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(54) METHODS AND DEVICES FOR MEASURING BODY TEMPERATURE IN A REDUCED TIME

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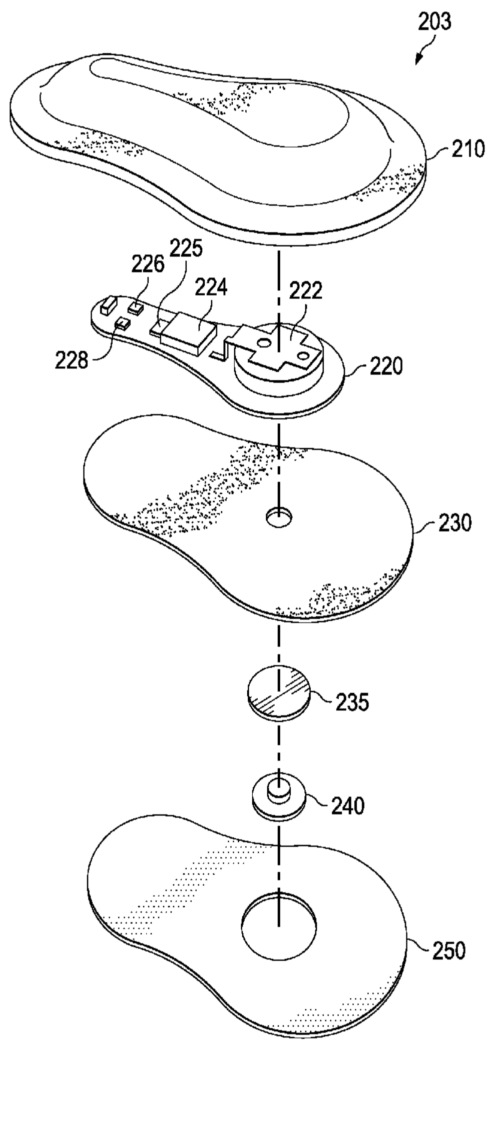
(57) **ABSTRACT**

Various methods and devices for reducing the time for a body-mountable temperature monitoring device to provide an accurate body temperature are disclosed. Methods are used to accurately predict the measured temperature once the monitoring device reaches thermal equilibrium. For example, in one embodiment, a method for measuring body temperature of a subject includes obtaining, by a temperature monitor attached to a body of the subject, a plurality of body temperature measurements at a plurality of times, determining parameters of a model used for predicting temperature based on the plurality of measurements, predicting a body temperature of the subject based on the model, and outputting the predicted body temperature as a current temperature reading.



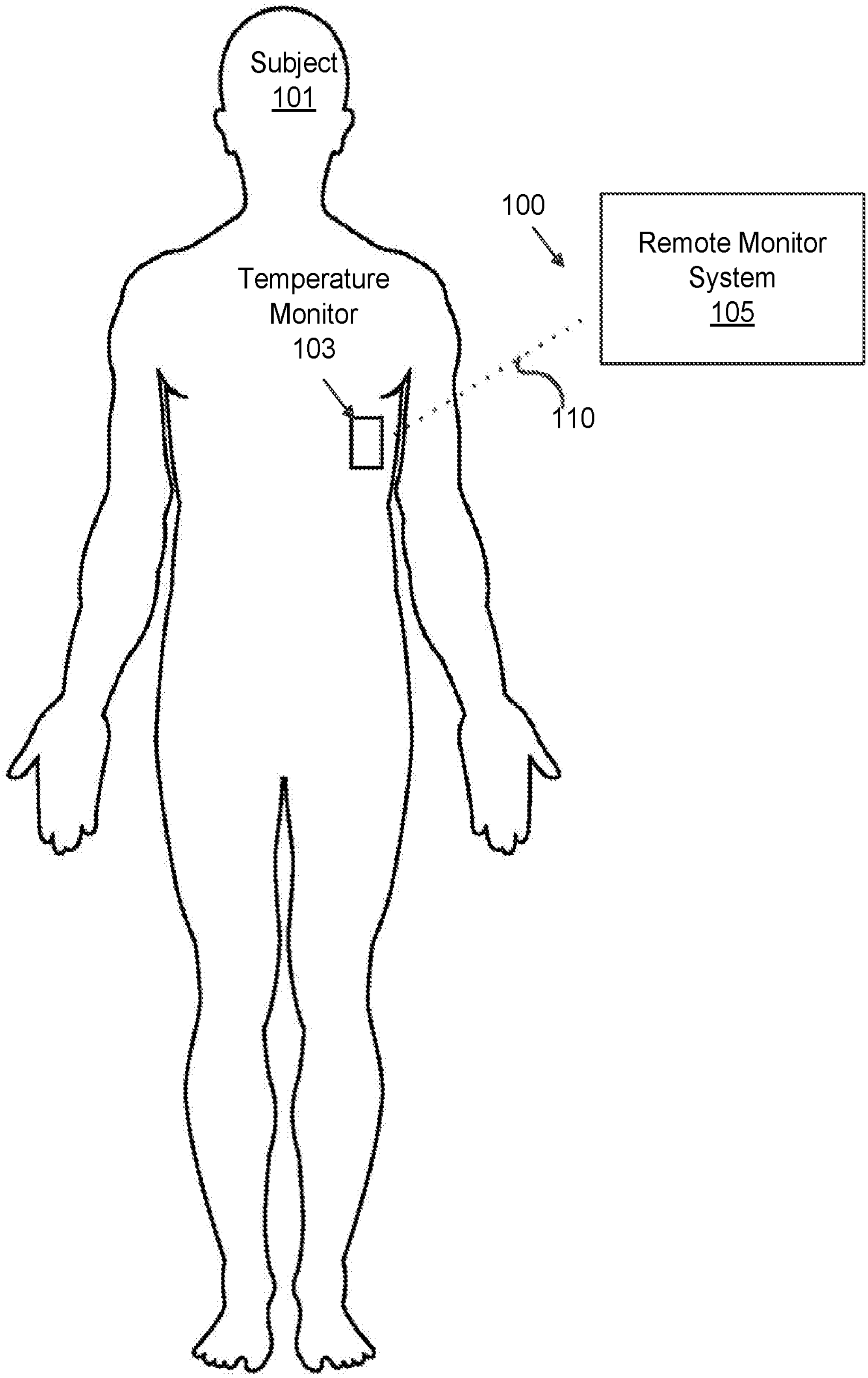

Subject
101
100
Remote Monitor
System
105
Temperature
Monitor
103
110

FIG. 1

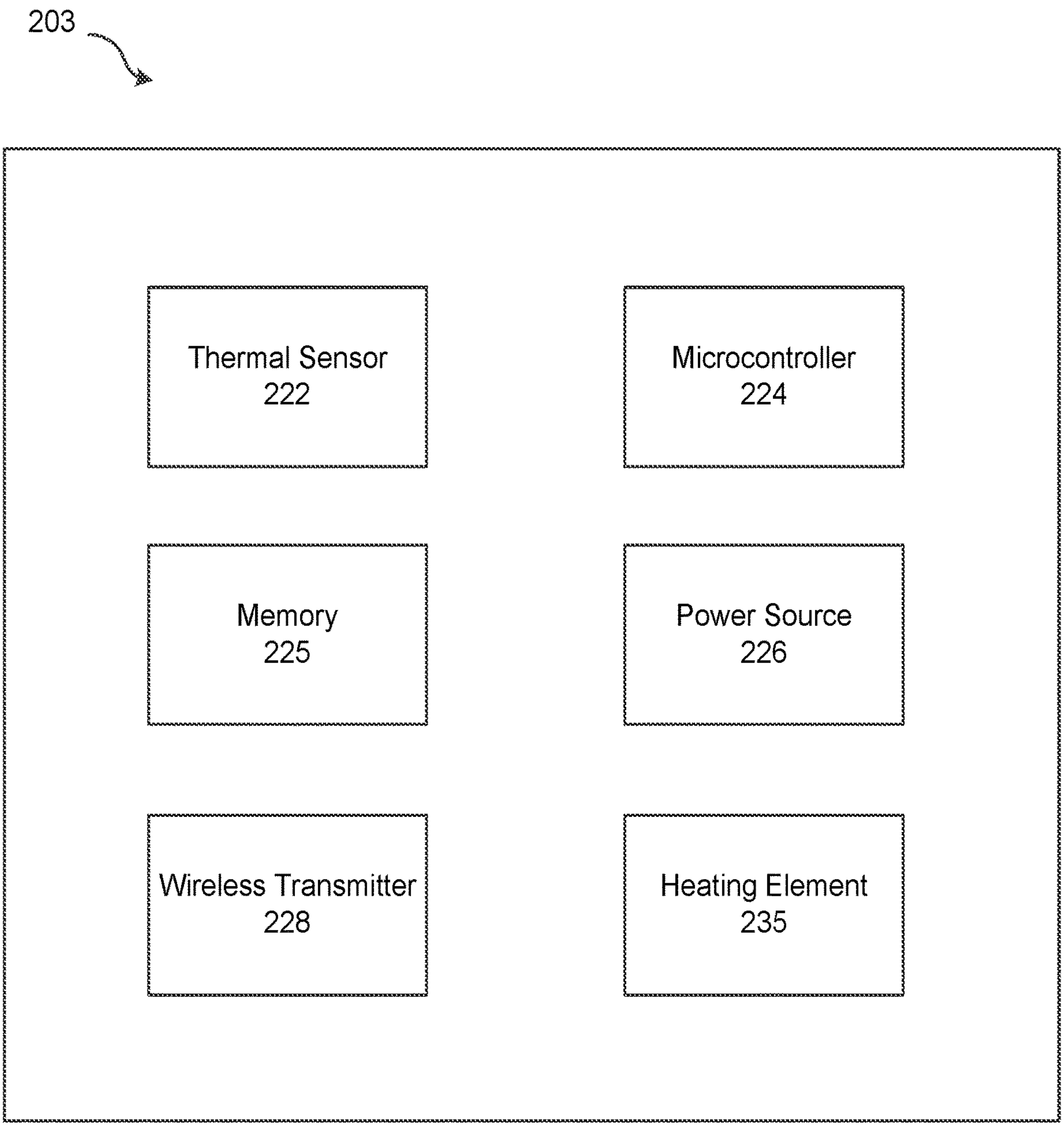

203
Thermal Sensor
222
Microcontroller
224
Memory
225
Power Source
226
Wireless Transmitter
228
Heating Element
235

FIG. 2

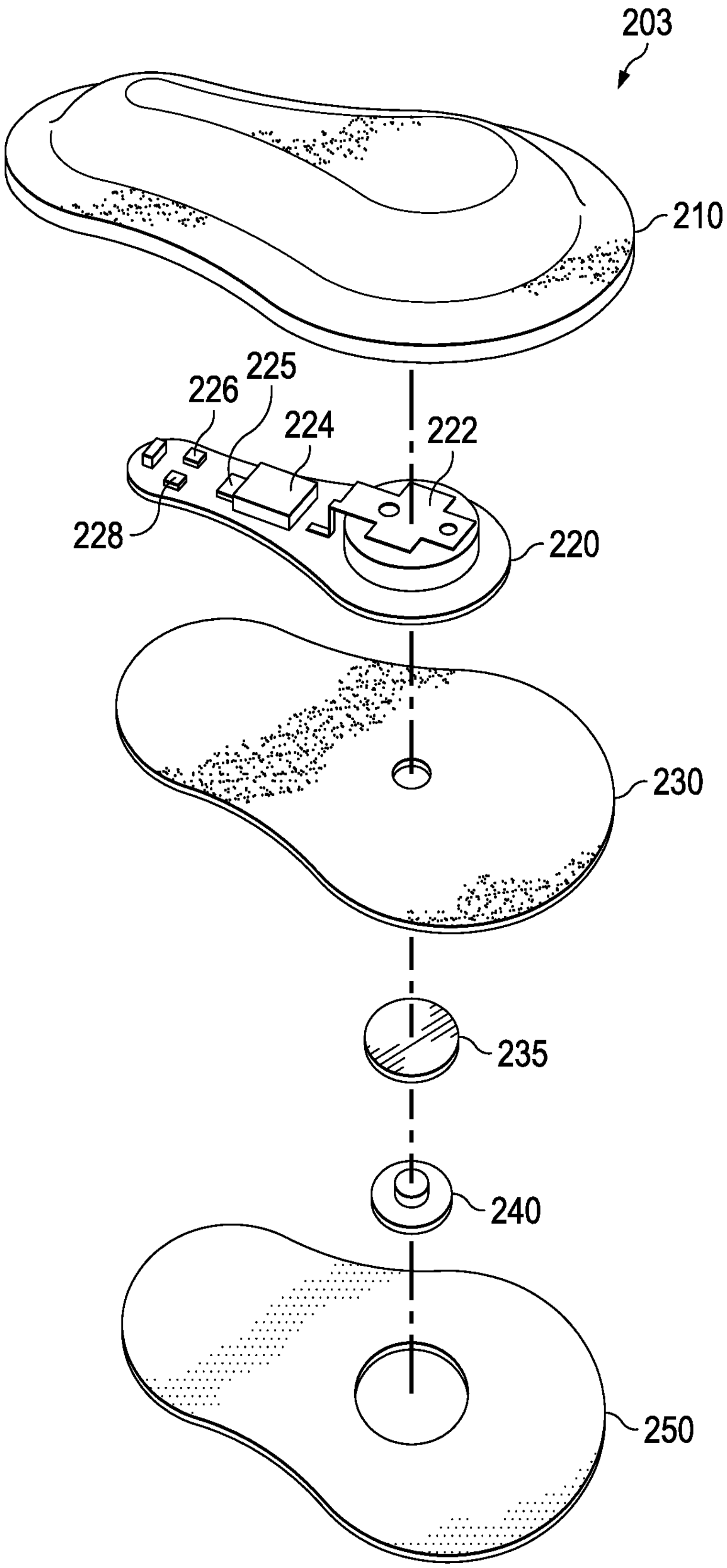


FIG. 3

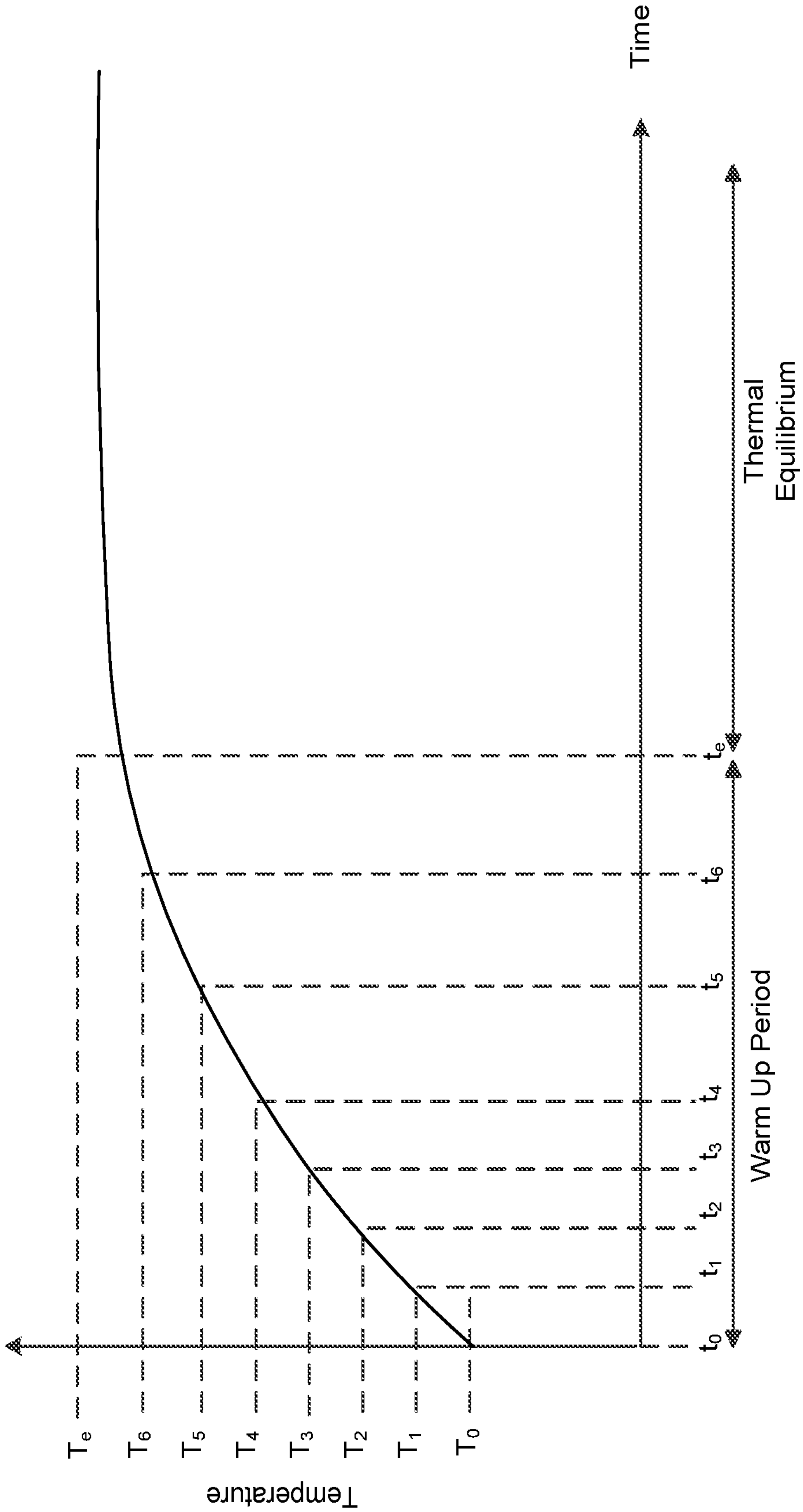

Temperature
T_e
T_6
T_5
T_4
T_3
T_2
T_1
T_0
t_0
t_1
t_2
t_3
t_4
t_5
t_6
t_e
Time
Warm Up Period
Thermal Equilibrium

FIG. 4

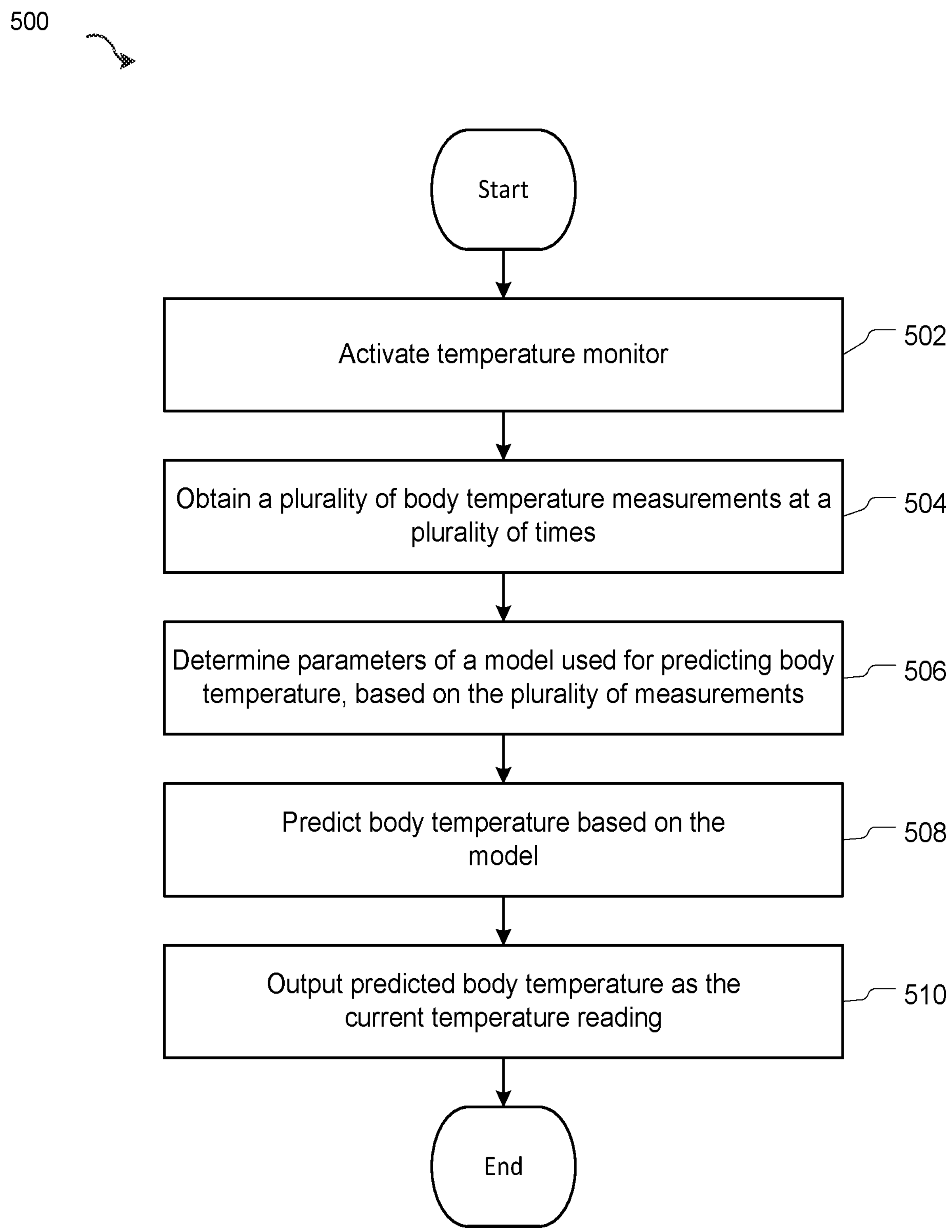

500
Start
Activate temperature monitor
502
Obtain a plurality of body temperature measurements at a plurality of times
504
Determine parameters of a model used for predicting body temperature, based on the plurality of measurements
506
Predict body temperature based on the model
508
Output predicted body temperature as the current temperature reading
510
End

FIG. 5

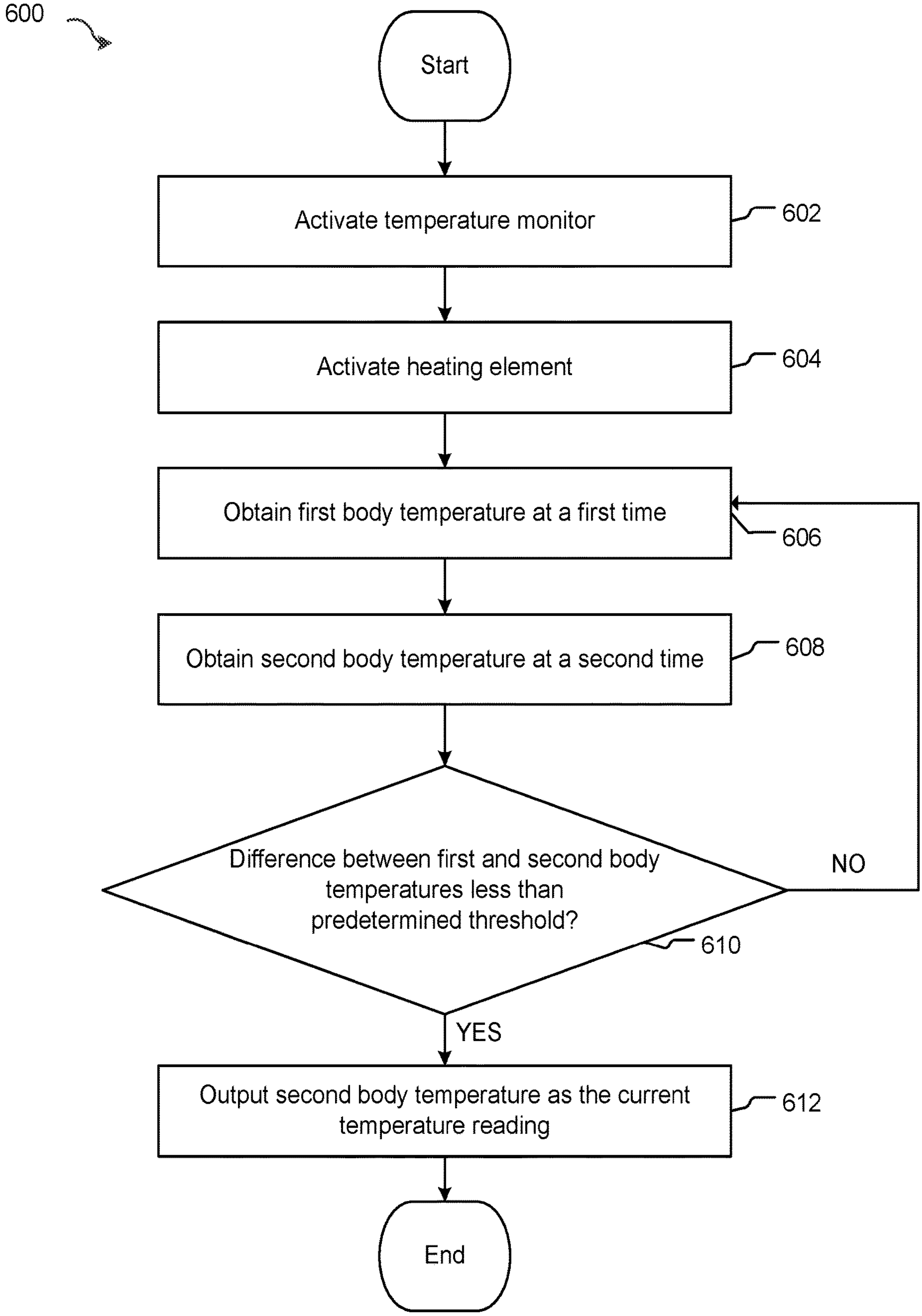

600
Start
Activate temperature monitor
602
Activate heating element
604
Obtain first body temperature at a first time
606
Obtain second body temperature at a second time
608
Difference between first and second body temperatures less than predetermined threshold?
NO
610
YES
Output second body temperature as the current temperature reading
612
End

FIG. 6

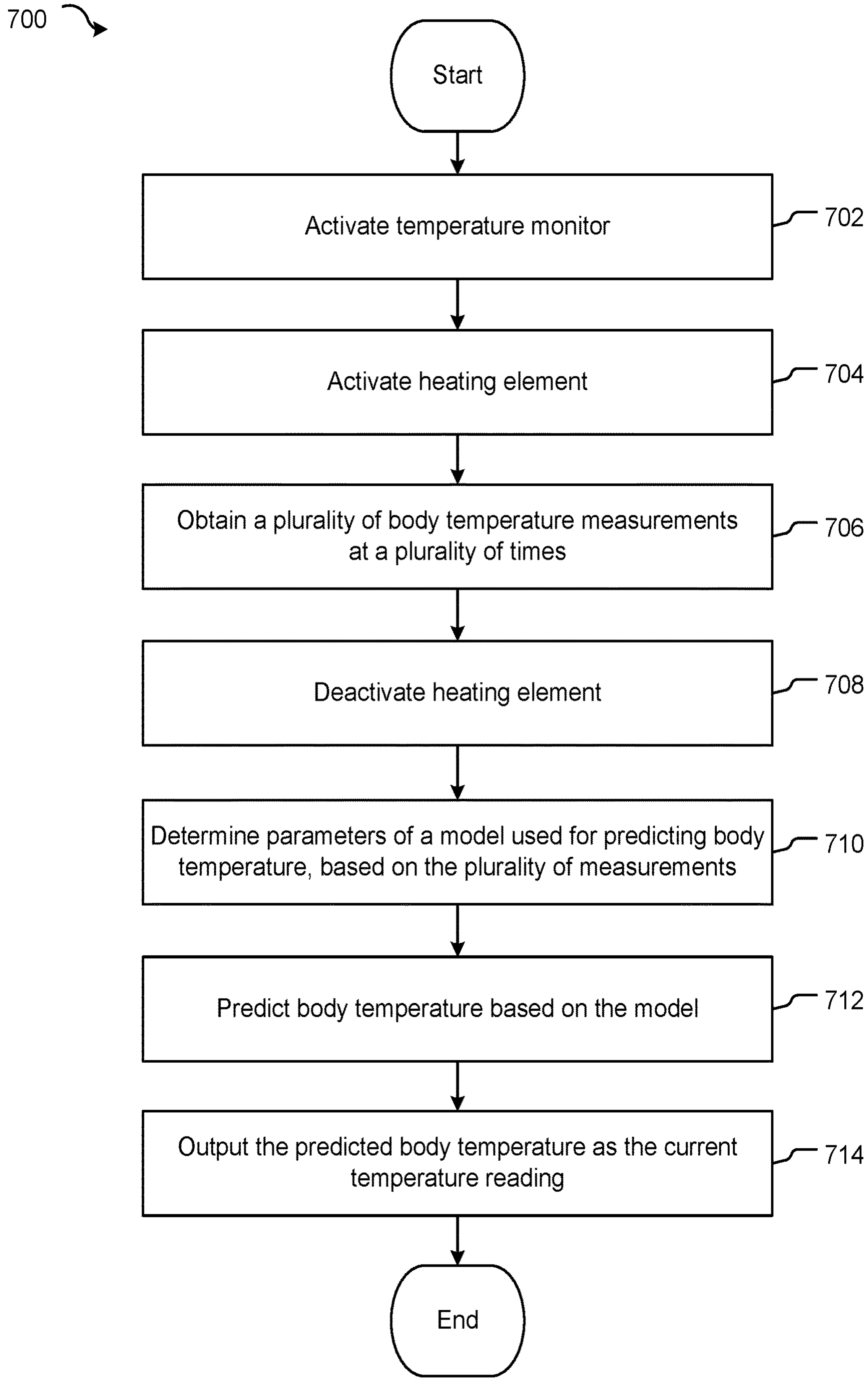

700
Start
Activate temperature monitor
702
Activate heating element
704
Obtain a plurality of body temperature measurements at a plurality of times
706
Deactivate heating element
708
Determine parameters of a model used for predicting body temperature, based on the plurality of measurements
710
Predict body temperature based on the model
712
Output the predicted body temperature as the current temperature reading
714
End

FIG. 7

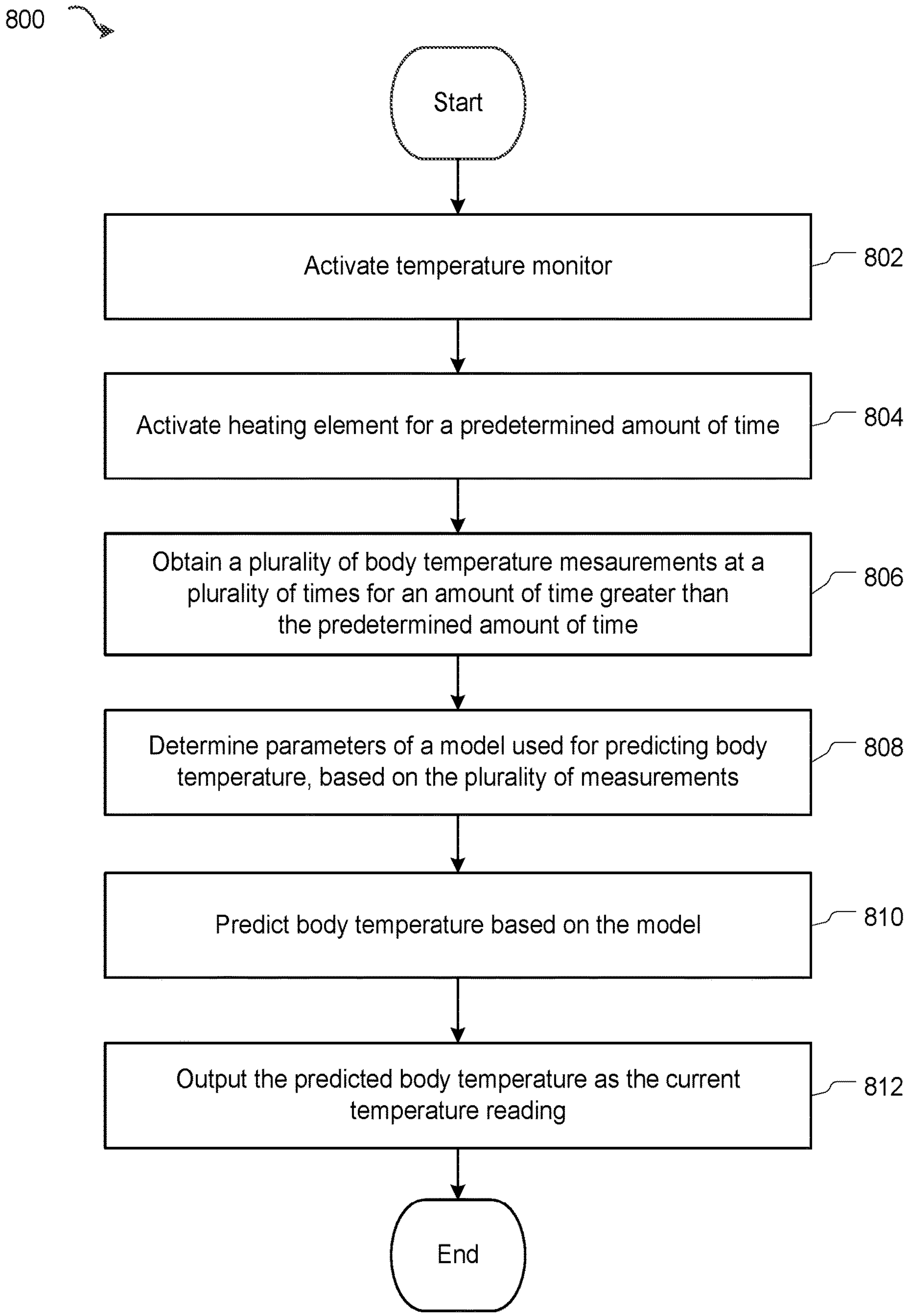

800
Start
Activate temperature monitor
802
Activate heating element for a predetermined amount of time
804
Obtain a plurality of body temperature mesaurements at a plurality of times for an amount of time greater than the predetermined amount of time
806
Determine parameters of a model used for predicting body temperature, based on the plurality of measurements
808
Predict body temperature based on the model
810
Output the predicted body temperature as the current temperature reading
812
End

FIG. 8

METHODS AND DEVICES FOR MEASURING BODY TEMPERATURE IN A REDUCED TIME

RELATED APPLICATIONS

[0001] The present application claims the benefit of the filing date of U.S. Provisional Patent Application No. 62/671,784, filed May 15, 2018, the disclosure of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to physiological monitoring and, in particular, to wearable devices and associated methods for monitoring a patient's temperature. For example, a wearable temperature monitoring device may include one or more heating elements to provide for accurate body temperature measurements in a short amount of time.

BACKGROUND

[0003] A long-term goal of health-related wearable electronics is to gather a patient's health data in real time to provide remote, continuous monitoring of human health. A temperature monitoring device typically requires an initial warm up period that can last at least a few minutes, thereby delaying the ability to accurately monitor temperature. This time delay in measurement can be caused by the heat capacity of a sensing element of the temperature monitoring device and the fact that applying the temperature monitoring device to the patient tissues or skin draws down the temperature of the tissues or skin in the immediate region of the temperature monitoring device.

[0004] For example, body-mountable temperature monitoring devices typically require several minutes (e.g., 5-10 minutes) to reach a steady-state temperature once applied to the body due to their thermal mass. Therefore, the temperature reading from these devices can be highly inaccurate during that time. This causes an inconvenient delay for users who want to measure body temperature quickly.

SUMMARY

[0005] Various methods and devices for reducing the time for a body-mountable temperature monitoring device to provide an accurate body temperature are disclosed. Methods are used to accurately predict the measured temperature once the monitoring device reaches thermal equilibrium. A body-mountable device may include one or more separate heating elements to accelerate the device reaching thermal equilibrium. In some embodiments, the devices and methods use both temperature prediction and a heating element to provide an accurate body temperature in a shorter amount of time. For example, the heating element can be turned on and then the body temperature can be predicted, or the heating element can be turned on for a short amount of time and turned off, and then the temperature can be predicted.

[0006] For example, in one embodiment, a method for measuring body temperature of a subject includes: obtaining, by a temperature monitor attached to a body of the subject, a plurality of body temperature measurements at a plurality of times for the subject; determining, by the temperature monitor, parameters of a model used for predicting temperature, based on the plurality of measurements; predicting, by the temperature monitor, a body temperature of the subject based on the model; and outputting, by the temperature monitor, the predicted body temperature as a current temperature reading.

[0007] In some embodiments, the model comprises an exponential model for temperature, and wherein determining the parameters of the model comprises determining values of a plurality of parameters in the exponential model. In some embodiments, the model comprises:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and wherein determining the parameters of the model comprises determining values of α and T_e. In some embodiments, predicting a body temperature of the subject based on the model comprises: determining a value of a of the model; and inputting a time into the model.

[0008] In some aspects, the method further comprises: continuing to obtain a plurality of body temperature measurements at a plurality of times after the predicted body temperature is outputted; and updating the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times. In some embodiments, the plurality of times comprises predetermined intervals. In other aspects, the method further comprises activating a heating element coupled to the temperature monitor. In some embodiments, the heating element is activated when the temperature monitor detects that the temperature monitor is attached to the body of the subject. In some embodiments, activating the heating element comprises activating the heating element for a predetermined amount of time; and wherein obtaining the plurality of body temperature measurements comprises obtaining the plurality of body temperature measurements over a period of time that is greater than the predetermined amount of time.

[0009] According to another embodiment of the present disclosure, a temperature monitoring device for measuring body temperature of a subject includes: a thermal sensor configured to sense a body temperature and to obtain a plurality of body temperature measurements at a plurality of times for the subject; and a microcontroller configured to: receive the plurality of measurements from the thermal sensor, determine parameters of a model used for predicting body temperature based on the plurality of measurements, predict a body temperature of the subject based on the model, and output the predicted body temperature as a current temperature reading.

[0010] In some embodiments, the model comprises:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and wherein determining the parameters of the model comprises determining values of α and T_e. In some embodiments, the microcontroller is further configured to: continue to obtain a plurality of body temperature measurement at a plurality of times after the predicted body temperature is outputted; and update the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

[0011] In some aspects, the device includes a thermal contact configured to contact the body of the subject and a heating element adjacent to the thermal contact, wherein the microcontroller is configured to activate the heating element. In still other embodiments, the microcontroller is further configured to: detect that the temperature monitoring device is attached to the body of the subject, and activate the heating element upon the detection. In other aspects, the device further includes an adhesive patch incorporating the heating element.

[0012] According to another embodiment of the present disclosure, a temperature monitoring device comprises: a thermal contact configured to contact a body of the subject; a heating element adjacent to the thermal contact and configured to heat the thermal contact; a thermal sensor configured to sense a temperature of the thermal contact and to obtain a plurality of body temperature measurements at a plurality of times for a time greater than a predetermined amount of time; and a microcontroller configured to: activate the heating element for the predetermined amount of time, receive the plurality of measurements from the thermal sensor, determine parameters used for predicting body temperature based on the plurality of measurements, predict a body temperature of the subject based on the parameters, and output the predicted body temperature as a current temperature reading.

[0013] In some embodiments, the parameters are part of a model and the model comprises:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and wherein determining the parameters of the model comprises determining values of α and T_e. In some embodiments, the microcontroller is further configured to: continue to obtain a plurality of body temperature measurement at a plurality of times after the predicted body temperature is outputted; and update the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

[0014] Additional aspects, features, and advantages of the present disclosure will become apparent from the following detailed description

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The following figures are included to illustrate certain aspects of the present invention, and should not be viewed as an exclusive embodiment. The subject matter disclosed is capable of considerable modification, alteration, and equivalents in form and function, as will occur to those of ordinary skill in the art and having the benefit of this disclosure.

[0016] FIG. **1** illustrates a system for wirelessly measuring the body temperature of a subject using a body-mountable temperature monitoring device according to one or more embodiments of the present disclosure;

[0017] FIG. **2** schematically illustrates a body-mountable temperature monitoring device that may be used according to one or more embodiments of the present disclosure;

[0018] FIG. **3** illustrates an exploded cross-sectional view of an exemplary body-mountable temperature monitoring device that may be used according to one or more embodiments of the present disclosure;

[0019] FIG. **4** illustrates a graph that shows the variation in detected body temperature over time according to one or more embodiments;

[0020] FIG. **5** depicts a first method for measuring body temperature in a reduced time according to one or more embodiments;

[0021] FIG. **6** depicts a second method for measuring body temperature in a reduced time according to one or more embodiments;

[0022] FIG. **7** depicts a third method for measuring body temperature in a reduced time according to one or more embodiments; and

[0023] FIG. **8** depicts a fourth method for measuring body temperature in a reduced time according to one or more embodiments.

DETAILED DESCRIPTION

[0024] For the purposes of promoting an understanding of the principles of the present disclosure, reference will now be made to the embodiments illustrated in the drawings, and specific language will be used to describe the same. It is nevertheless understood that no limitation to the scope of the disclosure is intended. Any alterations and further modifications to the described devices, systems, and methods, and any further application of the principles of the present disclosure are fully contemplated and included within the present disclosure as would normally occur to one skilled in the art to which the disclosure relates. In particular, it is fully contemplated that the features, components, and/or steps described with respect to one embodiment may be combined with the features, components, and/or steps described with respect to other embodiments of the present disclosure. For the sake of brevity, however, the numerous iterations of these combinations will not be described separately.

[0025] The methods described herein provide a quick response in monitoring the body temperature of a subject using a body-mountable temperature monitoring device or a "temperature monitor." When the temperature monitor is first attached to the subject's body (or re-attached to the body after detachment), there exists a significant thermal unbalance between the subject's body and the temperature monitor. Until the temperature monitor reaches thermal equilibrium with the subject's body, the temperature readout does not accurately reflect the body temperature of the subject. Once thermal equilibrium is reached (i.e., the temperature reported by the temperature monitor has reached a constant level), the body temperature of the subject can be determined and accurately reported.

[0026] In one embodiment, the methods sample multiple body temperatures for a certain amount of time and predict what the final body temperature will be based on the sampled body temperatures. In another embodiment, the methods activate a heating element of the temperature monitor to speed up or accelerate the time it takes for the temperature monitor to reach thermal equilibrium. In some embodiments, the methods include both prediction of the final body temperature and use of the heating element.

[0027] FIG. **1** illustrates an exemplary system **100** for wirelessly sensing the body temperature of a subject **101**. As shown, the system **100** includes a temperature monitor **103** and a remote monitoring system **105**. The temperature monitor **103** can send temperature information (e.g., a visual readout of the core body temperature of the subject **101** and other related information) to the remote monitoring system **105**, where the temperature information can be shown on a display. Alternatively, the temperature monitor **103** may include a display where the information is provided.

[0028] In one or more embodiments, the temperature monitor **103** may be worn or carried by the subject **101**. In various embodiments, the temperature monitor **103** is removably attached to a portion of the subject's body or the subject's skin. For example, the temperature monitor **103** can be worn on different locations of the subject's body, such as the forehead, torso, neck, arm, leg, or other suitable locations. In exemplary embodiments, the temperature monitor **103** is implemented as a wearable patch that is attachable to the skin of the subject **101**, as will be further explained below and in FIG. **2**.

[0029] The remote monitoring system **105** communicates with the temperature monitor **103**. The remote monitoring system **105** can receive signals from the temperature monitor **103** via the wireless communication link **110**. The wireless communication link **110** can be established as short range wireless communication, such as radio frequency identification (RFID) communication, near field communication (NFC), Bluetooth communication, or Wi-Fi communication.

[0030] In some embodiments, the remote monitoring system **105** is operable to present the data transmitted from the temperature monitor **103** on a display. For example, the remote monitoring system **105** may include a display screen and operate to present the transmitted data on the screen in a visible format. The remote monitoring system **105** can also output the data in an audible format, and/or provide an alert in visible and/or audible ways.

[0031] The remote monitoring system **105** can be used by a guardian and/or a healthcare practitioner to monitor the measurement of the temperature monitor **103**. Examples of the guardian include a parent of the subject **101**, a family member of the subject **101**, a caregiver of the subject **101**, a primary physician of the subject **101**, and any other interested parties. The healthcare practitioner is a person who provides healthcare service to the subject **101**. Examples of healthcare practitioners include primary care providers (e.g., doctors, nurse practitioners, and physician assistants), nursing care providers (e.g., nurses), specialty care providers (e.g., professionals in various specialties), and health professionals that provide preventive, curative, promotional and rehabilitative health care services. The healthcare practitioner can be an institution, company, business, and/or entity. In other embodiments, the temperature monitor **103** can be operated by the subject **101** him or herself.

[0032] The remote monitoring system **105** can be of various types. In various embodiments, the remote monitoring system **105** is a computing device dedicated to particular temperature monitors **103**. In other embodiments, other consumer level computing devices can be used for the remote monitoring system **105**. Such computing devices can include a mobile computing device, such as a smartphone, a tablet computer, and a personal digital assistant (PDA). The remote monitoring system **105** can include a desktop computer, a laptop computer, and/or any other suitable devices operable to send and receive signals, store and retrieve data, and/or execute modules.

[0033] FIG. **2** illustrates a block diagram of a temperature monitor **203**. As shown, the temperature monitor **203** includes a sensor or plurality of sensors **222** (e.g., a thermal sensor), a microcontroller **224**, a memory **225**, a power source **226**, a wireless transmitter **228**, and optionally a heating element **235**. In general, the sensor **222** operates to detect the body temperature of the subject **101**, and may include one sensor or a plurality of sensors. The microcontroller **224** operates to process signals received from the sensor **222**. Data processed by the microcontroller **224** can be stored in the memory **225**. The memory **225** provides the microcontroller **224** with non-transitory, computer-readable storage to facilitate execution of computer instructions by the microcontroller **224**. The power source **226** supplies power to the components of the temperature monitor **203**. The wireless transmitter **228** operates to send signals obtained by the temperature monitor **203** to the remote monitoring system **105** via the wireless communication link **110**. The heating element **235**, when present, operates to heat a thermal contact that provides the body temperature of the subject **101** to the sensor **222**.

[0034] FIG. **3** illustrates an exemplary temperature monitor **203**. As shown, temperature monitor **203** includes an upper elastomeric housing **210**, a printed circuit board **220**, a bottom elastomeric housing **230**, a thermal contact **240**, and an adhesive patch **250**. Consistent with one embodiment, a heating element **235** is included adjacent thermal contact **240**. The heating element **235** is optional and need not be included in all embodiments. The temperature monitor **203** may be utilized for monitoring of infants and children, elderly patients, and hospitalized patients.

[0035] The temperature monitor **203** includes an enclosure that includes the upper elastomeric housing **210** and the bottom elastomeric housing **230**. The upper and lower elastomer housings **210** and **230** can be any biocompatible housing or casing configured to shield components of the temperature monitor **203**. The enclosure can be constructed of various materials, including plastics and/or rubbers that provide durability and moisture resistance to the temperature monitor **203**.

[0036] The temperature monitor **203** further includes a printed circuit board **220** that can communicate information to the remote monitoring system **105**. The printed circuit board **220** typically includes a sensor **222**, a microcontroller **224**, a memory **225**, a power source **226**, and a wireless transmitter **228**. The sensor **222** can be a multitude of sensors, including a thermal sensor that senses temperature, such as a thermistor, a resistor temperature detector, a thermocouple, or any other miniature temperature responsive sensor, and other types of sensors, such as an ambient temperature sensor that detects ambient air temperature of the environment of the subject **101** and/or an accelerometer that detects movement/activity and body orientation. In some embodiments, the temperature monitor **203** includes a contact temperature sensor (referred to in some embodiments as a primary temperature sensor) that measures temperature based on contact, and one or more other temperature sensors (referred to in some embodiments as secondary temperature sensors), which may be contact temperature sensors or non-contact temperature sensors (e.g., an infrared sensor), or a combination of these. The secondary temperature sensor(s) give a measure of ambient temperature in the vicinity of the temperature monitor **203**.

[0037] In one embodiment, the sensor **222** includes a thermal sensor. In other embodiments, the sensor **222** includes a thermal sensor and one or more other sensors configured to detect and measure environmental effects that may impact the detected body temperature. For example, the sensor **222** may include one or more sensors that detect contextual data such as a microphone or other acoustic sensor to detect sounds and other environmental noises, relative and global positioning sensors to determine the location of the subject **101**, torque and rotation acceleration sensors to determine orientation of the subject **101** in space, and sensors configured to detect pollen, humidity, ozone, and other environmental conditions. Contextual data as used herein means data relating to the environment, surroundings, location and condition of the subject **101**, including, but not limited to, air quality, audio sound quality, ambient temperature, ambient light, global positioning, humidity, altitude, barometric pressure, and the like. Contextual data may also include further abstractions or derivations regarding the condition and status of the subject **101**.

[0038] The microcontroller **224** is configured to estimate body temperature of the subject **101** based, at least in part, on the temperature measurements of the thermal sensor. Additionally, the microcontroller **224** can use inputs from other sensors in addition to the temperature measurements from the thermal sensor to compensate and estimate body temperature. Advantageously, the microcontroller **224** can utilize thermal sensor readings in combination with other sensor readings to adjust the detected body temperature.

[0039] In certain embodiments, the microcontroller **224** receives data from multiple sensors on the temperature monitor **203** to adjust temperature readings to account for environmental and other conditions. For example, in hot, humid conditions, it is difficult for the body to dissipate heat because of the moisture in the air and small temperature gradient between the skin and the ambient air (e.g., as measured by one or more contact temperature sensors and one or more secondary temperature sensors, respectively), resulting in an elevated body temperature. On the other hand, in frigid or windy conditions, a great deal of metabolic work is necessary to produce body heat and prevent it from leaving the body, resulting in a drop in body temperature. In another example, physical activity (e.g., exercise) can affect body temperature. The response of the body to physical activity is an increase in metabolic rate, resulting in increased heat production within the body and elevated body temperature.

[0040] In various embodiments, the microcontroller **224** takes into account differences between temperatures detected by a thermal sensor and an ambient temperature sensor, how fast temperature readings are changing, and the duration of changing temperature readings to output a more accurate estimate of core body temperature of the subject **101**. If the subject **101** is determined to be in a hot, humid environment, the body temperature of the subject **101** that is output can be adjusted downwards to account for the effect of the weather.

[0041] In some embodiments, the microcontroller **224** provides an activity classification to apply corresponding temperature adjustment parameters to the subject **101**. For example, the microcontroller **224** can determine the activity level of the subject **101** using an accelerometer and humidity sensors. If the activity classification of the subject **101** is high, the body temperature of the subject **101** that is output can be adjusted downwards to account for the effect of physical activity.

[0042] In several embodiments, a confidence qualifier is attached to the data, which is based on the temperature differences and the activity classification. The confidence qualifier indicates the probability or likelihood that the actual body temperature falls within the outputted body temperature. For example, if large temperature differences and a high activity classification are determined, the confidence qualifier is a lower value than if small temperature differences and a low activity classification is determined.

[0043] In some embodiments, the microcontroller **224** processes the readings from primary and secondary sensors to calculate the heat transfer between body and environment and estimate core body temperature using the following steps. When primary and secondary temperature sensor measurements are within a few tenths of degrees Celsius of each other and are not changing, a high confidence is assigned that the determined temperature represents core temperature. When a measured temperature from a secondary sensor drops/increases, followed by drop/increase, respectively, in measured temperature from a primary sensor, the microcontroller **224** may determine that the temperature measured by the primary sensor is affected by changes in the vicinity of the secondary sensor. In this scenario, final core temperature estimates may be determined by fitting exponentials and can then calculate core temperature assuming a thermal gradient, as above. The more data points available for the fit, the higher the confidence in the predicted result. Likewise, when a measured temperature from the primary sensor drops/increases, followed by drop/increase, respectively, in a measured temperature from a secondary sensor, in a method it may be determined that the secondary sensor measurement is affected by change in conditions in the vicinity of the primary sensor (e.g., skin temperature) and the underlying core temperature estimate may take these changes into account.

[0044] In additional embodiments, the data received from various sensors is subject to adaptive filtering, such as assigning different weights to different temperature measurements from different sensors at different times. In some embodiments, data is averaged and higher confidence data (e.g., data with a higher confidence qualifier) is provided greater weight in the determination of body temperature.

[0045] In various embodiments, the microcontroller **224** is a small computer or other circuitry that retrieves and executes software from memory. In exemplary embodiments, the microcontroller **224** is configured to perform any necessary computations to deliver an equilibrium temperature of the temperature monitor **203**. For example, the microcontroller **224** can be programmed and/or otherwise configured to run the algorithms necessary to predict body temperature and other related data. In some embodiments, the microcontroller **224** is implemented as an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), application-specific standard part (ASSP), a system-on-chip (SoC), a digital signal processor (DSP), or a general-purpose processor. In various embodiments, a power source **226**, such as a battery, is provided. Some embodiments of the temperature monitor **203** also include a storage device or memory **225** for storing instructions for microcontroller **224**, such as random access memory (RAM) devices including dynamic RAM (DRAM), synchronous DRAM (SDRAM), solid state memory devices, and/or a variety of other memory devices known in the art In one more embodiments, a wireless transmitter **228** is provided.

[0046] A thermal contact **240** is also provided in the temperature monitor **203**. The thermal contact **240** has a surface adapted for thermal coupling with the skin of the subject **101**. The thermal contact **240** is generally made of any conductive material. In some embodiments, the thermal contact **240** is a gold-plated brass disc that facilitates thermal coupling with the skin of the subject **101**. The thermal sensor senses the temperature of the thermal contact **240**.

[0047] The heating element **235** can be disposed on the printed circuit board **220** or embedded in the adhesive patch **250**. The heating element may be implemented as a resistive heater, a microheater, or a positive temperature coefficient (PTC) thermistor. In some embodiments, the heating element **235** is implemented as a wire loop embedded in the printed circuit board **220**. This could be heated from an external source, for example, by passing current through the wire. Instead of a resistive wire loop, one or more resistors can be implemented on the printed circuit board **220** to achieve the desired heating function. In one embodiment, the heating element **235** is thermally coupled to the thermal contact **240**. In other embodiments, the heating element **235** can be incorporated directly into the adhesive patch **250** and thermally coupled to the thermal contact **240**, as described below. In various embodiments, the heating element **235** can be on the printed circuit board or on, around, and/or under the adhesive patch **250**. For example, a heater wire can be warmed up when a voltage is applied from a contact to the printed circuit board **220**.

[0048] The heating element **235** is typically deactivated or turned off after a predetermined amount of time (e.g., before thermal equilibrium is reached or before the warm up period ends) at a predetermined temperature level. The heating element **235** can accelerate the rate at which the thermal contact **240** warms up, reducing the total time for the thermal contact **240** to reach thermal equilibrium with the body of the subject **101**. In other words, use of the heating element **235** reduces the warm up period. In one or more embodiments, the heating element **235** is activated for a short amount of time (e.g., less than a minute) to provide a quick burst of heat, and then turned off to allow the temperature monitor **203** to settle.

[0049] An adhesive patch **250** allows the temperature monitor **203** to be removably attached to the skin of the subject **101**. The adhesive patch **250** can be constructed of various materials, including plastics, or natural or synthetic fibers. The materials are chosen to provide durability and breathability to the temperature monitor **203**. In some embodiments, the adhesive patch **250** includes a biocompatible adhesive. A film or paper can be pulled away from the adhesive patch **250** prior to applying the temperature monitor **203** to the skin of the subject **101**. The adhesive patch **250** can include a hydrogel, which can provide skin-adhesion properties. In addition or alternatively, the adhesive patch **250** can include a pressure-sensitive adhesive. The adhesive patch **250** generally includes a cutout or opening for the thermal contact **240**.

[0050] The adhesive patch **250** can further function as a thermal conduit between the thermal sensor/thermal contact **240** and the skin of the subject **101**. For example, the adhesive patch **250** can include biocompatible thermally and electrically conductive materials to improve thermal contact reliability. Suitable materials include silver nanowires, carbon nanotubes, silver, gold, platinum, activated carbon powders (ACP) and major conducting polymer materials, namely, polyaniline, polypyrrole, polythiophene and derivatives of polythiophene, as well as composites of these materials with carbon nanotubes. The electrical conductivity of these materials may improve wireless communication and range performance by creating a larger, solid ground plane, which may improve antenna radiation efficiency. In some embodiments, non-biocompatible materials (e.g., copper) can be used as long as the non-biocompatible materials are sealed and/or are not in contact with the body of the subject **101**.

[0051] As explained above, temperature monitoring devices typically require several minutes to warm up and reach thermal equilibrium, which results in highly inaccurate temperature readings until the devices reach a stabilized temperature. Generally, when the temperature monitor **203** is attached to the skin of the subject **101**, the skin of the subject **101** will transfer heat energy to the thermal contact **240**, or vice versa, depending on ambient conditions. Eventually, the thermal contact **240** will reach a state of thermal equilibrium, in which the temperature of the thermal contact **240** of the monitor **203** is relatively stable and substantially matches the body temperature of the subject **101**. Using conventional techniques, it is only after the thermal contact **240** reaches thermal equilibrium that an accurate body temperature can be sensed by the thermal sensor and provided to a user.

[0052] FIG. **4** illustrates the variation in temperature over time as the temperature monitor **203** detects the body temperature of the subject **101**. Initially, the thermal contact **240** is at ambient or room temperature (To). In this example, ambient temperature is lower than body temperature (e.g., 65° Fahrenheit (F) to 75° F.), but the methods also apply if ambient temperature is higher than body temperature. After attaching the temperature monitor **203** to the skin of the subject **101**, heat flow from the subject's body will raise the temperature of the thermal contact **240**, so that the thermal sensor will report rising temperatures (T_1-T_6). Ultimately, the temperature of the thermal contact **240** will reach an equilibrium temperature (T_e) that is sensed by the thermal sensor.

[0053] As described herein, the thermal sensor is not ready to immediately detect the body temperature of the subject **101** when the temperature monitor **203** and associated thermal contact **240** is first attached to a body portion (e.g., skin or tissues) of the subject **101**. Such measurement time delay can occur for various reasons. Such reasons can include the construction of the temperature monitor **203** including the location of the thermal contact **240** within the temperature monitor **203**, the heat capacity of the thermal contact **240**, a difference in temperature between the thermal contact **240** and the subject's body, and an improper attachment of the temperature monitor **203** and/or thermal contact **240** on the subject's body. Because of such various reasons, when the temperature monitor **203** is first engaged with the subject's body, the temperature detected by the thermal sensor can be unstable or fluctuate during the initial warm up period (e.g., t_1-t_6 as illustrated in FIG. **3**) until the thermal contact **240** becomes in thermal equilibrium with the body portion on which the temperature monitor **203** is attached. As the thermal contact **240** and the engaged body portion become in thermal equilibrium, the temperature detected by the temperature monitor **203** is stabilized, and thus can be used as an accurate measurement of the subject's body temperature.

[0054] As such, the temperature monitor **203** typically requires some time until it can reliably measure the body temperature of the subject **101**. It is preferable, however, to take body temperature measurements as quickly as possible in many situations.

[0055] Advantageously, the methods and devices described herein reduce the amount of time it takes to obtain an accurate reading of the body temperature of the subject **101** in two ways. First, the methods predict the final stabilized body temperature by taking a plurality of temperature readings, and then curve fit these data points to determine where the curve will settle. Second, the methods accelerate the time the thermal contact **240** takes to reach thermal equilibrium so that a final stabilized body temperature is reached faster.

[0056] FIG. **5** is a flowchart illustrating an exemplary method **500** for measuring a body temperature of a subject in a reduced time. The method **500** begins when the temperature monitor **203** is arranged in place on a predetermined location of the body of the subject **101** and activated at step **502**. At step **504**, the temperature monitor **203** obtains a plurality of body temperature measurements at a plurality of times. For example, the temperature monitor **203** can sample **10** temperature readings at **10** different times. The plurality of times may be at predetermined intervals (e.g., every second, every 5 seconds, etc.), and the intervals need not be the same amount of time. For example, referring back to FIG. **4**, the thermal sensor can provide a temperature T_1 at time t_1, a temperature T_2 at time t_2, a temperature T_3 at time t_3, a temperature T_4 at time t_4, a temperature T_5 at time t_5, and a temperature T_6 at time t_6 to the microcontroller **224**. The time between t_1 and t_2 does not need to be the same amount of time as the time between t_2 and t_3.

[0057] At step **506**, the temperature monitor **203** determines parameters of a model used for predicting body temperature, based on the plurality of measurements. For example, referring back to FIG. **4**, the microcontroller **224** plots data points temperature T_1 at time t_1, temperature T_2 at time t_2, temperature T_3 at time t_3, temperature T_4 at time t_4, temperature T_5 at time t_5, and temperature T_6 at time t_6, on a graph and connect the data points with a curve. In several embodiments, the microcontroller **224** determines the curve equation from the plurality of data points. There are a variety of potential models to use to predict temperature. In one model, the rate of change of temperature is assumed to be proportional to the difference between the temperature of the monitor **203** and the temperature of the body, yielding an exponential model. For example, in one embodiment, the curve equation for the curve in FIG. **4** is:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0 is the initial temperature, T_e=the final temperature and α=a thermal time constant. T_e and k are unknown quantities to be determined by curve fitting or solving for these values. By substituting the data points for temperature and time into the equation, the values for the unknown quantities can be obtained and one or more future temperatures predicted. Other types of curves (e.g., a polynomial model, a combination of exponential models, or a combination of a polynomial model and an exponential model) may be used. For example, experimental measurement data in different scenarios may be stored either on the body-wearable device or remote device used to predict temperature and used to predict temperature. In other embodiments, "learned" parameters from the device and the uses can be stored. For example, after the first few fits, the model can refine itself.

[0058] At step **508**, the temperature monitor **203** predicts the body temperature of the subject based on the model. For example, the microcontroller **224** uses the plotted curve to determine at what temperature the curve will settle or stabilize. In another example, the microcontroller **224** determines the approximate time the temperature of the temperature monitor **203** will stabilize (e.g., 5-10 minutes) and then inputs the time into the curve equation to yield the stabilized body temperature.

[0059] At step **510**, the temperature monitor **203** outputs the predicted body temperature as the current temperature reading. This final projected value of the body temperature can be transmitted as the current temperature instead of the actual current temperature detected by the temperature monitor **203**. In some embodiments, the method **500** can be completed in about a minute.

[0060] In several embodiments, the algorithm on the microcontroller **224** can continue running during the warm up period, and the projected final value of the body temperature can continue to be updated and refined as more data points are used for the exponential fit. In this way, higher fit accuracy can be achieved.

[0061] Accordingly, if it is found that the temperature detected by the temperature monitor **203** is not stabilized yet, temperature monitor **203** can be configured to predict the body temperature of the subject **101** for quicker body temperature determination, even during the warm up period, thereby reducing or eliminating delay in providing feedback to a user, particularly as compared to waiting until thermal equilibrium is achieved before communicating body temperature.

[0062] FIG. **6** is a flowchart illustrating another exemplary method **600** for measuring a body temperature of a subject in a reduced time. The method **600** begins when the temperature monitor **203** is arranged in place on a predetermined location of the body of the subject **101** and activated at step **602**.

[0063] At step **604**, a heating element **235** of the temperature monitor **203** is activated. The heating element **235** can be activated when the temperature monitor **203** detects that the thermal contact **240** is placed on the body. For example, the temperature monitor **203** can activate the heating element **235** upon detection of a rise in temperature, or when a button is pressed, or using capacitive sensing as examples. Moreover, the temperature monitor **203** can include a second temperature sensor for sensing ambient temperature and the system can activate the heating element **235** when the thermal contact temperature deviates from the sensed ambient temperature.

[0064] At step **606**, the temperature monitor **203** obtains a first body temperature at a first time. At step **608**, the temperature monitor **203** obtains a second body temperature at a second time. For example, the first time in step **606** is set as a time (i.e., to in FIG. **4**) at which, or shortly after, the temperature monitor **203** is activated. The second time in step **608** is set as a predetermined time (i.e., t_1 in FIG. **4**) after the temperature monitor **203** is activated. In other embodiments, the first and second times can be different points in time at different intervals after the temperature monitor **203** is activated. For example, in FIG. **4**, the first and second times can be any combination selected from t_0, t_1, t_2, t_3, t_4, t_5, and t_6 to the extent that the first time is before the second time.

[0065] At step **610**, the temperature monitor **203** calculates the difference between the first and second body temperatures to determine if the difference is less than a predetermined threshold. In general, during the initial warm up period, the temperature monitor **203** obtains at least two body temperatures at different times, determines a rate of body temperature increase, and compares the rate with a predetermined threshold to indicate that the body temperature has been sufficiently stabilized to provide a reliable reading. The threshold is set close to zero to represent that the body temperature is so stabilized over time as to provide a reliable reading on the body temperature.

[0066] If the temperature difference between the two body temperatures does not meet the predetermined threshold, the temperature monitor **203** returns to steps **606** and **608**. If the temperature difference between the two body temperatures does meet the predetermined threshold, the method **600** continues to step **612**, where the temperature monitor **203** outputs the second body temperature as the current temperature reading.

[0067] FIG. **7** is a flowchart illustrating another exemplary method **700** for measuring a body temperature of a subject in a reduced time. The method **700** employs a model and use of a heating element.

[0068] The method **700** begins when the temperature monitor **203** is arranged in place on a predetermined location of the body of the subject **101** and activated at step **702**. At step **704**, the temperature monitor **203** activates the heating element **235**, for example, upon detecting that the temperature monitor **203** is placed on the body of the subject **101**, similar to step **604** in method **600**.

[0069] At step **706**, the temperature monitor **203** obtains a plurality of body temperature measurements at a plurality of times. Step **706** is similar to step **504** in method **500**. At step **708**, the temperature monitor **203** deactivates the heating element **235**. The heating element **235** is activated while the temperature monitor **203** obtains a plurality of body temperatures at a plurality of times for determining parameters of the model.

[0070] At step **710**, the temperature monitor **203** determines parameters of a model used for predicting body temperature, based on the plurality of measurement. Step **708** is similar to steps **506** in method **500**.

[0071] At step **712**, the temperature monitor **203** predicts the body temperature based on the model. At step **714**, the temperature monitor **203** outputs the predicted body temperature as the current temperature reading. Steps **712** and **714** are similar to steps **508** and **510** in method **500**.

[0072] FIG. **8** is a flowchart illustrating another exemplary method **800** for measuring a body temperature of a subject in a reduced time. The method **800** also employs a model and use of a heating element.

[0073] The method **800** begins when the temperature monitor **203** is arranged in place on a predetermined location of the body of the subject **101** and activated at step **802**. At step **804**, the temperature monitor **203** activates the heating element **235** for a predetermined amount of time (e.g., for an amount of time shorter than the warm up period) upon detecting that the temperature monitor **203** is placed on the body of the subject **101**.

[0074] At step **806**, the temperature monitor **203** obtains a plurality of body temperature measurements at a plurality of times for an amount of time greater than the predetermined amount of time. That is, the heating element **235** is deactivated before the temperature monitor **203** obtains a sufficient number of body temperature measurements at different times.

[0075] At step **808**, the temperature monitor **203** determines parameters of a model used for predicting body temperature, based on the plurality of measurements. At step **810**, the temperature monitor predicts the body temperature based on the model. At step **812**, the temperature monitor **203** outputs the predicted body temperature as the current temperature reading. Steps **806-812** are similar to steps **504-510** in method **500**.

[0076] According to one or more embodiments, a method for measuring body temperature of a subject is provided. Embodiments of the method may generally include obtaining, by a temperature monitor attached to a body of the subject, a plurality of body temperature measurements at a plurality of times for the subject; determining, by the temperature monitor, parameters of a model used for predicting temperature, based on the plurality of measurements; predicting, by the temperature monitor, a body temperature of the subject based on the model; and outputting, by the temperature monitor, the predicted body temperature as a current temperature reading.

[0077] In some embodiments, the model includes an exponential model for temperature, and determining the parameters of the model includes determining values of a plurality of parameters in the exponential model. In various embodiments, the model includes:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and determining the parameters of the model includes determining values of α and T_e. In several embodiments, predicting a body temperature of the subject based on the model includes determining a value of a of the model; and inputting a time into the model.

[0078] In one or more embodiments, the method further includes continuing to obtain a plurality of body temperature measurements at a plurality of times after the predicted body temperature is outputted; and updating the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

[0079] In certain embodiments, the plurality of times includes predetermined intervals.

[0080] According to one or more embodiments, a temperature monitoring device for measuring body temperature of a subject is provided. The temperature monitoring device generally includes a thermal sensor configured to sense a body temperature and to obtain a plurality of body temperature measurements at a plurality of times for the subject; and a microcontroller configured to receive the plurality of measurements from the thermal sensor; determine parameters of a model used for predicting body temperature based on the plurality of measurements, predict a body temperature of the subject based on the model, and output the predicted body temperature as a current temperature reading.

[0081] In some embodiments, the model includes:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and determining the parameters of the model includes determining values of α and T_e.

[0082] In several embodiments, the microcontroller is further configured to continue to obtain a plurality of body temperature measurement at a plurality of times after the predicted body temperature is outputted; and update the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

[0083] According to one or more embodiments, another method of measuring body temperature of a subject is provided. The method generally includes activating a heating element of a temperature monitor attached to a body of the subject; obtaining, by the temperature monitor, a first body temperature of the subject at a first time; obtaining, by the temperature monitor, a second body temperature of the subject at a second time; calculating, by the temperature monitor, a difference between the first body temperature and the second body temperature; determining, by the temperature monitor, that the difference is less than a predetermined threshold; and outputting, by the temperature monitor, the second body temperature as a current temperature reading.

[0084] In certain embodiments, the heating element is activated when the temperature monitor detects that the temperature monitor is attached to the body of the subject. In some embodiments, the heating element is embedded in an adhesive patch of the temperature monitor.

[0085] According to one or more embodiments, another temperature monitoring device is provided. The temperature monitoring device generally includes a thermal contact configured to contact a body of the subject; a heating element adjacent to the thermal contact and configured to heat the thermal contact; a thermal sensor configured to sense a temperature of the thermal contact and to obtain a first body temperature of the subject at a first time and a second body temperature of the subject at a second time; and a microcontroller configured to activate the heating element, receive the first and second body temperatures from the thermal sensor, calculate a difference between the first and second body temperatures, determine that the difference is less than a predetermined threshold, and output the second body temperature as a current temperature reading.

[0086] In several embodiments, the microcontroller is further configured to detect that the temperature monitoring device is attached to the body of the subject, and activate the heating element upon the detection.

[0087] In some embodiments, the temperature monitoring device further includes an adhesive patch incorporating the heating element.

[0088] According to one or more embodiments, yet another method of measuring body temperature of a subject is provided. The method generally includes activating a heating element of a temperature monitor attached to a body of the subject; obtaining, by the temperature monitor, a plurality of body temperature measurements at a plurality of times for the subject; deactivating the heating element after obtaining the plurality of body temperature measurements at a plurality of times; determining, by the temperature monitor, parameters of a model used for predicting body temperature, based on the plurality of measurements; predicting, by the temperature monitor, a body temperature based on the model; and outputting, by the temperature monitor, the predicted body temperature as a current temperature reading.

[0089] In certain embodiments, the model includes an exponential model for temperature, and determining the parameters of the model includes determining values of a plurality of parameters in the exponential model. In one or more embodiments, the model includes:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and determining the parameters of the model includes determining values of α and T_e.

[0090] In several embodiments, predicting a body temperature of the subject based on the model includes determining a value of a of the model; and inputting a time into the model.

[0091] In some embodiments, the method further includes continuing to obtain a plurality of body temperature measurements at a plurality of times after the predicted body temperature is outputted; and updating the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times. In one embodiment, the plurality of times includes predetermined intervals.

[0092] In certain embodiments, the heating element is activated when the temperature monitor detects that the temperature monitor is attached to the body of the subject. In other embodiments, the heating element is embedded in an adhesive patch of the temperature monitor.

[0093] According to one or more embodiments, another temperature monitoring device is provided. Embodiments of the temperature monitoring device generally include a thermal contact configured to contact a body of the subject; a heating element adjacent to the thermal contact and configured to heat the thermal contact; a thermal sensor configured to sense a temperature of the thermal contact and to obtain a plurality of body temperature measurements at a plurality of times; and a microcontroller configured to activate and deactivate the heating element, receive the plurality of measurements from the thermal sensor, determine parameters of a model used for predicting body temperature based on the plurality of measurements, predict a body temperature of the subject based on the model, and output the predicted body temperature as a current temperature reading.

[0094] In exemplary embodiments, the model includes:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and determining the parameters of the model comprises determining values of α and T_e.

[0095] In several embodiments, the microcontroller is further configured to continue to obtain a plurality of body temperature measurement at a plurality of times after the predicted body temperature is outputted; and update the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

[0096] In one or more embodiments, the temperature monitoring device further includes an adhesive patch incorporating the heating element.

[0097] According to one or more embodiments, another method of measuring body temperature of a subject is provided. The method generally includes activating a heating element of a temperature monitor attached to a body of the subject for a predetermined amount of time; obtaining, by the temperature monitor, a plurality of body temperature measurements at a plurality of times for the subject for a time greater than the predetermined amount of time; determining, by the temperature monitor, parameters of a model used for predicting body temperature, based on the plurality of measurements; predicting, by the temperature monitor, a body temperature based on the model; and outputting, by the temperature monitor, the predicted body temperature as a current temperature reading.

[0098] In some embodiments, the model includes an exponential model for temperature, and wherein determining the parameters of the model includes determining values of a plurality of parameters in the exponential model. In certain embodiments, the model includes:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and determining the parameters of the model includes determining values of α and T_e.

[0099] In several embodiments, predicting a body temperature of the subject based on the model includes determining a value of a of the model; and inputting a time into the model.

[0100] In various embodiments, the method further includes continuing to obtain a plurality of body temperature measurements at a plurality of times after the predicted body temperature is outputted; and updating the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times. In several embodiments, the plurality of times includes predetermined intervals.

[0101] In certain embodiments, the heating element is activated when the temperature monitor detects that the temperature monitor is attached to the body of the subject. In some embodiments, the heating element is embedded in an adhesive patch of the temperature monitor.

[0102] According to one or more embodiments, another temperature monitoring device is provided. The temperature monitoring device generally includes a thermal contact configured to contact a body of the subject; a heating element adjacent to the thermal contact and configured to heat the thermal contact; a thermal sensor configured to sense a temperature of the thermal contact and to obtain a plurality of body temperature measurements at a plurality of times for a time greater than a predetermined amount of time; and a microcontroller configured to activate the heating element for the predetermined amount of time, receive the plurality of measurements from the thermal sensor, determine parameters of a model used for predicting body temperature based on the plurality of measurements, predict a body temperature of the subject based on the model, and output the predicted body temperature as a current temperature reading.

[0103] In various embodiments, the model includes:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and determining the parameters of the model includes determining values of α and T_e

[0104] In several embodiments, the microcontroller is further configured to continue to obtain a plurality of body temperature measurement at a plurality of times after the predicted body temperature is outputted; and update the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

[0105] In various embodiments, the temperature monitoring device further includes an adhesive patch incorporating the heating element.

[0106] Generally, any creation, storage, processing, and/or exchange of user data associated the method, apparatus, and/or system disclosed herein is configured to comply with a variety of privacy settings and security protocols and prevailing data regulations, consistent with treating confidentiality and integrity of user data as an important matter. For example, the apparatus and/or the system may include a module that implements information security controls to comply with a number of standards and/or other agreements. In some embodiments, the module receives a privacy setting selection from the user and implements controls to comply with the selected privacy setting. In other embodiments, the module identifies data that is considered sensitive, encrypts data according to any appropriate and well-known method in the art, replaces sensitive data with codes to pseudonymize the data, and otherwise ensures compliance with selected privacy settings and data security requirements and regulations.

[0107] Persons skilled in the art will recognize that the apparatus, systems, and methods described above can be modified in various ways. Accordingly, persons of ordinary skill in the art will appreciate that the embodiments encompassed by the present disclosure are not limited to the particular exemplary embodiments described above. In that regard, although illustrative embodiments have been shown and described, a wide range of modification, change, and substitution is contemplated in the foregoing disclosure. It is understood that such variations may be made to the foregoing without departing from the scope of the present disclosure. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the present disclosure.

What is claimed is:

1. A method for measuring body temperature of a subject, comprising:
- obtaining, by a temperature monitor attached to a body of the subject, a plurality of body temperature measurements at a plurality of times for the subject;
- determining, by the temperature monitor, parameters of a model used for predicting temperature, based on the plurality of measurements;
- predicting, by the temperature monitor, a body temperature of the subject based on the model; and
- outputting, by the temperature monitor, the predicted body temperature as a current temperature reading.

2. The method of claim **1**, wherein the model comprises an exponential model for temperature, and wherein determining the parameters of the model comprises determining values of a plurality of parameters in the exponential model.

3. The method of claim 1, wherein the model comprises:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and
wherein determining the parameters of the model comprises determining values of α and T_e.

4. The method of claim 3, wherein predicting a body temperature of the subject based on the model comprises:
determining a value of a of the model; and
inputting a time into the model.

5. The method of claim 1, further comprising:
continuing to obtain a plurality of body temperature measurements at a plurality of times after the predicted body temperature is outputted; and
updating the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

6. The method of claim 1, wherein the plurality of times comprises predetermined intervals.

7. The method of claim 1, further comprising activating a heating element coupled to the temperature monitor.

8. The method of claim 7, wherein the heating element is activated when the temperature monitor detects that the temperature monitor is attached to the body of the subject.

9. The method of claim 7, wherein activating the heating element comprises activating the heating element for a predetermined amount of time; and wherein obtaining the plurality of body temperature measurements comprises obtaining the plurality of body temperature measurements over a period of time that is greater than the predetermined amount of time.

10. A temperature monitoring device for measuring body temperature of a subject, which comprises:
a thermal sensor configured to sense a body temperature and to obtain a plurality of body temperature measurements at a plurality of times for the subject; and
a microcontroller configured to:
receive the plurality of measurements from the thermal sensor,
determine parameters of a model used for predicting body temperature based on the plurality of measurements,
predict a body temperature of the subject based on the model, and
output the predicted body temperature as a current temperature reading.

11. The temperature monitoring device of claim 10, wherein the model comprises:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and
wherein determining the parameters of the model comprises determining values of α and T_e.

12. The temperature monitoring device of claim 10, wherein the microcontroller is further configured to:
continue to obtain a plurality of body temperature measurement at a plurality of times after the predicted body temperature is outputted; and
update the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

13. The temperature monitoring device of claim 10, further comprising a thermal contact configured to contact the body of the subject and a heating element adjacent to the thermal contact, wherein the microcontroller is configured to activate the heating element.

14. The temperature monitoring device of claim 13, wherein the microcontroller is further configured to:
detect that the temperature monitoring device is attached to the body of the subject, and
activate the heating element upon the detection.

15. The temperature monitoring device of claim 13, further comprising an adhesive patch incorporating the heating element.

16. A temperature monitoring device, which comprises:
a thermal contact configured to contact a body of the subject;
a heating element adjacent to the thermal contact and configured to heat the thermal contact;
a thermal sensor configured to sense a temperature of the thermal contact and to obtain a plurality of body temperature measurements at a plurality of times for a time greater than a predetermined amount of time; and
a microcontroller configured to:
activate the heating element for the predetermined amount of time,
receive the plurality of measurements from the thermal sensor,
determine parameters used for predicting body temperature based on the plurality of measurements,
predict a body temperature of the subject based on the parameters, and
output the predicted body temperature as a current temperature reading.

17. The temperature monitoring device of claim 16, wherein the parameters are part of a model, wherein the model comprises:

$$t(\text{time})=(T_e-T_0)(1-e^{-\alpha t})+T_0,$$

where t=time, T_0=an initial temperature, T_e=a final temperature, and α=a thermal time constant, and
wherein determining the parameters of the model comprises determining values of a and T_e.

18. The temperature monitoring device of claim 16, wherein the microcontroller is further configured to:
continue to obtain a plurality of body temperature measurement at a plurality of times after the predicted body temperature is outputted; and
update the predicted body temperature based on the continued obtainment of the plurality of body temperature measurements at a plurality of times.

19. The temperature monitoring device of claim 16, further comprising an adhesive patch incorporating the heating element.

20. The temperature monitoring device of claim 16, wherein the microcontroller is further configured to:
detect that the temperature monitoring device is attached to the body of the subject, and
activate the heating element upon the detection.

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摘要(译)

公开了用于减少可安装于身体的温度监测装置提供准确的体温的时间的各种方法和装置。一旦监视设备达到热平衡，就可以使用方法来准确预测所测温度。例如，在一个实施例中，一种用于测量对象的体温的方法包括：通过附接到对象的身体的温度监视器来多次获得多个体温测量值，确定用于以下目的的模型的参数：基于所述多个测量值来预测温度，基于所述模型来预测对象的体温，并且输出所预测的体温作为当前温度读数。