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(54) **PORTABLE HYDRATION SENSOR**

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A61B 5/01 (2006.01)

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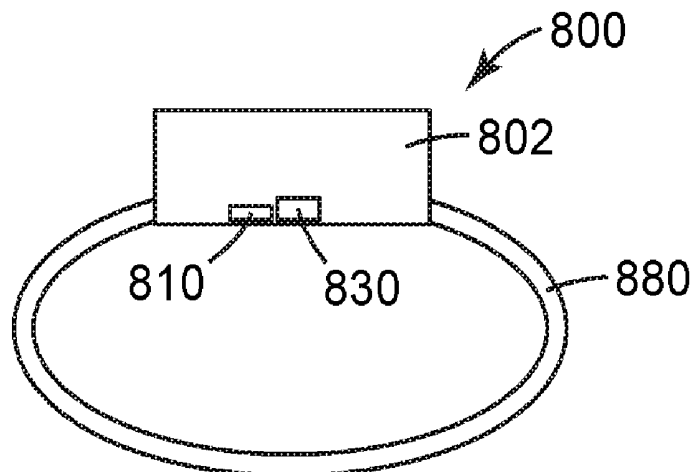
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(57) **ABSTRACT**

A portable sensor for measuring a hydration level of an object in close physical proximity with the sensor includes a portable housing having a total volume of less than about 50 cm³. First circuitry disposed in the housing includes a thermal source, a controller electrically coupled to the thermal source, a temperature sensing element, and a processor coupled to the temperature sensing element. When the object is in close physical proximity with the sensor, the thermal source is energized by the controller with a signal having a known function of time. The object affects a time variation of a temperature of the thermal source, the temperature sensing element senses the affected time variation of the temperature of the thermal source, and the processor

(Continued)



determines a hydration level of the object based on a characteristic of the affected time variation of the temperature of the thermal source.

14 Claims, 4 Drawing Sheets

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(58) Field of Classification Search

USPC 600/549
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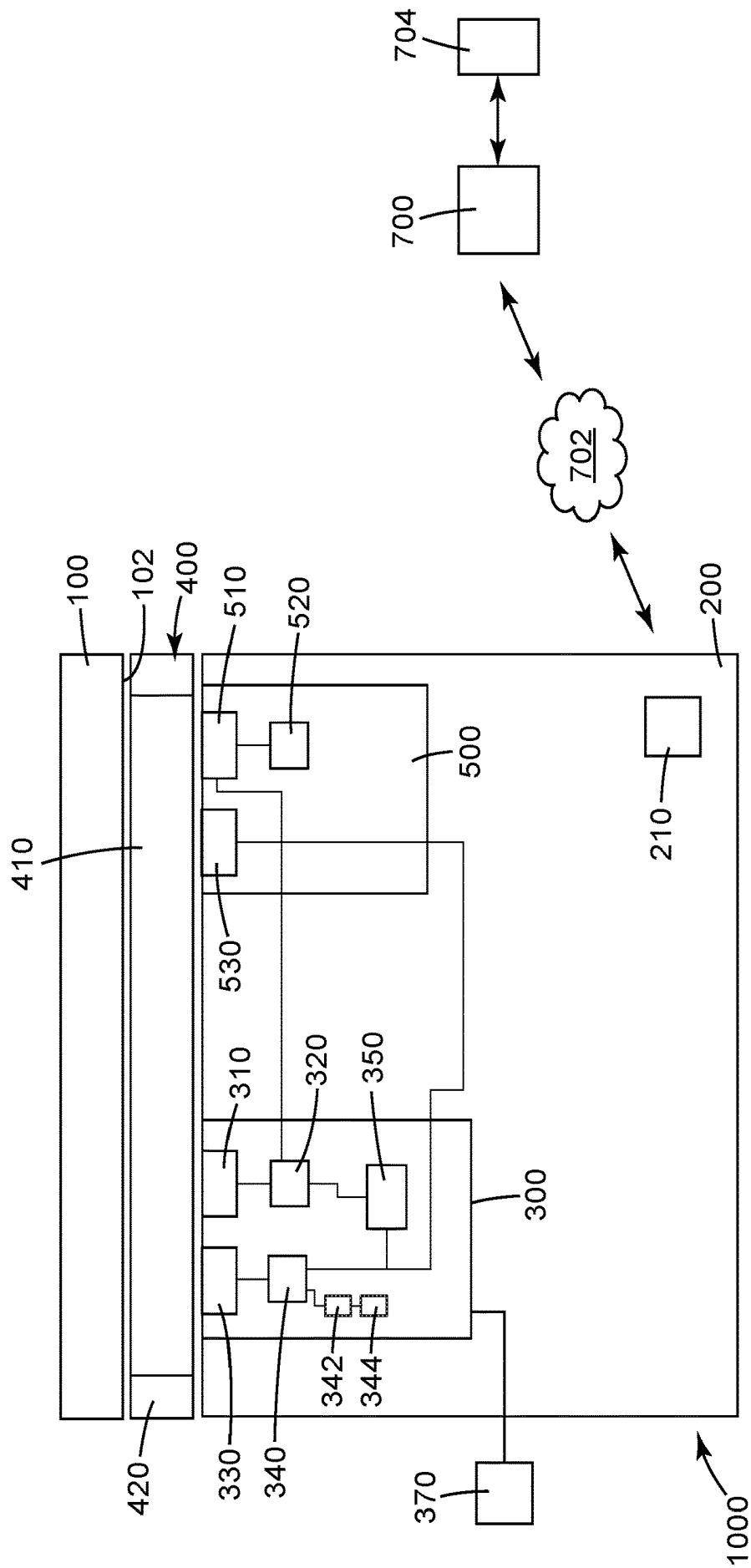
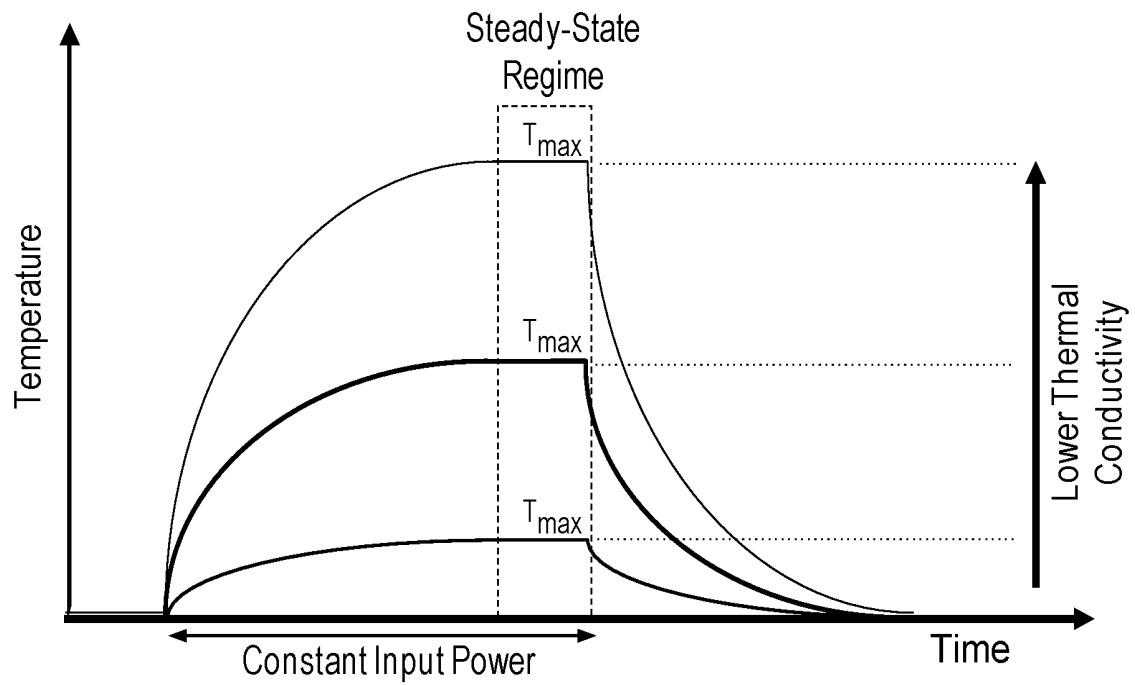


Fig. 1

***Fig. 2***

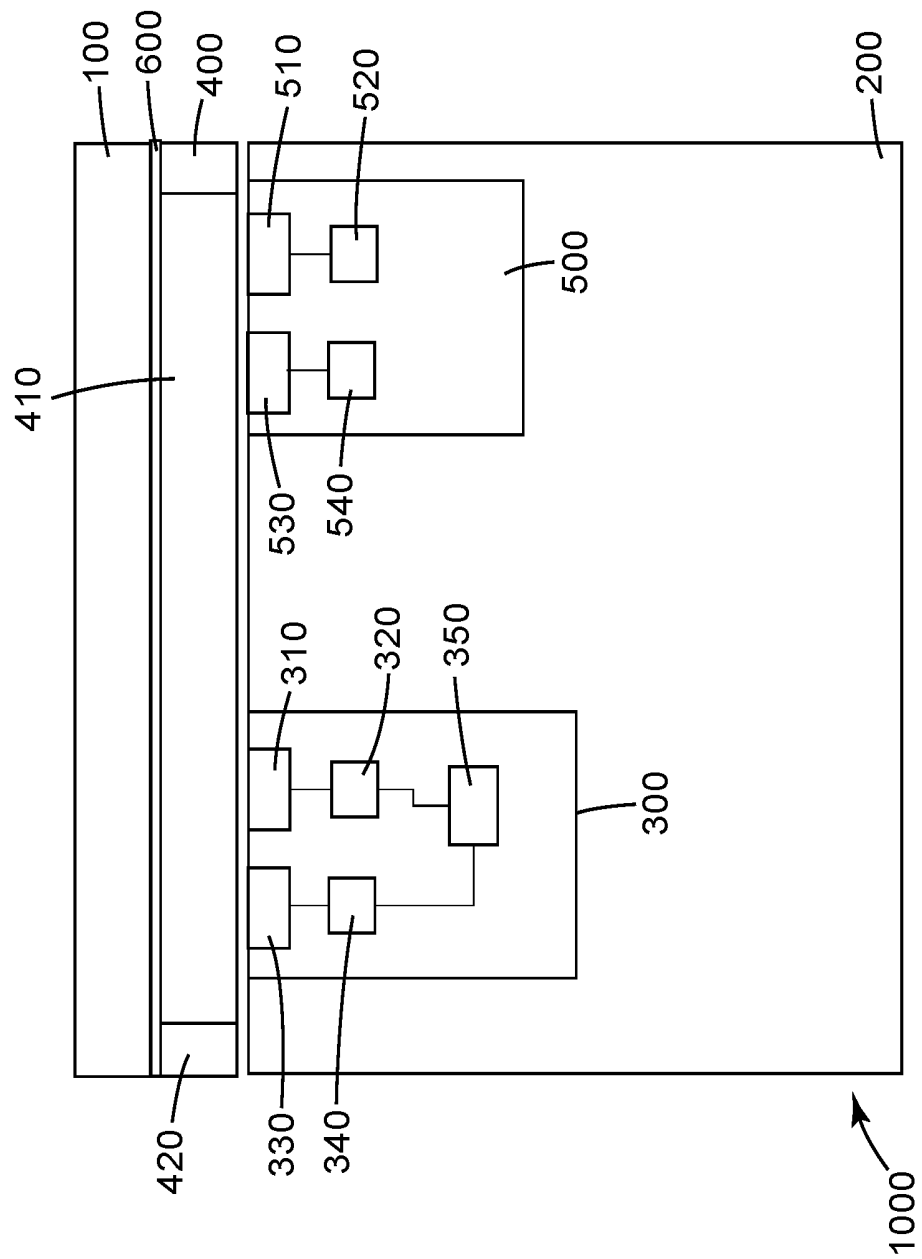


Fig. 3

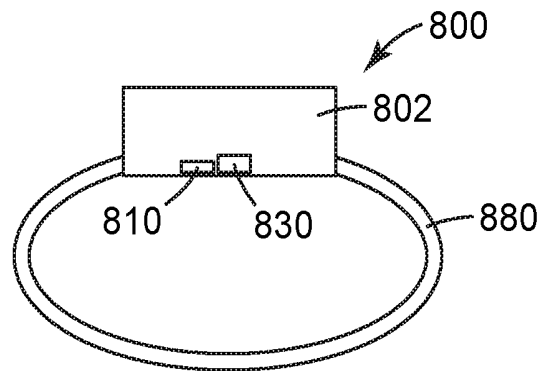


Fig. 4

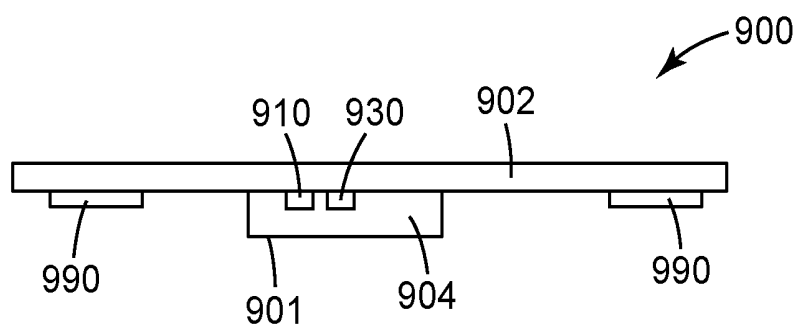


Fig. 5

PORTABLE HYDRATION SENSOR**CROSS REFERENCE TO RELATED APPLICATIONS**

This application is a national stage filing under 35 U.S.C. 371 of PCT/US2017/030356, filed May 1, 2017, which claims the benefit of U.S. application Ser. No. 62/332,886, filed May 6, 2016, the disclosure of which is incorporated by reference in its/their entirety herein.

BACKGROUND

Normal hydration can be important for health and well-being. Even small losses of body water can have a negative effect on muscle strength, endurance and maximal oxygen uptake, so it can be important to quickly, accurately, and continuously measure the hydration level of a human or animal host.

For example, hydration may be measured in a laboratory to test the effects of sports drinks, diets or exercise sessions, in a clinical environment to ensure the wellbeing of patients, by the military to evaluate whether personnel can fulfill active duties while remaining healthy, at major sporting events to ensure that athletes achieve their performance potential, or in a home setting to monitor if a family member, particularly an elderly person or child, is drinking a sufficient amount of fluid.

Hydration can be measured by, for example, acute changes in body mass, blood tests to evaluate hemoglobin concentration, sodium concentration or osmolarity, urine tests, or saliva flow rate, osmolarity or composition.

The practicalities of monitoring hydration levels to promote health and wellbeing are difficult due to the dynamic state of hydration and differences in how individuals respond to fluid gains and losses.

SUMMARY

Current methods for measuring hydration are conducted in a laboratory with expensive equipment. The present disclosure provides an inexpensive sensor for measuring hydration outside the laboratory setting. The hydration sensor is sufficiently small to be portable, and as such can be incorporated into a wide variety of wearable devices, clothing, medical equipment, and the like.

In general, the present disclosure is directed to a portable hydration sensor which, when positioned in close physical proximity to an object, can measure a hydration level of the object. The hydration sensor determines the thermal properties of the object, and these thermal properties are used to infer the hydration state of the object.

In one non-limiting example, where the object is a skin layer of a host, the portable hydration sensor is sufficiently small and compact to integrate into a torso-mounted, head-mounted, or an appendage-mountable wearable device such as a wristwatch, a fitness monitor, or a medical patient monitor. In other embodiments, the portable hydration sensor may be made a part of a wearable item that contacts the skin of the host such as, for example, clothing, eyewear, personal protection equipment, or bandages.

In some embodiments, an interface between the host and sensor can optionally include an interface material. In some embodiments, the interface material can be a disposable or reusable moisture management layer, and the portable hydration sensor can determine a hydration level of the object based on the thermal characteristics of the moisture

management layer. In some embodiments, the interface material can more effectively isolate the skin of the host from the thermal source of the sensor, which can improve sensor response times.

In one aspect, the present disclosure is directed to a portable sensor for measuring a hydration level of an object in close physical proximity with the portable sensor. The sensor includes a portable housing having a total volume of than about 50 cm³; and a first circuitry disposed in the housing. The first circuitry includes a thermal source, a controller electrically coupled to the thermal source, a temperature sensing element, and a processor coupled to the temperature sensing element. When an object is in close physical proximity with the thermal source and the temperature sensing element, the thermal source is energized by the controller with a signal having a known function of time, the object affects a time variation of a temperature of the thermal source, the temperature sensing element senses the affected time variation of the temperature of the thermal source, and the processor determines a hydration level of the object based on a characteristic of the affected time variation of the temperature of the thermal source.

In another embodiment, the present disclosure is directed to a portable sensor for measuring a thermal characteristic of an object in close physical proximity with the portable sensor, including a portable housing and one or more circuitries disposed in the housing. Each circuitry includes a thermal source; a controller electrically coupled to the thermal source, and a temperature sensing element. A moisture management layer is in thermal contact with the thermal source and the temperature sensing element. The moisture management layer, when substantially dry, has a known time variation of temperature in response to the thermal source being energized with a signal having a known function of time. When an object is in close physical proximity with the moisture management layer, the moisture management layer controls a rate of moisture transfer between the object and the moisture management layer, the thermal source is energized by the controller with the signal having the known function of time, the energized thermal source delivers thermal energy to the moisture management layer, and the temperature sensing element senses a time variation of a temperature of the moisture management layer.

In another embodiment, the present disclosure is directed a method of sensing a fluid content of an object, including steps of: transferring fluid from an object to a moisture management layer placed in close physical proximity to the object, the moisture management layer, when substantially dry, having a known time variation of temperature in response to thermal energy having a known function of time delivered to the moisture management layer; delivering to the moisture management layer thermal energy having the known function of time; and sensing a time variation of a temperature of the moisture management layer.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic, cross-sectional diagram of an embodiment of a portable temperature sensor.

FIG. 2 is a schematic profile of a heater element before, during, and after constant input power, wherein the heater

element in thermal contact with **3** different materials each having different thermal properties.

FIG. **3** is a schematic, cross-sectional diagram of another embodiment of a portable temperature sensor

FIG. **4** is a schematic perspective view of a wristwatch including a portable temperature sensor.

FIG. **5** is a schematic cross-sectional view of a bandage including a portable temperature sensor.

Like symbols in the drawings indicate like elements.

DETAILED DESCRIPTION

Referring to FIG. **1**, a portable sensor **1000** measures a hydration level of an object **100** in close physical proximity with the portable sensor. The portable sensor **1000** includes a housing **200** which, in various example embodiments that are not intended to be limiting, can have a total volume of less than about 100 cm^3 , or less than about 50 cm^3 , or less than about 20 cm^3 , less than about 10 cm^3 , less than about 5 cm^3 , or less than about 1 cm^3 .

The portable sensor **1000** includes a first electrical circuitry **300** disposed in the housing **200**. The first circuit **300** includes a thermal source or heater **310** maintained in close thermal contact with the object **100** and substantially thermally isolated from the housing **200**. The thermal source **310** locally warms or cools at least a portion of a surface **102** of the object **100**. The thermal source **310** may vary widely depending on the intended application, and may include any heater circuit such as, for example, a resistance heater, an induction heater, and the like. In some embodiments, the thermal source may be powered by a power source **350** as described in more detail below. In another embodiment, the thermal source **310** may utilize waste heat of a subsystem to alter the temperature of the object **100**. For example, when a Bluetooth radio is turned on, its waste heat could be used as the thermal source **310**, and hydration sensing of the object **100** could be opportunistically determined at these times with little additional power expenditure.

The first circuit **300** further includes a controller **320** electrically coupled to the thermal source **310**. The controller **320** provides a constant (or a known power vs. time) input power to the thermal source **310**.

A temperature sensing element **330**, which in various embodiments can be adjacent to or spaced apart from the thermal source **310**, is electrically coupled to the thermal source **310**. The temperature sensing element **330** is electrically coupled to a processor **340**, which is used to evaluate the results of the temperature sensing element **330** over time and, based at least in part on these results, infer hydration of the object **100**.

For example, the processor **340** executes instructions stored in memory **342** or instructions stored on storage devices **344**. Memory **342** or storage devices **344** may store sensor information including calibration data, reference information, serial number, model, usage history, or construction information. Memory **342**, which may be a non-transient, computer-readable storage medium, is configured to store information, and in some embodiments may include a temporary memory, i.e. an area for information to be maintained when the first circuit **300** is turned off. Examples of such temporary memory include volatile memories such as random access memories (RAM), dynamic random access memories (DRAM), and static random access memories (SRAM). The memory **342** also maintains program instructions for execution by the processor **340**. In some embodiments, the processor and controller may be combined into one element.

The storage devices **344** also include one or more non-transient computer-readable storage media. The storage devices **344** are generally configured to store larger amounts of information than memory **342**, and may further be configured for long-term storage of information. In some examples, storage devices **344** include non-volatile storage elements such as, for example, magnetic hard discs, optical discs, floppy discs, flash memories, ferroelectric random access memories (FRAM), or forms of electrically programmable memories (EPROM) or electrically erasable and programmable (EEPROM) memories.

In some embodiments, a temperature-dependent electrically resistive element **360** disposed in the housing **200** can function as both the thermal source **310** and the temperature sensing element **330**.

In the embodiment shown in FIG. **1**, the first circuit **300** includes an internal power source **350** disposed in the housing **200**, although power sources **370** external to the housing **200** may be used in addition to or in place of the internal power source **350**. The power source **350** is electrically coupled to at least one of the thermal source **310**, the controller **320**, the temperature sensing element **330**, and the processor **340**. In various embodiments, the power source **350** includes one or more of a battery, a fuel cell, a capacitor, a supercapacitor, and a mechanical potential energy storage source. Non-limiting examples of power sources **350** include single-use power sources, rechargeable power sources, and/or power sources developed from nickel-cadmium, lithium-ion, or other suitable material. In some embodiments, the mechanical potential energy storage source for the power source **350** can include one or more springs, compressed fluid, an elevated weight, and a fly-wheel.

In some embodiments, the portable sensor **1000**, or the device of which the portable sensor **1000** is a part, such as, for example, a smart phone, a personal digital assistant (PDA), a tablet computer, a wearable computer or watch, a laptop computer, a video-game console, or the like, is equipped with communication elements **210**. The communication elements **210** enable the sensor **1000** to establish communicative connections when they are brought into proximity of other devices capable of establishing a communicative connection. For example, the communicative connection may be established through a near field communications (NFC) protocol, Bluetooth, ANT, ZigBee, WiFi, or through a variety of other protocols.

In some embodiments, the portable sensor **1000** may be connected to a server **700** (or cloud-based platform) through a data network **702**. The server **700** is additionally connected to a database **704**. The network **702** may be either a wired or a wireless network, and may include elements of a Bluetooth network, WiFi network, cellular network, a voice over internet protocol (VoIP) network, a public switched telephone network (PSTN), or a combination thereof. Example networks include but are not limited to a long term evolution (LTE) network, a global system for mobile communications (GSM) network, a code division multiple access (CDMA) network, a fiber optic network, and other voice or data networks. The network **702** may also include elements of wireless local area network (WLAN) or wireless personal area network (WPAN) networks that enable the sensor **1000** to connect to other components of the network, for example an LTE network, a WiFi network, or a Bluetooth network.

The network **702** allows the sensor **1000** to communicate with the server **700**. For example, the sensor **1000** may transmit information to the server **700** and receive informa-

tion from the server **700**. The server **700** includes processors and memory configured to receive information from the sensor **1000** and to provide information to the sensor **1000**. The information received by the server **700** may include data pertaining to a user account affiliated with the sensor **1000**, data pertaining to contextual information relevant to the sensor **1000** or a user account affiliated with the client device, and the like.

The database **704** may store a variety of information, including, e.g., information pertaining to one or more user accounts for the sensor **1000**. Information pertaining to the one or more user accounts may include, but is not limited to, a user account name, the name of a user to whom the user account belongs, verification information for the user account, a social network profile associated with the user account, images associated with the user account, documents and media content associated with the user account, various user account settings, and sensor information including calibration data, reference information, serial number, model, usage history, or construction information.

In operation, the thermal source **310** is energized by the controller **320** with a signal having a known function of time. The thermal source **310** locally warms (or cools) the temperature of at least a portion of the surface **102** of the object **100** in close physical proximity with the thermal source **310**. The temperature sensor **330** measures the local temperature change of the surface **102**. The object **100** alters or otherwise affects a time variation of a temperature of the thermal source **310**. The temperature sensing element **330** senses the affected time variation of the temperature of the thermal source **310**, and the processor **340** determines a hydration level of the object **100** based on a characteristic of the affected time variation of the temperature of the thermal source **310**.

In various example embodiments, which are not intended to be limiting, the characteristic of the affected time variation utilized by the processor **340** to determine hydration level of the object **100** includes a time rate of change of the affected time variation of the temperature of the thermal source **310**, or a magnitude of the temperature when a time rate of change of the affected time variation of the temperature of the thermal source **310** is less than a threshold value.

In various embodiments, the processor **340** may be configured to provide a wide variety of output signals. For example, the processor **340** may produce a digital output energizing a LED or number of LEDs, a digital display, or digital data communicated to another device via a data download cable or wirelessly. In some embodiments, the output of the processor **340** may be analog, such as controlling the brightness of a LED, or the apparent color of a LED, or a combination thereof.

For example, if a constant input power is applied by the controller **320** to the thermal source **310**, as shown in FIG. 2, the increase in temperature of the thermal source **310** in proximity with the surface **102** of the object **100** will have an associated time constant and an associated steady state temperature. This increase in temperature of the thermal source **310** will have a temperature-time profile dependent on the material of the surface **102** of the object **100** proximal the thermal source **310**.

In one example, which is not intended to be limiting, the thermal source **310** can be placed in close proximity to an area of human skin to measure the hydration level thereof. The hydration level of the skin near the thermal source **310** may be inferred from the thermal properties of the skin, which indicate its hydration status. For example, when the surface of the skin proximal the thermal source **310** is

relatively dehydrated, its thermal conductivity is relatively low, conversely, when the surface of the skin is relatively hydrated its thermal conductivity is relatively high. If the skin surface is relatively well hydrated, the temperature rise before reaching steady-state will be relatively small, as opposed to a relatively large temperature rise when the skin surface is relatively dry.

As noted above, the surface **102** of the object **100** should be maintained in close physical proximity with the thermal source **310** and the temperature sensing element **330**. In various embodiments, an external force may be applied to maintain the physical proximity of the object **100** and the thermal source **310** and the temperature sensing element **330**. In some embodiments, the object **100** and the portable sensor **1000** should be maintained in sufficiently close proximity to one another such that the components of the portable sensor **1000** are in close thermal contact with the surface **102** of the object **100**. Close thermal contact means that thermal energy can transfer from the thermal source **310** to the surface **102** of the object **100** to alter the temperature of at least a portion of the surface **102**; or, sufficient thermal energy can transfer from the object **100** to the temperature sensing element **330** such that the temperature sensing element **330** can detect a change in the temperature of the surface **102** of the object **100**. In various embodiments, thermal energy transfers from the components of the portable sensor **1000** to the surface **102** of the object **100** by at least one of thermal conduction, radiation, or convection. In some embodiments, the thermal energy transfers from the components of the portable sensor **1000** to the surface **102** of the object **100** predominately by conduction, or substantially by conduction.

In one example, which is not intended to be limiting, if the portable sensor **1000** is incorporated into a wrist watch or a fitness monitor, the band of the watch maintains the relative positions of the sensor **1000** and the surface of the skin of the host such that the separation between the sensor **1000** and the skin of the host is no more than 10 mm, or no more than about 5 mm. Larger separations between the sensor **1000** and the surface of the skin of the host may temporarily occur, but if thermal energy cannot effectively transfer from the thermal source **310** to the skin of the host, suspension or cessation of device measurement activity may result. Larger separations between the sensor **1000** and the object **100** may adversely impact the accuracy of the transfer of thermal energy between the object and at least one of the thermal source **310** and the temperature sensing element **330**, which can cause erroneous hydration values (or no hydration values) to be output by the sensor **1000**.

For example, in another embodiment, the object **100** is kept in close physical proximity with the thermal source **310** and the temperature sensing element **330** by an adhesive layer **600** between the surface **102** of the object **100** and the housing **200** (see FIG. 3). The adhesive layer **600** at least temporarily bonds the object **100** to the portable sensor **1000**.

As another example, if the portable sensor **1000** is configured to measure a hydration level of human skin in close physical proximity with the portable sensor **1000**, the human skin is kept in close physical proximity with the thermal source and the temperature sensing element by an applied external force provided by apparel, a headband, a wristband, a watch, a glove, a soft support brace for wrapping around a human body part, a hard support brace, footwear, and the like.

In another embodiment, the portable hydration sensor **1000** includes a moisture management layer **400** in thermal

contact with the thermal source **310** and the temperature sensing element **330**. In some embodiments, the moisture management layer **400** is a porous substantially water-repelling or hydrophobic material such as, for example, polytetrafluoroethylene, stretched polytetrafluoroethylene, melamine foam, hydrophobic polyurethanes, hydrophobic silicones, hydrophobic polyacrylates, polyolefins, and polyester. In other embodiments, the moisture management layer **400** is a porous, substantially hydrophilic material such as, for example, hydrophilic polyurethanes, hydrophilic silicones, hydrophilic polyacrylates, hydrogels, cellulose, polyacrylic amides, polyamides, ethoxylated graphed polymers, natural fibers, rayon, and cotton. In some embodiments, the moisture management layer **400** has an adhesive property. In some embodiments, the moisture management layer **400** and the adhesive layer **600** (FIG. 3) are combined.

In some embodiments, the moisture management layer **400** is selected from materials suitable to control a rate of moisture transfer to or from the moisture management layer **400** from or to the surface **102** of the object **100**. In various embodiments, transpiration may be controlled by the use of hydrophilic or hydrophobic moisture control materials for the moisture management layer **400**, which may be in the form of a reusable or disposable pad. Suitable materials for controlling the rate of moisture transfer include, but are not limited to, foamed polymeric materials such as polyurethanes, polyolefins, polyesters, polyvinyl chlorides, ethylene vinyl acetate, polyvinyl alcohols, polyvinyl acetates, and or nonwoven materials such as polypropylene, polyethylene terephthalate, cellulose, rayon, synthetic rayon, nylon, polyester, and polyethylene. In some embodiments, the transpiration control by the moisture management layer **400** can be used to augment thermal contact between the object **100** and the hydration sensor **1000**.

The moisture management layer **400**, when substantially dry, has a known time variation of temperature in response to the thermal source **310** being energized by the controller **320** with a signal having the known function of time. In some embodiments, the moisture management layer **400**, when containing a known amount of fluid, has a known time variation of temperature in response to the thermal source **310** being energized by the controller **320** with a signal having the known function of time. When the surface **102** of the object **100** is in close physical proximity with the moisture management layer **400**, and the moisture management layer **400** is disposed between the object **100** and the thermal source **310** and the temperature sensing element **330**, the moisture management layer **400** controls a moisture transfer rate between the object **100** and the moisture management layer **400**. When the thermal source **310** is energized by the controller **320** with the signal having the known function of time, the energized thermal source **310** delivers thermal energy to the moisture management layer **400**, the moisture transfer between the surface **102** of the object **100** and the moisture management layer **400** affects a time variation of a temperature of the thermal source **310**. The temperature sensing element **330** senses the affected time variation of the temperature of the thermal source **310**, and the processor **340** determines a hydration level of the object **100** based on a characteristic of the affected time variation of the temperature of the thermal source **310**.

In some embodiments, wherein the moisture management layer **400** is sufficiently thick and/or the temperature sensing element **330** senses the time variation of the temperature of the thermal source **310** over a sufficiently short period of time such that substantially no thermal energy, or no thermal energy, is delivered by the portable sensor **1000** to the

surface **102** of the object **100** while the temperature sensing element **330** senses the time variation of the temperature of the thermal source **310**.

In some embodiments, a suitable thickness of the moisture management layer **400** necessary to prevent delivery of thermal energy from the portable sensor **1000** to the object **100** as the sensing element **330** senses the time variation of the temperature of the thermal source **310** is about 0.1 mm to about 10 mm, or about 0.5 mm to about 3 mm. In various embodiments, the sensing element **330** senses the time variation of the temperature of the thermal source **310** over a time period of about 0.1 second to about 10 minutes, or about 1 seconds to about 60 seconds.

In some embodiments, the moisture management layer **400** includes an inner region **410** surrounded by a perimeter region **420**. The inner region **410** is substantially hydrophilic (water-absorbing) and the perimeter region **420** is substantially hydrophobic (water-repelling).

Referring again to FIG. 1, in some embodiments the portable sensor **1000** further includes reference circuitry **500** that provides a reference signal to be used by a processor in assessing the hydration level of the object **100**. The reference circuitry includes a second thermal source **510**, a second controller **520** electrically coupled to the second thermal source **510**, and a second temperature sensing element **530**.

In some embodiments, the object **100** is in close physical proximity with the thermal source **310** and the temperature sensing element **330** of the first circuitry **300**, but the object **100** is not in close physical proximity with the thermal source **510** and the temperature sensing element **530** of the reference circuitry **500**, so the reference circuitry **500** is thermally isolated from the first circuitry **300**. However, such a thermal isolation arrangement between the first circuitry **300** and the reference circuitry **500** is not required, and either or both of the thermal sources **310, 510** and the temperature sensing elements **330, 530** may be in close physical proximity with object **100**.

In operation, the thermal sources **310, 510** are energized by the controllers **320, 520** with a signal having a known function of time. The object **100** affects a time variation of a temperature of at least one of the thermal sources **310, 510**, and at least one of the temperature sensing elements **330, 530** sense the affected time variation of the temperature of the affected thermal source **310, 510**. The processor **340** then compares the affected time variation of the temperatures of the thermal sources **310, 510** of the first and reference circuitries **300, 500**, and determines the hydration level based on a characteristic of the affected time variation of the temperature of at least one of the thermal sources **310, 510**.

In some embodiments, for example, the object **100** has substantially no effect on the time variation of a temperature of the thermal source **510** of the reference circuitry **500**, and the reference circuitry **500** provides a reference signal to be used by the processor **340** in the determination of the hydration level of the object **100**.

In other embodiments, the controller **520** applies to the reference thermal source **510** a signal having a known function of time, and the temperature sensing element **530** of the reference circuitry **500** senses a time variation of the temperature of the thermal source **510**. The time variation of the temperature of the thermal source **510** may also be used by the processor **340** to determine the hydration level of the object **100** (alone or including the sensed time variation information from the thermal source **310** and the sensing element **330**).

As shown in FIG. 1, the thermal sources **310**, **510** can be energized by the same signal from the controller **320**. In the alternative, as shown in FIG. 3, the thermal sources **310**, **510** can be energized by signals from a first controller **320** in the first circuit **300** and a second controller **520** in the reference circuit **500**.

The portable hydration sensor **1000** shown in FIGS. 1 and 3 can be used to sense hydration of a wide variety of hosts in which moisture level may impact product quality such as, for example foods, construction materials (wood, areas susceptible to mold), pharmaceuticals, soil and the like. In these examples, the housing **200** may be permanently attached to the object to be measured, or the host may be touched by at least a portion of the sensing system.

The portable hydration sensor **1000** can be used a wide variety of torso-mountable, head-mountable, or appendage-mountable wearable devices such as a wristwatch, a fitness monitor, personal protective apparel, personal protective equipment, or a medical patient monitor. For example, as shown in FIG. 4, a wrist-mounted watch **800** includes a case **802** with a thermal source **810** and a temperature sensor **830**. A watch band **880** provides a normal force between the thermal source **810** and temperature sensor **830** and a wearer's skin.

In other embodiments, the portable hydration sensor may be made a part of a wearable item that maintains contact between the thermal source **310** and the sensing element **330** and the skin of the host. Examples include, but are not limited to, clothing such as sports compression clothing, wraps, headbands, undergarments, gloves, footwear, diapers. Additional examples include protective articles such as eyewear, earmuffs, helmets, personal athletic protection equipment such as helmets or mouthpieces, or bandages. For example, as shown in FIG. 5, a bandage **900** includes a nonwoven backing **902** and an absorbent moisture management layer **904**. A thermal source **910** and a temperature sensor **930** reside above or within the moisture management layer **904**. An adhesive **990** or watch band **880** provides a normal force between the thermal source **910** and temperature sensor **930** and a wearer's skin, which is adjacent to a surface **901** of the moisture management layer **904**.

In any of the above embodiments, an interface between the host and sensor can optionally include an interface material such as a disposable or reusable foamed or non-woven moisture management layer, and the portable hydration sensor can determine a hydration level of the object based on the thermal characteristics of the moisture management layer as described above.

Referring again to FIGS. 1 and 3, in another aspect the present disclosure is directed to a method of sensing a fluid content of an object **100**. The method includes transferring fluid from a surface **102** of an object **100** to a moisture management layer **400** placed in close physical proximity to the object. The moisture management layer, when substantially dry, has a known time variation of temperature in response to thermal energy having a known function of time delivered to the moisture management layer **400**.

Thermal energy having a known function of time is then delivered to the moisture management layer, and sensing a time variation of a temperature of the moisture management layer is sensed by a sensor including a thermal source **310** and a sensing element **330**. In some embodiments, a hydration level of the object is determined based on comparing the sensed time variation of the temperature of the moisture management layer **400** with the known time variation of temperature.

Exemplary Embodiments

Item 1. A portable sensor for measuring a hydration level of an object in close physical proximity with the portable sensor, comprising:

a portable housing having a total volume of less than about 50 cm³; and

a first circuitry disposed in the housing and comprising:

a thermal source;

a controller electrically coupled to the thermal source;

a temperature sensing element; and

a processor coupled to the temperature sensing element, such that when the object is in close physical proximity with the thermal source and the temperature sensing element, the thermal source is energized by the controller with a signal having a known function of time, the object affects a time variation of a temperature of the thermal source, the temperature sensing element senses the affected time variation of the temperature of the thermal source, and the processor determines a hydration level of the object based on a characteristic of the affected time variation of the temperature of the thermal source.

Item 2. The portable sensor of Item 1, wherein the characteristic comprises a time rate of change of the affected time variation of the temperature of the thermal source.

Item 3. The portable sensor of Item 1 or 2, wherein the characteristic comprises a magnitude of the temperature when a time rate of change of the affected time variation of the temperature of the thermal source is less than a threshold value.

Item 4. The portable sensor of any one of Items 1-3 further comprising a power source disposed in the housing and coupled to at least one of the thermal source, the controller, the temperature sensing element, and the processor.

Item 5. The portable sensor of Item 4, wherein the power source comprises one or more of a battery, a fuel cell, a capacitor, a supercapacitor, and a mechanical potential energy storage source.

Item 6. The portable sensor of Item 5, wherein the mechanical potential energy storage source comprises one or more springs.

Item 7. The portable sensor of any one of Items 1-6 further comprising an electrically resistive element disposed in the housing and functioning as the thermal source and the temperature sensing element.

Item 8. The portable sensor of any one of Items 1-7 further comprising a moisture management layer in thermal contact with the thermal source and the temperature sensing element, the moisture management layer, when substantially dry, having a known time variation of temperature in response to the thermal source being energized with the signal having the known function of time, such that when an object is in close physical proximity with the moisture management layer with the moisture management layer disposed between the object and the thermal source and the temperature sensing element, the moisture management layer controls a moisture transfer rate between the object and the moisture management layer, the thermal source is energized by the controller with the signal having the known function of time, the energized thermal source delivers thermal energy to the moisture management layer, the moisture transfer between the object and the moisture management layer affects a time variation of a temperature of the moisture management layer, the temperature sensing element senses the affected time variation of the temperature of the moisture management layer, and the processor deter-

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mines a hydration level of the object based on a characteristic of the affected time variation of the temperature of the moisture management layer.

Item 9. The portable sensor of Item 8, wherein the moisture management layer comprises an inner region surrounded by a perimeter region, the inner region being substantially water-absorbing and the perimeter region being substantially water-repelling.

Item 10. The portable sensor of Item 8, wherein the moisture management layer comprises a porous substantially water-repelling material.

Item 11. The portable sensor of any one of Items 1-10 further comprising a reference circuitry substantially thermally isolated from the first circuitry and comprising:

- a thermal source;
- a controller electrically coupled to the thermal source; and
- a temperature sensing element.

Item 12. The portable sensor of Item 11, wherein when an object is in close physical proximity with the thermal source and the temperature sensing element of each of the first and reference circuitries, for each of the first and reference circuitries: the thermal source is energized by the controller with a signal having a known function of time, the object affects a time variation of a temperature of the thermal source, the temperature sensing element senses the affected time variation of the temperature of the thermal source, and the portable sensor compares the affected time variation of the temperatures of the thermal sources of the first and reference circuitries.

Item 13. The portable sensor of Item 11, wherein when an object is in close physical proximity with the thermal source and the temperature sensing element of the first circuitry, the object does not affect, or affects very little, a time variation of a temperature of the thermal source of the reference circuitry.

Item 14. The portable sensor of Item 13, wherein the thermal source of the reference circuitry is energized by the controller of the reference circuitry with a signal having a known function of time, and the temperature sensing element of the reference circuitry senses a time variation of the temperature of the thermal source of the reference circuitry.

Item 15. The portable sensor of Item 14, wherein the thermal sources of the first and reference circuitries are energized by a same signal.

Item 16. The portable sensor of Item 11, wherein when an object is in close physical proximity with the thermal source and the temperature sensing element of the first circuitry, the object is not in close physical proximity with the thermal source and the temperature sensing element of the reference circuitry.

Item 17. The portable sensor of Item 11, wherein the reference circuitry further comprises a processor distinct from the processor of the first circuitry.

Item 18. The portable sensor of Item 11, wherein the processor of the first circuitry is also a processor for the reference circuitry.

Item 19. The portable sensor of any one of Items 1-18, wherein when an object is in close physical proximity with the thermal source and the temperature sensing element, the object is in thermal contact with the thermal source and the temperature sensing element.

Item 20. The portable sensor of any one of Items 1-19, wherein when an object is in close physical proximity with the thermal source and the temperature sensing element, the object is kept in close physical proximity with the thermal

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source and the temperature sensing element by virtue of an adhesive layer at least temporarily bonding the object to the portable sensor.

Item 21. The portable sensor of any one of Items 1-20, wherein when an object is in close physical proximity with the thermal source and the temperature sensing element, the object is kept in close physical proximity with the thermal source and the temperature sensing element by virtue of an applied external force.

Item 22. The portable sensor of Item 1 configured to measure a hydration level of a human skin in close physical proximity with the portable sensor.

Item 23. The portable sensor of Item 22, wherein when a human skin is in close physical proximity with the thermal source and the temperature sensing element, the human skin is kept in close physical proximity with the thermal source and the temperature sensing element by virtue of an applied external force.

Item 24. The portable sensor of Item 23, wherein the external force comprises force from an apparel, a headband, a wristband, a glove, a soft support brace for wrapping around a human body part, a hard support brace, or a footwear.

Item 25. An electronic wrist watch comprising the portable sensor of any one of Items 1-24.

Item 26. The portable sensor of any one of Items 1-25, wherein the portable housing has a total volume of less than about 20 cm³.

Item 27. The portable sensor of any one of Items 1-26, wherein the portable housing has a total volume of less than about 10 cm³.

Item 28. The portable sensor of any one of Items 1-27, wherein the portable housing has a total volume of less than about 5 cm³.

Item 29. The portable sensor of any one of Items 1-28, wherein the portable housing has a total volume of less than about 1 cm³.

Item 30. A portable sensor for measuring a thermal characteristic of an object in close physical proximity with the portable sensor, comprising:

- a portable housing;
- one or more circuitries disposed in the housing, each circuitry comprising:

- a thermal source;
- a controller electrically coupled to the thermal source; and
- a temperature sensing element; and

a moisture management layer in thermal contact with the thermal source and the temperature sensing element, the moisture management layer, when substantially dry, having a known time variation of temperature in response to the thermal source being energized with a signal having a known function of time,

such that when an object is in close physical proximity with the moisture management layer, the moisture management layer controls a rate of moisture transfer between the object and the moisture management layer, the thermal source is energized by the controller with the signal having the known function of time, the energized thermal source delivers thermal energy to the moisture management layer, and the temperature sensing element senses a time variation of a temperature of the moisture management layer.

Item 31. The portable sensor of Item 30, wherein the moisture management layer is sufficiently thick and/or the temperature sensing element senses the time variation of the temperature of the moisture management layer over a sufficiently short period of time that no, or very little, thermal energy is delivered by the portable sensor to the object while

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the temperature sensing element senses the time variation of the temperature of the moisture management layer.

Item 32. The portable sensor of Item 30 or 31, wherein the moisture management layer further controls a rate of moisture transfer from the moisture management layer to the object.

Item 33. The portable sensor of any one of Items 30-32 further comprising a processor disposed in the portable housing and coupled to the temperature sensing element, the processor configured to determine a hydration level of the moisture management layer based on the time variation of the temperature of the moisture management layer.

Item 34. The portable sensor of any one of Items 30-32 further comprising a processor disposed in the portable housing and coupled to the temperature sensing element, the processor configured to determine a transfer of thermal energy between the moisture management layer and the thermal source based on the time variation of the temperature of the moisture management layer.

Item 35. The portable sensor of any one of Items 30-34, such that when an object is in close physical proximity with the moisture management layer, the portable sensor measures an amount of moisture transferred from the object to the moisture management layer based on the sensed time variation of the temperature of the moisture management layer.

Item 36. The portable sensor of any one of Items 30-35, wherein the amount comprises a total amount transferred from the object to the moisture management layer.

Item 37. The portable sensor of any one of Items 30-36, wherein the object comprises a human skin.

Item 38. A method of sensing a fluid content of an object, comprising steps of:

transferring fluid from an object to a moisture management layer placed in close physical proximity to the object, the moisture management layer, when substantially dry, having a known time variation of temperature in response to thermal energy having a known function of time delivered to the moisture management layer;

delivering to the moisture management layer thermal energy having the known function of time; and

sensing a time variation of a temperature of the moisture management layer.

Item 39. The method of Item 38 further comprising a step of determining a hydration level of the object based on comparing the sensed time variation of the temperature of the moisture management layer with the known time variation of temperature.

Various embodiments of the invention have been described. These and other embodiments are within the scope of the following claims.

The invention claimed is:

1. A portable sensor for measuring a hydration level of an object in close physical proximity with the portable sensor, comprising:

a portable housing having a total volume of less than about 50 cm³; and

a first circuitry disposed in the housing and comprising:

a thermal source;

a controller electrically coupled to the thermal source;

a temperature sensing element; and

a processor coupled to the temperature sensing element, a moisture management layer in thermal contact with the thermal source and the temperature sensing element, the moisture management layer, when substantially dry, having a known time variation of temperature in response to the thermal source being energized with the

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signal having a known function of time, such that when the object is in close physical proximity with the moisture management layer with the moisture management layer disposed between the object and the thermal source and the temperature sensing element, the moisture management layer controls a moisture transfer rate between the object and the moisture management layer, the thermal source is energized by the controller with the signal having the known function of time, the energized thermal source delivers thermal energy to the moisture management layer, the moisture transfer between the object and the moisture management layer affects the time variation of the temperature of the moisture management layer, the temperature sensing element senses the affected time variation of the temperature of the moisture management layer, and the processor determines the hydration level of the object based on a characteristic of the affected time variation of the temperature of the moisture management layer.

2. The portable sensor of claim 1, wherein the characteristic comprises a time rate of change of the affected time variation of the temperature of the thermal source.

3. The portable sensor of claim 1, wherein the characteristic comprises a magnitude of the temperature when a time rate of change of the affected time variation of the temperature of the thermal source is less than a threshold value.

4. The portable sensor of claim 1 further comprising a power source disposed in the housing and coupled to at least one of the thermal source, the controller, the temperature sensing element, and the processor.

5. The portable sensor of claim 4, wherein the power source comprises one or more of a battery, a fuel cell, a capacitor, a supercapacitor, and a mechanical potential energy storage source.

6. The portable sensor of claim 1 further comprising an electrically resistive element disposed in the housing and functioning as the thermal source and the temperature sensing element.

7. The portable sensor of claim 1, wherein the moisture management layer comprises an inner region surrounded by a perimeter region, the inner region being substantially water-absorbing and the perimeter region being substantially water-repelling.

8. The portable sensor of claim 1 further comprising a reference circuitry substantially thermally isolated from the first circuitry and comprising:

a thermal source;

a controller electrically coupled to the thermal source; and

a temperature sensing element.

9. The portable sensor of claim 8, wherein when the object is in close physical proximity with the thermal source and the temperature sensing element of each of the first and reference circuitries, for each of the first and reference circuitries: the thermal source is energized by the controller with a signal having the known function of time, the object affects the time variation of the temperature of the thermal source, the temperature sensing element senses the affected time variation of the temperature of the thermal source, and the portable sensor compares the affected time variation of the temperatures of the thermal sources of the first and reference circuitries.

10. A portable sensor for measuring a thermal characteristic of an object in close physical proximity with the portable sensor, comprising:

a portable housing;

one or more circuitries disposed in the housing, each circuitry comprising:

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a thermal source;
 a controller electrically coupled to the thermal source;
 and
 a temperature sensing element; and
 a moisture management layer in thermal contact with the
 thermal source and the temperature sensing element,
 the moisture management layer, when substantially dry,
 having a known time variation of temperature in
 response to the thermal source being energized with a
 signal having a known function of time,
 such that when the object is in close physical proximity
 with the moisture management layer, the moisture
 management layer controls a rate of moisture transfer
 between the object and the moisture management layer,
 the thermal source is energized by the controller with
 the signal having the known function of time, the
 energized thermal source delivers thermal energy to the
 moisture management layer, and the temperature sens-
 ing element senses the time variation of the temperature
 of the moisture management layer.

11. The portable sensor of claim 10, wherein the moisture
 management layer is sufficiently thick and/or the tempera-
 ture sensing element senses the time variation of the tem-

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perature of the moisture management layer over a suffi-
 ciently short period of time that no, or very little, thermal
 energy is delivered by the portable sensor to the object while
 the temperature sensing element senses the time variation of
 the temperature of the moisture management layer.

12. The portable sensor of claim 10 further comprising a
 processor disposed in the portable housing and coupled to
 the temperature sensing element, the processor configured to
 determine a transfer of thermal energy between the moisture
 management layer and the thermal source based on the time
 variation of the temperature of the moisture management
 layer.

13. The portable sensor of claim 10, such that when the
 object is in close physical proximity with the moisture
 management layer, the portable sensor measures an amount
 of moisture transferred from the object to the moisture
 management layer based on the sensed time variation of the
 temperature of the moisture management layer.

14. The portable sensor of claim 10, wherein the amount
 comprises a total amount transferred from the object to the
 moisture management layer.

* * * * *

专利名称(译)	便携式水合传感器		
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[标]申请(专利权)人(译)	明尼苏达州采矿制造公司		
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摘要(译)

一种用于测量与传感器紧密物理接近的物体的水合水平的便携式传感器，其便携式外壳的总体积小于约50 cm³。布置在壳体中的第一电路包括热源，电耦合至热源的控制器，温度感测元件以及耦合至温度感测元件的处理器。当物体与传感器的物理距离很近时，控制器会通过具有已知时间函数的信号为热源供电。物体影响热源温度的时间变化，温度感测元件感测热源温度的受影响的时间变化，并且处理器基于受影响的时间变化的特征来确定物体的水合水平。热源的温度。

