected value of the physiological parameter, to calculate an auxiliary signal that, in combination with the test signal produced by the patient monitor, causes the response signal on the connector to represent the corrected value of the physiological parameter, and to generate and output the auxiliary signal to the connector so as to cause the patient monitor to measure the corrected value.



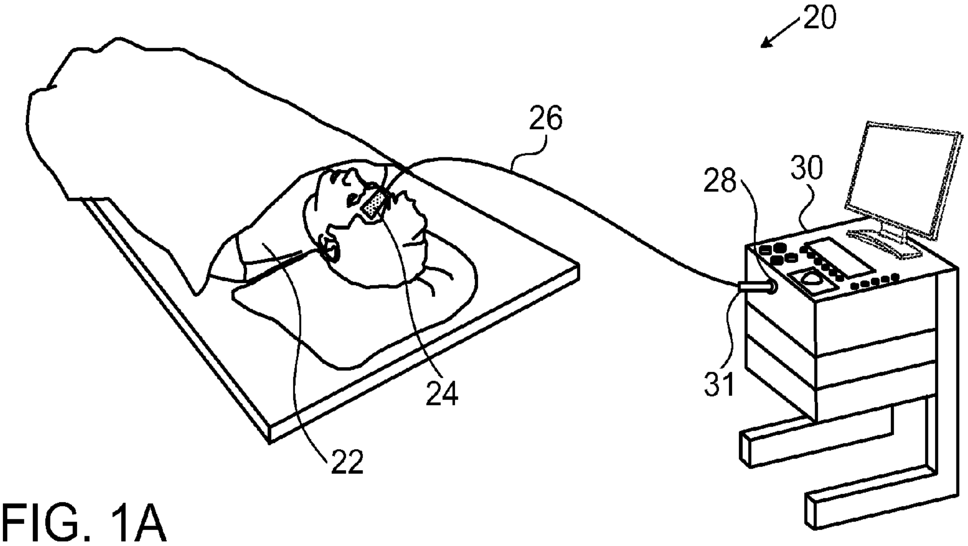


FIG. 1A

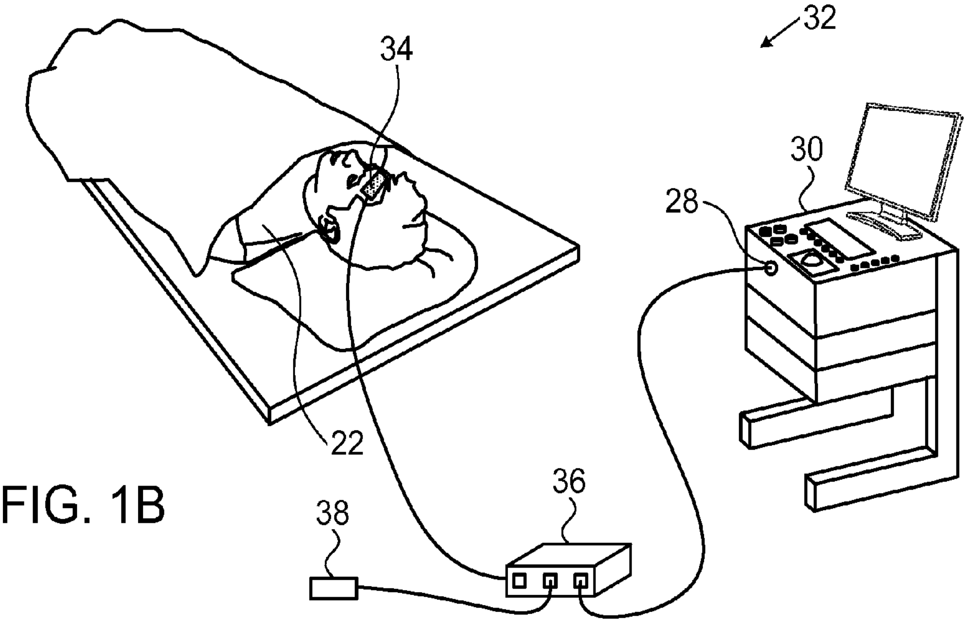
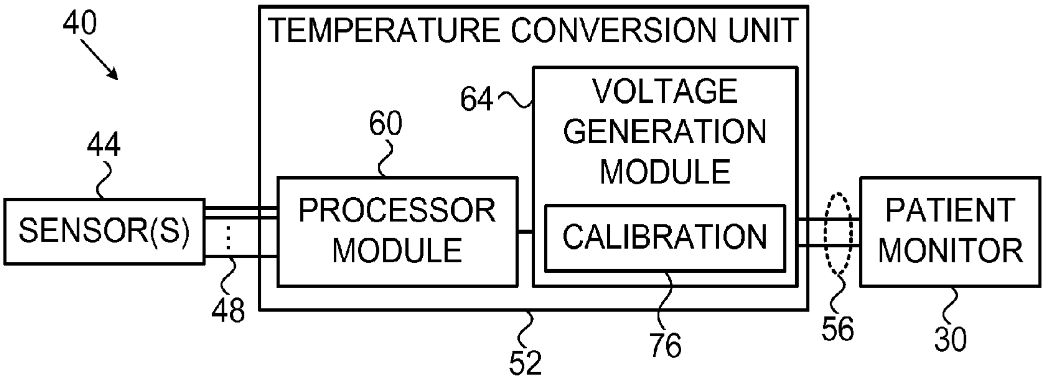


FIG. 1B

FIG. 2



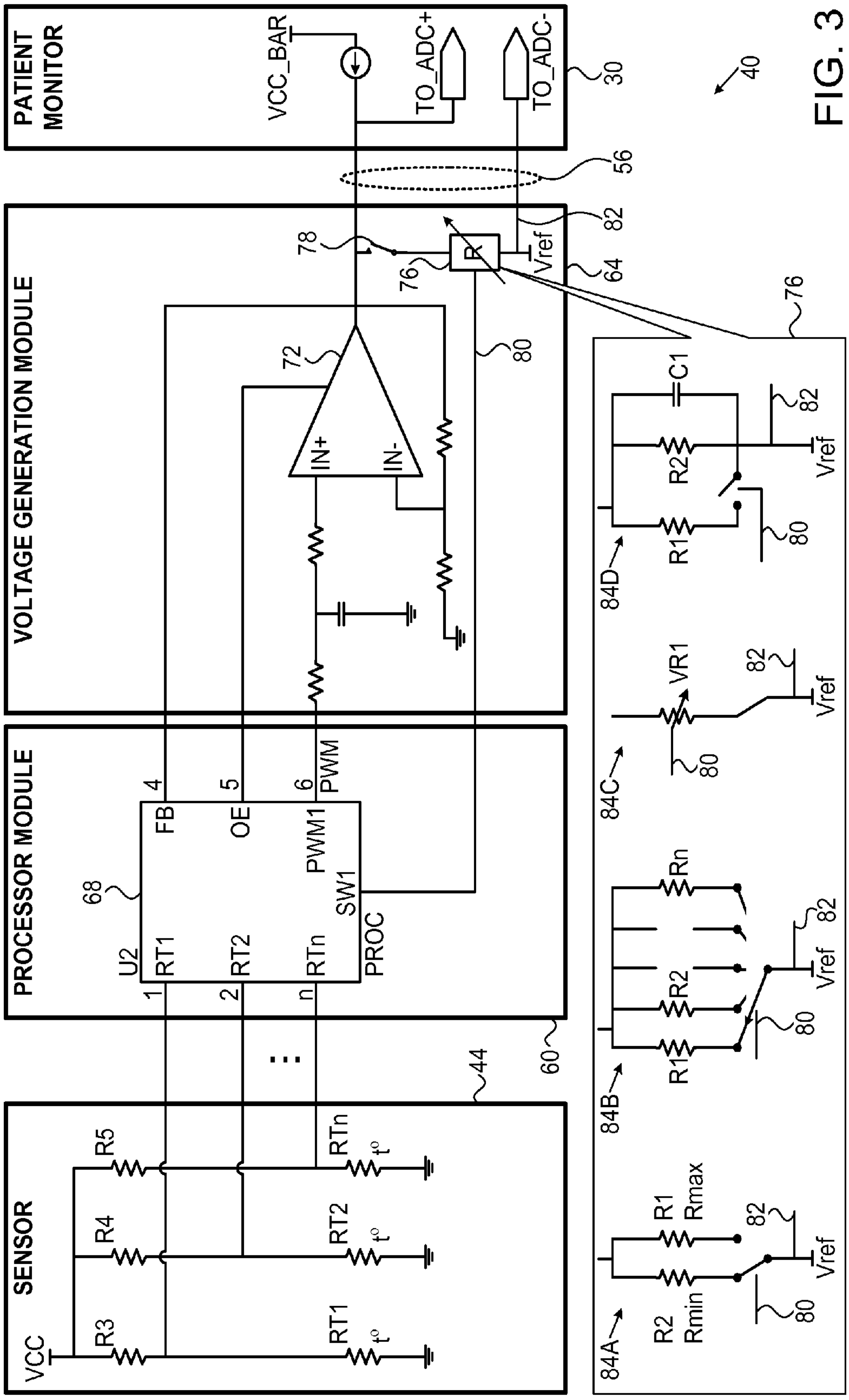

SENSOR
VCC
R3
R4
R5
RT1
RT2
RTn
t°
44
PROCESSOR MODULE
U2
68
RT1
RT2
RTn
PROC
1
2
n
...
SW1
PWM1
OE
FB
4
5
6
PWM
60
VOLTAGE GENERATION MODULE
IN+
IN-
72
80
76
R
78
Vref
82
64
56
PATIENT MONITOR
VCC_BAR
TO_ADC+
TO_ADC-
30
40
84A
R2
Rmin
R1
Rmax
84B
Rn
84C
VR1
84D
C1

FIG. 3

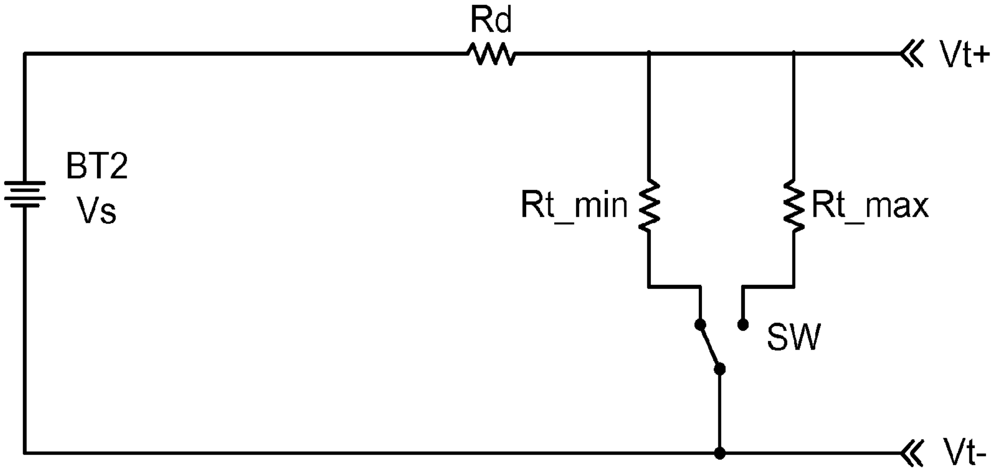


FIG. 4A

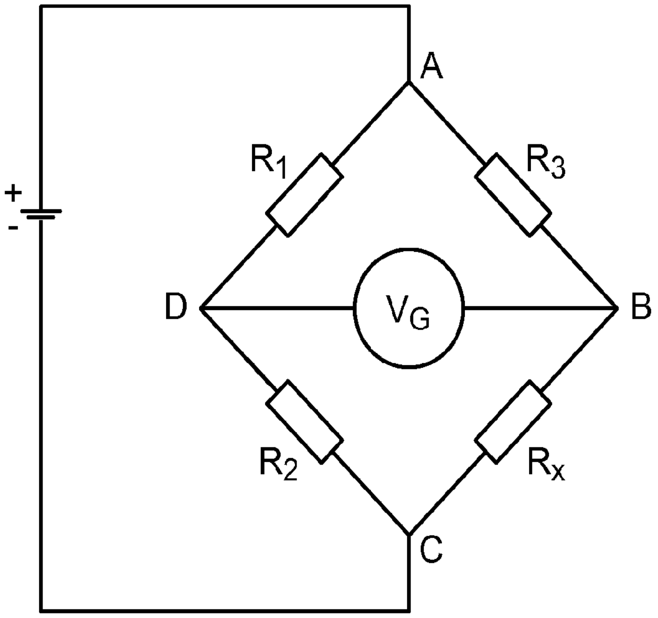


FIG. 4B

INTERFACE BETWEEN VITAL-SIGNS SENSORS AND PATIENT MONITOR

FIELD OF THE INVENTION

[0001] The present invention relates generally to monitoring of vital signs, and particularly to methods and systems for interfacing between vital-sign sensors and patient monitors.

BACKGROUND OF THE INVENTION

[0002] Monitoring of patient vital signs is used in various medical environments, such as hospital wards, operating rooms and Intensive Care Units (ICUs). Vital-signs monitors, also referred to as Patient Monitors (PMs), typically monitor physiological parameters such as temperature, heart rate and peripheral oxygen saturation (S_pO_2) in the blood, among others.

[0003] Many vital-signs monitors include a standard plug for connecting to a thermistor-based temperature probe. Probes of this type were originally developed and standardized by YSI Inc. and include the YSI 400 and YSI 700 types. Such probes include a thermistor sensor, with a calibrated temperature response, and a cable with a standard connector for plugging into the monitor. The vital-signs monitor simply measures the resistance value across the output connector of the cable. The monitor calculates and displays the temperature according to the measured resistance and the known calibration curve.

[0004] Patient temperature measurement can be performed using various kinds of temperature sensors. Some types of temperature sensors are non-invasive, and typically measure the body-surface temperature. Non-invasive temperature sensors are described, for example, in U.S. Pat. No. 7,625,117 and in U.S. Patent Application Publication 2009/0299682, whose disclosures are incorporated herein by reference.

[0005] U.S. Pat. No. 7,641,390, whose disclosure is incorporated herein by reference, describes a method for digitally controlling the resistive output of a temperature probe. The method uses a temperature sensor, a processor and means under the control of the processor for modifying the resistive output, such as a digital potentiometer. In one embodiment, the processor reads the temperature sensor and adjusts the potentiometer based on a correlative or predictive technique so as to provide a modified output that matches that of a standard resistive temperature probe and is compatible for display on a multi-parameter monitor.

[0006] U.S. Pat. No. 7,484,887, whose disclosure is incorporated herein by reference, describes an interface for a monitor and a temperature probe including a temperature sensor. The interface includes a logic circuit for determining a modified resistive output for the temperature sensor and a means for providing the modified resistive output. The means for providing the modified resistive output includes a Field-Effect Transistor (FET), which is coupled to the logic circuit via a first terminal and via a feedback arrangement, providing a FET resistance corresponding to the modified resistive output.

[0007] U.S. Patent Application Publication 2012/0065540, whose disclosure is incorporated herein by reference, describes a temperature sensor with calibrated analog resistive output. In some embodiments, a thermometric apparatus includes at least one body-surface sensor, which is configured to be placed at a location on a body surface of a patient and generates a sensor output that varies according to a body-surface temperature at the location. Analog conversion circuitry is coupled between the at least one body-surface sensor and a connector for coupling to a patient monitor. The circuitry is configured to convert the sensor output into an output resistance across the connector that is indicative of a corrected temperature of the patient.

SUMMARY OF THE INVENTION

[0008] An embodiment of the present invention that is described herein provides an apparatus including at least one sensor, a connector and a conversion unit. The at least one sensor is configured to be coupled to a body of a patient so as to measure a physiological parameter of the body. The connector is configured for coupling to a patient monitor, which measures a value of the physiological parameter by applying a test signal via the connector and measuring a response signal on the connector in response to the test signal. The conversion unit is coupled between the at least one sensor and the connector, and is configured to determine a corrected value of the physiological parameter, to calculate an auxiliary signal that, in combination with the test signal produced by the patient monitor, causes the response signal on the connector to represent the corrected value of the physiological parameter, and to generate and output the auxiliary signal to the connector so as to cause the patient monitor to measure the corrected value.

[0009] In some embodiments, the physiological parameter includes a temperature of the body. In an example embodiment, the at least one sensor includes a body-surface temperature sensor, the measured value includes a body-surface temperature, and the corrected value includes an estimated inner-body temperature. In an embodiment, the measured value includes interim temperature measurements, and the corrected value includes a predicted equilibrium temperature calculated based on the interim temperature measurements. In some embodiments, the conversion unit is configured to read a resistance of the at least one sensor, and to calculate the auxiliary signal based on the resistance.

[0010] In an embodiment, the test signal includes a known current that the patient monitor causes to flow through the at least one sensor, the response signal includes a desired voltage across the connector, and the conversion unit is configured to calculate the auxiliary signal that would produce the desired voltage across the connector in response to the known current. In another embodiment, the test signal includes a known voltage that the patient monitor applies across the connector, the response signal includes a desired current flowing through the connector, and the conversion unit is configured to calculate the auxiliary signal that would produce the desired current through the connector in response to the known voltage.

[0011] In some embodiments, the conversion unit is configured to calibrate a relation between the test signal and the response signal on the connector, and to generate the auxiliary signal based on the calibrated relation. In a disclosed embodiment, the conversion unit is configured to calibrate the relation by connecting multiple known resistances to the connector, and measuring respective response signals or test signals corresponding to the respective known resistances. The conversion unit may be configured to connect the multiple known resistances, for example, using two or more selectable resistors or a digital potentiometer. In another embodiment, the conversion unit is configured to generate the auxiliary signal using a Pulse-Width Modulation (PWM) circuit. In yet another embodiment, the conversion unit is configured to generate the auxiliary signal using a Digital to Analog Converter (DAC).

[0012] There is additionally provided, in accordance with an embodiment of the present invention, a method including coupling to a body of a patient at least one sensor, which measures a physiological parameter of the body, for output by a patient monitor that measures a value of the physiological parameter by applying a test signal via the connector and measuring a response signal on the connector in response to the test signal. A corrected value of the physiological parameter is determined. An auxiliary signal that, in combination with the test signal produced by the patient monitor, causes the response signal on the connector to represent the corrected value of the physiological parameter, is calculated. The auxiliary signal is generated and output to the connector, so as to cause the patient monitor to measure the corrected value.

[0013] The present invention will be more fully understood from the following detailed description of the embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIGS. **1**A and **1**B are schematic, pictorial illustrations of systems for patient monitoring, in accordance with embodiments of the present invention;

[0015] FIG. **2** is a block diagram that schematically illustrates a system for patient monitoring, in accordance with an embodiment of the present invention;

[0016] FIG. **3** is a circuit diagram of elements of a system for patient monitoring, in accordance with an embodiment of the present invention; and

[0017] FIGS. **4**A and **4**B are electrical models of Patient Monitors (PM), used for calibration of a system for patient monitoring, in accordance with embodiments of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Overview

[0018] Embodiments of the present invention that are described herein provide improved methods and systems for measuring and monitoring patient physiological parameters. The embodiments described herein focus on temperature monitoring, although the disclosed techniques can be used, mutatis mutandis, in monitoring various other types of physiological parameters.

[0019] A typical patient monitoring system comprises a temperature sensor and a Patient Monitor (PM). The temperature sensor typically comprises a thermistor that changes its resistance depending on the measured temperature. The PM measures the resistance across its input connector, and displays the corresponding temperature value. Typically, the temperature-resistance dependence of the sensor is known, and the PM uses this dependence to translate the measured resistance to temperature.

[0020] In practice, however, it is sometimes useful for the PM to display a corrected temperature that differs from the temperature measured by the sensor. For example, in some scenarios the sensor measures the body-surface temperature, but the PM should display an estimate of the core-body temperature or some other inner-body temperature. As another example, it is sometimes desirable to measure temperature over a short time period, and use these measurements to predict and display the equilibrium temperature (which typically stabilizes only after several minutes). Another use-case for displaying a corrected temperature is when the temperature sensor uses a resistance-temperature dependence that is different from the dependence known to the PM. In yet another scenario, the temperature sensor is not a resistive-type sensor, but has a voltage output rather than resistive output, such as in an Infra-Red (IR) or thermocouple sensor. In all the above cases, the output of the temperature sensor should be modified or converted in order to display the desired temperature on the PM.

[0021] In some disclosed embodiments of the present invention, a temperature conversion unit is connected between the temperature sensor and the input connector of the PM. The temperature conversion unit carries out a conversion that causes the PM to display the corrected temperature instead of the temperature measured by the sensor. Several example conversion schemes and implementations are described herein. The conversion schemes described herein are active, in the sense that they generate and impose on the PM a corrected voltage or current, which causes the PM to display the desired corrected temperature. These techniques are in sharp contrast to passive conversion schemes that merely reflect a modified resistive output to the PM.

[0022] Typically, the PM is conventionally designed to measure the resistance across its input connector by applying a test signal to the connector (e.g., known voltage across the connector or known current through the connector), and measuring a resulting response signal on the connector (e.g., the current flowing through the connector in response to the known voltage, or the voltage developing across the connector in response to the known current). This sort of conventional design assumes that the sensor coupled across the connector is a passive, resistive sensor, such as a thermistor. Such PM designs typically assume that the sensor has some known resistance-temperature dependence, such as YSI-400.

[0023] In order to cause the PM to display a corrected temperature that is different from the temperature measured by the sensor, the temperature conversion unit generates an auxiliary signal (voltage or current) that, in combination with the test signal produced by the PM, causes the resulting response signal to indicate the corrected temperature instead of the measured temperature. This sort of correction is referred to herein as "active conversion"—as opposed to "passive conversion" that merely provides the PM with a modified resistive output.

[0024] In an example embodiment, the PM applies a known voltage across the connector, and deduces the temperature from the current that flows through the connector (and is thus expected to be proportional to the resistance of the sensor). In this embodiment, the temperature conversion unit may calculate and generate an auxiliary voltage that, jointly with the known voltage applied by the PM, causes a current that corresponds to the corrected temperature. Generally, however, the test signal, response signal and auxiliary signal may each comprise either a current or a voltage. The temperature conversion unit may generate the auxiliary signal in any suitable way, such as using a Pulse-Width Modulation (PWM) circuit or a Digital to Analog Converter (DAC).

[0025] In some embodiments, although not necessarily, the temperature conversion unit carries out a calibration process that connects various known resistances and records the resulting response signal levels. Using this calibration, the temperature conversion unit is able to calculate the appropriate auxiliary signal, without relying on any a-priori knowledge as to the mode of operation of the PM.

[0026] In summary, the disclosed techniques provide highly-accurate temperature conversion between the temperature sensor and the PM. These techniques enable, for example, the use of non-invasive body-surface temperature sensors while still displaying the core-body temperature.

System Description

[0027] FIG. **1**A is a schematic, pictorial illustration of a patient monitoring system **20**, in accordance with an embodiment of the present invention. The system typically monitors multiple physiological parameters of a patient **22** in an operating room or hospital ward. The present example refers mainly to the parts of the system that are involved in temperature measurement. Nevertheless, the disclosed techniques can be used in measurements of other suitable physiological parameters, such as, for example, heart rate, blood perfusion, blood pressure and/or oxygen saturation (S_pO_2).

[0028] In the example of FIG. **1**A, a temperature-sensing patch **24** is affixed to the patient's body surface, such as to the skin of the patient's forehead or elsewhere on the body. Patch **24** comprises one or more temperature sensors, which measure the body-surface temperature, along with some ancillary circuitry (e.g., sensor sampling) and possibly one or more ambient temperature-measurement sensors (not shown explicitly in the figure).

[0029] A temperature conversion unit **31** is mounted on or connected to a cable **26** that connects patch **24** with a Patient Monitor (PM) **30**. Unit **31** reads the temperature measured by patch **24**, and causes PM **30** to display a converted temperature that is computed based on the measured temperature. Example temperature conversion techniques (which can also be used for conversion and display of other physiological parameters) are explained in detail below. In some embodiments, unit **31** further comprises an ambient sensing probe that senses the ambient room temperature.

[0030] In the present example, unit **31** is mounted immediately adjacent to a connector plug **28** of cable **26**, which plugs into PM **30**. For example, unit **31** may be implemented as a dongle. In another example, unit **31** may be mounted at some middle location along cable **26**. In yet another example, the interconnection between patch **24** and unit **31**, and/or the interconnection between unit **31** and PM **30**, may be wireless. The patient monitor typically comprises a processor, with suitable input circuits for receiving signals from various physiological sensors. The input circuits include a standard receptacle for receiving plug **28**.

[0031] Conventionally, monitor **30** measures the resistance across plug **28** and converts the resistance to a temperature value according to a pre-programmed calibration function. The monitor typically displays the resulting temperature measurement and may also track the value over time and issue alarms when the temperature moves outside a preset safety range. Although the description that follows refers mainly to visual display of temperature, in alternative embodiments the patient monitor may output the temperature, to an operator or to another system, in any other suitable way. Recording the temperature for subsequent analysis is also regarded herein as a form of output.

[0032] FIG. **1**B is a schematic, pictorial illustration of a patient monitoring system **32**, in accordance with another embodiment of the present invention. The principles of operation of system **32** are similar to those of system **20**, as described above. In system **32** a temperature-sensing patch **34** on the patient's body measures the body-surface temperature (or temperatures) and possibly other vital signs. A temperature conversion unit **36** is contained in a separate enclosure and is connected by a cable to patch **34**. An ambient sensing probe **38** contains one or more ambient-temperature measurement sensors, such as thermistors. Patch **34** and probe **38** are connected via cables to circuitry **36**. Alternatively, ambient sensing probe **38** may be mounted on the enclosure of circuitry **36**. Typically, circuitry **36** is powered by a suitable power source (now shown in the figures). The power source may comprise, for example, a battery, a power supply, or both.

[0033] In other embodiments, not shown in the figures, alternative system configurations may be used. In an example implementation, the system comprises one processor (referred to as a sampling processor) located on the patch and another processor (referred to as a conversion processor) located in the temperature conversion unit. The two processors may be connected by a wire or wireless link. The sampling processor samples the temperature sensor output and generates digital signals that are transmitted to the conversion processor. This implementation is highly effective against noise and interference, which are common in medical environments. In a specific example the temperature-sensing patch may be connected to a wireless transmitter via a short (e.g., 40 cm) cable to avoid cross contamination. In this configuration, the patch may be disposable while the transmitter may be re-usable.

[0034] In yet another embodiment, temperature conversion unit **36** may be integrated with patch **34**. Alternatively, one or more ambient-measurement thermistors may be integrated with patch **34**, thus obviating probe **38**, while circuitry **36** is housed in a separate unit. Further alternatively, any other suitable configuration can be used.

Example Use-Cases

[0035] The techniques described herein can be used in a wide variety of scenarios and use cases, in which it is useful or necessary for the PM to display a temperature that differs from the temperature measured by the temperature sensor.

[0036] For example, in some scenarios the sensor measures the body-surface temperature, but the PM should display an estimate of some inner body temperature, such as the core-body temperature (defined as the temperature at the pulmonary artery), oral temperature, rectal temperature, axillary temperature, esophageal temperature, or any other suitable inner body temperature.

[0037] In another example scenario, it is sometimes desirable to operate in a predictive mode, i.e., to measure temperature over a short time period and use these measurements to predict the long-term equilibrium temperature measurement. Typically, temperature measurement stabilizes and reaches equilibrium after six to ten minutes. It is often desirable to shorten the measurement time to a time period of, for example, 10-120 seconds, so as to make the procedure easier both for the patient and for the care-giver.

[0038] Another use-case is when the temperature sensor has a resistance-temperature dependence that is different from the dependence known to the PM, or when the sensor is not a resistive-type sensor but has a voltage input rather than resistive output.

[0039] In all of these cases, as well as others, embodiments of the present invention can be used for converting the temperature measured by the temperature sensor or sensors, and causing the PM to display the corrected temperature.

Active Temperature Conversion Schemes

[0040] Typically, PM **30** monitors temperature by measuring the resistance across connector **28**, and translating the measured resistance into a temperature value to be displayed. The PM typically measures the resistance indirectly, e.g., by measuring the voltage across its input connector for a known applied current, or based on a known voltage applied across an internal resistor. The translation typically follows a known calibrated temperature-resistance curve that characterizes the temperature sensor (or using a temperature-voltage curve that takes into account the temperature-resistance dependence as well as the voltage-current dependence applied by the monitor). Temperature-resistance curves of this sort are specified, for example, in de-facto standards such as YSI 400 and YSI 700.

[0041] In some PM implementations, the PM applies a known voltage across connector **28**, and measures the current that flows through the connector in response to the known voltage. This sort of measurement may be implemented, for example, using a voltage divider, a Wheatstone bridge, or any other suitable scheme. In other PM implementations, the PM causes known current to flow through connector **28**, and measures the voltage across the connector in response to the known current. These configurations are also referred to as "current source" configurations. In both cases, the PM calculates the resistance across connector **28** from the measurement using Ohm's law or the equivalent voltage as explained above. The calculation usually takes into account the PM's internal resistance.

[0042] Generalizing the above examples, PM **30** applies a certain test signal (e.g., known voltage or current) to connector **28**, and measures the resulting response signal (e.g., resulting current or voltage) on the connector. The measured response signal can then be translated to resistance and then to temperature, using the known resistance-temperature curve. Alternatively, the measured response signal may be translated directly to temperature, e.g., using a look-up table, a predetermined formula embedded in the PM, or any other suitable means.

[0043] As noted above, the temperature conversion unit causes PM **30** to display a corrected temperature instead of the temperature measured by the temperature sensor. For this purpose, the temperature conversion unit generates an auxiliary signal (voltage or current) that, in combination with the test signal produced by the PM, causes the resulting response signal to indicate the corrected temperature instead of the temperature measured by the sensor.

[0044] In embodiments in which the PM applies a known voltage across the connector, the temperature conversion unit generates an auxiliary voltage that, jointly with the known voltage applied by the PM, causes the current through the connector to correspond to the corrected temperature. In embodiments in which the PM causes known current to flow through the connector, the temperature conversion unit generates an auxiliary current or voltage that, jointly with the known current applied by the PM, causes the voltage across the connector to correspond to the corrected temperature.

[0045] Generally, the test signal, response signal and auxiliary signal may each comprise either a current or a voltage. In some embodiments that are described further below, the temperature conversion unit is compatible with any suitable type of PM, without making prior assumptions as to the PM's mode of operation (known voltage or known current). In the disclosed embodiments, the impedance of the PM is typically matched to the impedance of the temperature conversion unit seen by the PM.

[0046] FIG. **2** is a block diagram that schematically illustrates a system **40** for patient monitoring, in accordance with an embodiment of the present invention. System **40** may be implemented in the configuration of FIG. **1**A, in the configuration of FIG. **1**B, or in any other suitable configuration.

[0047] System **40** comprises one or more temperature sensors **44**, e.g., non-invasive body-surface temperature sensors. Each sensor **44** typically comprises a thermistor that changes its resistance as a function of temperature. (As noted above, in some embodiments system **40** comprises a sampling processor that is adjacent to sensors **44**, and a conversion processor in unit **52**. In other words, the functions of processor module **60** may be split between the sampling processor and the conversion processor.

[0048] System **40** comprises a temperature conversion unit **52**, which is connected between sensors **44** and PM **30**. Unit **52** is connected to sensors **44** using lines **48** (which may also comprise a wireless link), and to PM **30** using a connector **56**. Unit **52** can be used for implementing unit of FIG. **1**A or unit **36** of FIG. **1**B, for example. Temperature conversion unit **52** comprises a processor module **60** and a voltage generation module **64**. Voltage generation module **64** comprises a calibration unit **76**, which carries out an automatic calibration process that is described in detail below. An example circuit implementation of modules **60** and **64** is given in FIG. **3** below.

[0049] The functional division of functions between modules **60** and **64** is presented purely by way of example. In alternative embodiments, the temperature conversion unit may be implemented using any other suitable internal configuration. In an example embodiment, processor module **60** controls the automatic calibration process carried out by unit **76**, which learns the PM characteristics (e.g., internal resistance), as will be described further below. In one embodiment, processor module **60** reads the resistance of each temperature sensor **44**, which corresponds to the temperature measured by that sensor. Module **60** calculates the corrected temperature that should be displayed by PM **30** in accordance with the measured temperature and the ambient temperature.

[0050] Module **60** may derive the corrected temperature from the measured sensor temperature in any suitable way, such as using a predefined table or function. In an example embodiment, the corrected temperature is given by a linear combination of the measured body temperature and the ambient temperature. Additional details regarding the relation between measured and corrected temperature are addressed, for example, in U.S. Pat. Nos. 6,280,397, 7,479,116, 7,597,668 and 8,185,341, whose disclosures are incorporated herein by reference, and in U.S. Pat. Nos. 7,484,887 and 7,641,390 and U.S. Patent Application Publication 2012/0065540, cited above.

[0051] Voltage generation module **64** generates an auxiliary signal that, in combination with the test signal generated by PM **30**, causes the response signal on connector **56** to correspond to the corrected temperature calculated by processing module **60**. The voltage generation module applies this auxiliary signal (voltage or current) to connector **56**. As a result, PM **30** is forced to display the corrected temperature instead of the temperature measured by the sensor.

[0052] In alternative embodiments, the functionality of processor module **60** is split between two processors—A sampling processor that is located adjacent to sensors **44**, and a conversion processor that is adjacent to module **64**. The sampling processor and the conversion processor may be linked using any suitable interface, for example a wireless link.

Example Circuit Implementation

[0053] FIG. **3** is a circuit diagram of elements of system **40**, in accordance with an embodiment of the present invention. In this example, the system comprises three temperature sensors **44**, comprising n respective thermistors denoted RT1 . . . RTn.

[0054] Processor module **60** comprises a processor **68**, which reads the resistances of the n thermistors and calculates the corresponding desired corrected temperature to be displayed on the PM and the appropriate auxiliary signals (voltages or currents) that should be applied in order for PM **30** to display the desired corrected temperature. Voltage generation module **64** comprises at least one operational amplifier **72**, which is connected in a feedback configuration.

[0055] At a given time, the output of amplifier **72** produces a given auxiliary signal, which is then applied to connector **56** of PM **30**. This auxiliary signal, together with the internal test signal of the PM (current or voltage—marked with a current source in the figure), causes the PM to display the appropriate corrected temperature.

[0056] In the embodiment of FIG. **3**, processor **68** controls amplifier **72** to produce the desired auxiliary signal using Pulse-Width Modulation (PWM). In this implementation, pin #6 of processor **68** produces a square-wave PWM signal that alternates between two voltage levels with a controlled duty-cycle. Processor **68** adjusts the duty cycle of the PWM signal such that the average voltage is proportional to the desired auxiliary signal. The PWM signal is filtered by a resistor-capacitor T-network, and then provided as input to amplifier **72**. In response to the PWM signal at its input, amplifier **72** generates the desired auxiliary signal at its output.

[0057] In an alternative embodiment, processor **68** uses a Digital-to-Analog Converter (not shown in the figure) instead of a PWM circuit to control voltage generation module **64**. In this embodiment, the processor controls the DAC to generate a control signal that is proportional to the desired auxiliary signal. The DAC output (voltage or current) is provided as input to operational amplifier **72**. Further alternatively, processor **68** may control voltage generation module **64** to generate the desired auxiliary signals in any other suitable way.

Automatic Calibration Scheme

[0058] In some embodiments, temperature conversion unit **52** does not make any a-priori assumptions as to the mode of operation of PM **30**. In these embodiments, unit **52** carries out an automatic calibration process that learns the PM characteristics (e.g., internal resistance and signals). Using the calibration results, unit **52** is able to accurately set the auxiliary signals, regardless of whether the PM uses voltage-source or current-source measurement and regardless of the actual internal resistance of the PM.

[0059] In an example embodiment (illustrated in FIG. **3**) voltage generation module **64** comprises a calibration unit **76**, which comprises a configurable resistance element. Unit **76** can be set by processor **68** to two or more known resistances, which are applied across connector **56** during calibration. Typically, these known resistances are chosen to be properly representative of the full range of minimal to maximal measured temperatures-resistances by the PM. Typically, the output of amplifier **72** is disabled during this process, so that the only resistance across connector **56** is that of unit **76**. By alternating between different resistances of unit **76**, processor **68** is able to measure the actual voltages that develop across connector **56** in response to various resistances. Unit **76** is typically connected across connector **56** of the PM only during calibration. During normal operation, unit **76** is disconnected, e.g., using a switch **78**.

[0060] In some embodiments, system **40** comprises measurement circuitry that measures the voltage across (or current through) the known resistance connected to the PM. In the example of FIG. **3**, the voltage across connector **56** is fed back to a feedback (FB) pin of processor **68** (pin **4**, denoted FB). Processor **68** digitizes the voltage on its FB pin using an internal Analog-to-Digital Converter (ADC). Alternatively, any other suitable measurement circuitry can be used.

[0061] In a typical calibration process, processor **68** sets various arbitrary resistances within the resistance range expected by the PM in unit **76**, measures the resulting voltages (response signals) on connector **56**, and builds a Look-Up Table (LUT) that translates between the measured response signals and resistance. During normal operation, processor **68** calculates the corrected temperature to be displayed by the PM (based on the measured sensor temperature and some correction algorithm), and then uses the known resistance-temperature dependence such as YSI 400 to determine the resistance that is expected by the PM in order to display the corrected temperature. Based on the desired resistance and the LUT, processor **68** calculates the auxiliary signal that corresponds to the desired resistance. Processor **68** then causes module **64** to generate the auxiliary signal that corresponds to this resistance.

[0062] In another example calibration process, the LUT translates temperatures directly into voltages. In this process, processor **68** sets various arbitrary resistances within the resistance range expected by the PM in unit **76**, and measures the resulting voltages (response signals) on connector **56**. Using a known temperature-resistance dependence such as YSI 400, processor **68** builds a LUT that translates between the measured response signals and respective temperatures to be displayed on the PM. During normal operation, processor calculates the corrected temperature to be displayed by the PM (based on the measured sensor temperature and some correction algorithm). Based on the corrected temperature and the LUT, processor **68** calculates the auxiliary signal that corresponds to the corrected temperature. Processor **68** then causes module **64** to generate the auxiliary signal that corresponds to this resistance.

[0063] In another embodiment, processor **68** builds a database, which comprises the internal resistance and the voltage that PM **30** applies. Based on this data, the processor module is able to calculate the auxiliary voltage needed in order to emulate the resistance corresponding to the desired displayed temperature. Example calibration schemes and formulas for constructing such a database are provided further below.

[0064] Unit **76** may be implemented in various ways. Four examples are shown at the bottom of FIG. **3**. In all these examples, processor **68** sets the resistance of unit **76** using a control signal **80**. A reference voltage V_{ref} is applied to one terminal of unit **76** (denoted **82**), which is also connected to one terminal of connector **56**. The other terminal of unit **76** is connected to the second terminal of connector **56**.

[0065] In a first example (denoted **84**A), unit **76** comprises two resistors R**1** and R**2**, which are selected by signal **80**. Typically, resistors R**1** and R**2** are set to the maximum and minimum resistances (R_{max} and R_{min}) of the resistance range of interest. When using YSI 400 temperature sensors, for example, R**1** and R**2** may be on the order of 2KΩ and 1KΩ, respectively. This example enables relatively coarse calibration using two data points.

[0066] In a second example (denoted **84**B), unit **76** comprises n resistors R**1** . . . Rn, which are selected by signal **80**. The resistances of resistors R**1** . . . Rn are typically distributed across the resistance range of interest, e.g., 1KΩ to 2KΩ. This implementation enables higher-accuracy calibration using multiple data points. A third implementation example (denoted **84**C) enables even finer calibration. In this example, unit **76** comprises a digital potentiometer (denoted VR**1**) that is controlled by signal **80**.

[0067] In a fourth implementation example (denoted **84**D), control signal **80** is a PWM signal that toggles the switch so as to alternate between resistances R**1** and R**2** at a certain duty cycle. By controlling the PWM duty cycle, control signal **80** is able to create various effective resistances.

[0068] Let D and Fpwm denote the duty cycle and frequency of signal **80**, respectively, such that D=0 means a constantly-open switch and D=1 means a constantly-closed switch. The effective resistance of unit **76** is Reff=Rp·D+R**1** (1−D), wherein Rp=R**1**·R**2**/(R**1**+R**2**). Varying the duty cycle enables setting of effective resistances in the range Rp≤Reff≤R**1**. For smooth circuit operation, capacitance C**1** should typically be chosen such that Reff·C**1**>>1/Fpwm. Further alternatively, calibration unit **76** may be implemented in any other suitable way.

[0069] The system configurations shown in FIGS. **1**A, **1**B and **2**, and the temperature conversion unit configuration shown in FIG. **3**, are example configurations that are chosen purely for the sake of conceptual clarity. In alternative embodiments, any other suitable configuration can be used. Some elements of the patient monitoring system, and in particular the temperature conversion unit, may be implemented in hardware, e.g., in one or more Application-Specific Integrated Circuits (ASICs) or Field-Programmable Gate Arrays (FPGAs). Additionally or alternatively, some elements of the system, including elements of the temperature conversion unit, can be implemented using software, or using a combination of hardware and software elements.

[0070] Some of the system functions, such as the functions of processor module **60**, may be carried out using a general-purpose processor, which is programmed in software to carry out the functions described herein. The software may be downloaded to the processor in electronic form, over a network, for example, or it may, alternatively or additionally, be provided and/or stored on non-transitory tangible media, such as magnetic, optical, or electronic memory.

Example Patient Monitor Models and Associated Calibration Schemes

[0071] In various embodiments, processor **68** of temperature conversion unit **52** performs the above-described automatic calibration under some assumption as to the structure of PM **30**. Two example types of PMs are a voltage-divider-based PM and a Wheatstone-bridge-based PM. In other embodiments, processor **68** does not make any such assumptions and regards the PM as a "black box."

[0072] FIG. **4**A is an electrical model of a voltage-divider-based PM, which is used for calibration of temperature conversion unit **52**, in accordance with an embodiment of the present invention. In this model, Vs denotes the internal voltage applied by the PM, Rd denotes the internal serial resistance of the PM, Rt_min denotes the minimal expected resistance of the temperature sensor, Rt_max denotes the maximal expected resistance of the temperature sensor, and Vt denotes the voltage drop across the temperature sensor (i.e., across connector **56**).

[0073] The temperature-dependent resistance of the temperature sensor is denoted Rt. In an embodiment, Rt_min and Rt_max are chosen as the minimal and maximal resistances in the YSI400 range of interest, respectively. The assumption in this model is that, in order to measure temperature, the PM measures Vt, which is a function of Rt. The relationship between Vt and Rt is given by:

$$Vt = Vs\frac{Rt}{Rd + Rt}$$

and therefore:

$$Rt = \frac{Rd}{\frac{Vs}{Vt} - 1}$$

[0074] The PM is assumed to measure Vt and use the above relationship to derive Rt and thus the temperature. Therefore, knowledge of Rd and Vs of the PM enables unit **52** to calculate the desired voltage Vt that needs to be applied across connector **56** in order to cause the PM to measure any desired temperature.

[0075] In an example process for estimating Rd and Vs of the PM, unit **52** connects two resistances Rt_min and Rt_max to connector **56**, one resistance at a time. By measuring the voltage drop across connector **56** in the presence of each resistance, unit **52** is able to derive Rd and Vs.

[0076] Analysis of the circuit of FIG. **4**A gives the following relationships:

$$Imin = \frac{Vtmin}{Rtmin}$$

$$Imax = \frac{Vtmax}{Rtmax}$$

[0077] Let Vd_min and Vd_max denote the minimal and maximal voltages across the constant resistance Rd, we get:

$$Vs = Vd\_\mathrm{min} + Vt\_\mathrm{min}$$

$$Vs = Vd\_\mathrm{max} + Vt\_\mathrm{max}$$

[0078] By subtracting the two equations, and assuming the same currents Imin and Imax flow through Rd, we get:

$$Vtmax - Vtmin = Rd(Imin - Imax)$$

-continued

or

$$Rd = \frac{Vtmax - Vtmin}{Imin - Imax}$$

and therefore:

$$Vs = Rd \cdot Imax + Vtmax$$

or

$$Vs = Rd \cdot Imin + Vtmin$$

[0079] By using the voltage-divider relationship, we get:

$$Vtx = \frac{Vs}{\left(\frac{Rd}{Rx} + 1\right)}$$

wherein Rx denotes any desired sensor resistance, and Vtx denotes the value of Vt needed to cause the PM to measure resistance Rx (and thus the corresponding temperature). The equation above gives the translation between voltage and resistance, but knowing the temperature-resistance dependence, this translation is equivalent to a direct translation between voltage and temperature.

[0080] FIG. **4**B is an electrical model of a Wheatstone-bridge-based PM, which is used for calibration of temperature conversion unit **52**, in accordance with another embodiment of the present invention. In such a PM, the relationship between the temperature-dependent resistance Rx and the voltage Vg (measured between points B and D in the figure) is given by:

$$Vg = \left(\frac{Rx}{R3 + Rx} - \frac{R2}{R1 + R2}\right)Vs$$

or

$$Vg = Vs\frac{Rx}{R3 + Rx} - Vs\frac{R2}{R1 + R2}$$

[0081] The equation above can be written as

$$Vg = Vt = V0$$

wherein V**0** is a constant voltage of the R**1**-R**2** voltage divider. This equation means that, for a Wheatstone-bridge PM, a similar calibration procedure can be used as used above for voltage-divider PMs.

[0082] In other embodiments, unit **52** may assume that the temperature-voltage dependence in the PM (e.g., for a voltage divider between internal resistance Rd and temperature-dependent resistance Rt) is close to linear. Therefore, unit **52** may use linear interpolation to calculate Vt as a function of the desired temperature T. For example, unit **52** may measure Vt_min and Vt_max for two constant resistors Rt_min and Rt_max, which are connected in turn to connector **56** of PM **30**. Knowing Tmin and Tmax from YSI400 T-R table, it is possible to calculate any Vt by:

$$Vt = Vtmax - \frac{(T - Tmin)(Vtmax - Vtmin)}{Tmax - Tmin}$$

[0083] The above example refers to two data points. Alternatively, the calibration process may be performed using a larger number of data points, so as to improve the calibration accuracy.

[0084] It will be appreciated that the embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and sub-combinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art. Documents incorporated by reference in the present patent application are to be considered an integral part of the application except that to the extent any terms are defined in these incorporated documents in a manner that conflicts with the definitions made explicitly or implicitly in the present specification, only the definitions in the present specification should be considered.

1. Apparatus, comprising:

at least one sensor, which is configured to be coupled to a body of a patient so as to measure a physiological parameter of the body;

a connector for coupling to a patient monitor, which measures a value of the physiological parameter by applying a test signal via the connector and measuring a response signal on the connector in response to the test signal; and

a conversion unit, which is coupled between the at least one sensor and the connector, and is configured to determine a corrected value of the physiological parameter, to calculate an auxiliary signal that, in combination with the test signal produced by the patient monitor, causes the response signal on the connector to represent the corrected value of the physiological parameter, and to generate and output the auxiliary signal to the connector so as to cause the patient monitor to measure the corrected value.

2. The apparatus according to claim **1**, wherein the physiological parameter comprises a temperature of the body.

3. The apparatus according to claim **2**, wherein the at least one sensor comprises a body-surface temperature sensor, wherein the measured value comprises a body-surface temperature, and wherein the corrected value comprises an estimated inner-body temperature.

4. The apparatus according to claim **3**, wherein the measured value comprises interim temperature measurements, and wherein the corrected value comprises a predicted equilibrium temperature calculated based on the interim temperature measurements.

5. The apparatus according to claim **1**, wherein the conversion unit is configured to read a resistance of the at least one sensor, and to calculate the auxiliary signal based on the resistance.

6. The apparatus according to claim **1**, wherein the test signal comprises a known current that the patient monitor causes to flow through the at least one sensor, wherein the response signal comprises a desired voltage across the connector, and wherein the conversion unit is configured to calculate the auxiliary signal that would produce the desired voltage across the connector in response to the known current.

7. The apparatus according to claim **1**, wherein the test signal comprises a known voltage that the patient monitor applies across the connector, wherein the response signal comprises a desired current flowing through the connector, and wherein the conversion unit is configured to calculate the auxiliary signal that would produce the desired current through the connector in response to the known voltage.

8. The apparatus according to claim **1**, wherein the conversion unit is configured to calibrate a relation between the test signal and the response signal on the connector, and to generate the auxiliary signal based on the calibrated relation.

9. The apparatus according to claim **8**, wherein the conversion unit is configured to calibrate the relation by connecting multiple known resistances to the connector, and measuring respective response signals or test signals corresponding to the respective known resistances.

10. The apparatus according to claim **9**, wherein the conversion unit is configured to connect the multiple known resistances using two or more selectable resistors or a digital potentiometer.

11. The apparatus according to claim **1**, wherein the conversion unit is configured to generate the auxiliary signal using a Pulse-Width Modulation (PWM) circuit.

12. The apparatus according to claim **1**, wherein the conversion unit is configured to generate the auxiliary signal using a Digital to Analog Converter (DAC).

13. A method, comprising:

coupling to a body of a patient at least one sensor, which measures a physiological parameter of the body, for output by a patient monitor that measures a value of the physiological parameter by applying a test signal via the connector and measuring a response signal on the connector in response to the test signal;

determining a corrected value of the physiological parameter, and calculating an auxiliary signal that, in combination with the test signal produced by the patient monitor, causes the response signal on the connector to represent the corrected value of the physiological parameter; and

generating and outputting the auxiliary signal to the connector so as to cause the patient monitor to measure the corrected value.

14. The method according to claim **13**, wherein the physiological parameter comprises a temperature of the body.

15. The method according to claim **14**, wherein the at least one sensor comprises a body-surface temperature sensor, wherein the measured value comprises a body-surface temperature, and wherein the corrected value comprises an estimated inner-body temperature.

16. The method according to claim **14**, wherein the measured value comprises interim temperature measurements, and wherein the corrected value comprises a predicted equilibrium temperature calculated based on the interim temperature measurements.

17. The method according to claim **13**, wherein calculating the auxiliary signal comprises reading a resistance of the at least one sensor and calculating the auxiliary signal based on the resistance.

18. The method according to claim **13**, wherein the test signal comprises a known current that the patient monitor causes to flow through the at least one sensor, wherein the response signal comprises a desired voltage across the connector, and wherein calculating the auxiliary signal comprises computing the auxiliary signal that would produce the desired voltage across the connector in response to the known current.

19. The method according to claim **13**, wherein the test signal comprises a known voltage that the patient monitor applies across the connector, wherein the response signal comprises a desired current flowing through the connector, and wherein calculating the auxiliary signal comprises computing the auxiliary signal that would produce the desired current through the connector in response to the known voltage.

20. The method according to claim **13**, wherein calculating the auxiliary signal comprises calibrating a relation between the test signal and the response signal on the connector, and wherein outputting the auxiliary signal comprises generating the auxiliary signal based on the calibrated relation.

21. The method according to claim **20**, wherein calibrating the relation comprises connecting multiple known resistances to the connector, and measuring respective response signals or test signals corresponding to the respective known resistances.

22. The method according to claim **21**, wherein connecting the multiple known resistances comprises selecting between two or more selectable resistors or setting a digital potentiometer.

23. The method according to claim **13**, wherein outputting the auxiliary signal comprises generating the auxiliary signal using a Pulse-Width Modulation (PWM) circuit.

24. The method according to claim **13**, wherein outputting the auxiliary signal comprises generating the auxiliary signal using a Digital to Analog Converter (DAC).

* * * * *

专利名称(译)	生命体征传感器与患者监护仪之间的接口		
公开(公告)号	US20150211944A1	公开(公告)日	2015-07-30
申请号	US14/164328	申请日	2014-01-27
[标]申请(专利权)人(译)	MEDISIM		
申请(专利权)人(译)	MEDISIM LTD.		
当前申请(专利权)人(译)	MEDISIM LTD.		
[标]发明人	YARDEN MOSHE GOROVETZ VLADIMIR		
发明人	YARDEN, MOSHE GOROVETZ, VLADIMIR		
IPC分类号	G01K15/00 A61B5/01 A61B5/00 A61B5/021 A61B5/026 A61B5/145 G01K7/16 A61B5/024		
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其他公开文献	US9599521		
外部链接	Espacenet USPTO		

摘要(译)

一种装置包括至少一个传感器，连接器和转换单元。传感器耦合到患者身体，以便测量身体的生理参数。连接器耦合到患者监视器，其通过经由连接器施加测试信号来测量生理参数的值，并且响应于测试信号测量连接器上的响应信号。转换单元耦合在至少一个传感器和连接器之间，并且被配置为确定生理参数的校正值，以计算辅助信号，该辅助信号与患者监视器产生的测试信号一起引起响应。连接器上的信号表示生理参数的校正值，并产生辅助信号并输出到连接器，以使患者监视器测量校正值。