

TEMPERATURE SENSOR CALIBRATOR AND METHOD OF CALIBRATION

Technical Field

- 5 [0001] Embodiments relate generally to temperature sensor calibrators and methods of calibration.

Background

- 10 [0002] Temperature measurement is vital for accurate evaluation of energy consumption in Heating and Ventilation Air Conditioning (HVAC) system especially in chilled water system where the temperature range is usually from 0°C to 40°C. Due to the high sensitivity to temperature changes, temperature sensors such as thermistors are extensively utilized in HVAC related application as temperature measurement components. However, the aggressively nonlinear
15 characteristic and poor consistency of thermistor affects its measurement accuracy and reliability.

- [0003] Calibration is an effective method to improve thermistor accuracy and reliability by acquiring the characteristic curve of each probe, and annual calibration of thermistors used in HVAC system is recommended. A commonly
20 used method is to calibrate the sensors in laboratory where the room temperature and humidity are controlled, put the thermistors into a controllable temperature source such as fixed-point cells or a high quality liquid bath, and test the sensors at three temperature points, which are triple point of water - TPW (0.01°C), Gallium melting point (29.765°C), and temperature point in between (15°C), respectively.
25 This laboratory calibration can provide high accuracy, but the procedure is time consuming and the system, which consists of fixed-cells or high quality liquid bath, high accuracy SPRT (Standard Platinum Resistance Thermometer), high precision readout, and a computer, is very costly to purchase and maintain. Moreover, the thermistors under test need to be removed from the site and brought to the lab,
30 which is quite inconvenient. Another alternative is field calibration, which requires portable calibration devices to be brought to the site for checking the sensor performance. Most of the commercial portable temperature calibrators are dry-well based. These kinds of portable devices which integrate heat source, reference, and

readout, can be used for fast calibration as they have fast heating and cooling capacity (usually 20min for heating or cooling, 8 min for stabilizing). Although it is more convenient to operate than laboratory calibration, the dry-well based temperature calibrators suffer from high thermal fluctuation (stability: 0.01°C ; 5 uniformity: $\pm 0.05^{\circ}\text{C}$), and the inbuilt reference and readout is not accurate enough (reference thermometer readout: $\pm 0.02^{\circ}\text{C}$ at 0°C), which will cause low end-to-end accuracy ($\pm 0.2^{\circ}\text{C}$). Some commercial Micro liquid bath or compact bath could meet the accuracy and portability requirement of field thermistor calibration. However, the calibrating procedure is time-consuming as it takes time to stabilize the liquid, 10 and extra reference sensor, readout device and external computer are required, which increase the complexity of system. Hence, current temperature calibration devices could not simultaneously satisfy the requirements of accuracy, portability, and time-saving capacity for field thermistor calibration.

[0004] Accordingly, example embodiments seek to provide a portable calibrator 15 and calibrating methods for high accuracy and rapid calibration of thermistors for HVAC related application that address at least some of the issues identified above.

Summary

[0005] According to various embodiments, there is provided a temperature 20 sensor calibrator, including a first chamber configured to receive a temperature sensor in a liquid, a second chamber separate from the first chamber, the second chamber surrounding the first chamber, a temperature-regulating component configured to adjust a temperature of a liquid received in the second chamber, and a temperature-homogenizing component disposed in the second chamber, the 25 temperature-homogenizing component configured to enhance temperature uniformity of the liquid in the second chamber. Advantageously, the calibrator may provide a preferable calibration conditions in which enhanced liquid temperature uniformity may be achieved in the first chamber for calibrating the temperature sensor.

30 **[0006]** According to various embodiments, the temperature sensor calibrator may further include an electronic module having a data acquisition unit and a plurality of input channels, wherein the data acquisition unit may be configured to acquire data from the plurality of input channels with high precision. The data

acquisition unit may be further configured to acquire data simultaneously from the plurality of input channels in a synchronized sampling manner. According to various embodiments, the electronic module may also include a processor with inbuilt algorithm for performing onboard calibration and calculation using the data acquired by the data acquisition unit. Advantageously, with the electronic module having the data acquisition unit and the plurality of input channels, the calibrator with enhanced temperature uniformity may be used to calibrate multiple temperature sensors simultaneously in a synchronized manner. This may significantly enhance the efficiency of the calibrator. Further, the calibrator may also be able to provide an all-in-one solution for performing high accuracy calibration on-site and providing calibration results on-site without requiring additional computational equipments or connection to external devices.

[0007] According to various embodiments, there is provided a method of manufacturing a temperature sensor calibrator. The method including providing a first chamber configured to receive a temperature sensor in a liquid, providing a second chamber to surround the first chamber wherein the second chamber is separate from the first chamber, providing a temperature-regulating component configured to adjust a temperature of a liquid received in the second chamber, and providing a temperature-homogenizing component in the second chamber, wherein the temperature-homogenizing component is configured to enhance temperature uniformity of the liquid in the second chamber.

[0008] According to various embodiments, there is provided a method of calibrating a temperature sensor. The method may include inserting the temperature sensor into a liquid in a first chamber, adjusting a temperature of a liquid in a second chamber surrounding the first chamber wherein the second chamber is separate from the first chamber, mixing the liquid in the second chamber to enhance temperature uniformity of the liquid in the second chamber, measuring a temperature of the liquid in the first chamber by means of the temperature sensor, and calibrating the temperature sensor based on a measurement result.

[0009] According to various embodiments, measuring a temperature of the liquid in the first chamber may include simultaneously measuring a liquid reference temperature of a reference temperature sensor inserted in the first chamber and a resistance of a to-be-calibrated temperature sensor inserted in the first chamber.

Advantageously, simultaneously measuring of the liquid reference temperature and the resistance of the to-be-calibrated temperature sensor may enhance calibration accuracy as well as realize fast calibration.

[0010] According to various embodiments, simultaneously measuring the liquid reference temperature of the reference temperature sensor and measuring the resistance of the to-be-calibrated temperature sensor may be via an electronic module having a data acquisition unit and a plurality of input channels, wherein each of the plurality of input channels is connected to either the reference temperature sensor or the to-be-calibrated temperature sensor. Accordingly, the method may include synchronized sampling of data by the data acquisition unit with the plurality of input channels. Advantageously, the synchronized sampling of data by the data acquisition unit may enhance the efficiency of simultaneously measuring of the liquid reference temperature and the resistance of the to-be-calibrated temperature sensor.

[0011] According to various embodiments, there is provided a method of calibrating a temperature sensor. The method may include inserting the temperature sensor into a controllable temperature source, obtaining readings from the temperature sensor at more than three temperature points, and calibrating the temperature sensor based on the readings obtained from the temperature sensor. According to various embodiments, calibrating the temperature may include calculating Steinhart-hart coefficient based on the readings from the temperature sensor. Advantageously, by using multiple temperature points for calibrating the temperature sensor, the calibration method may have an improved end-to-end accuracy.

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Brief description of the drawings

[0012] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments are described with reference to the following drawings, in which:

FIG. 1A shows a schematic diagram of a temperature sensor calibrator according to various embodiments;

FIG. 1B shows a temperature sensor calibrator according to various embodiments;

FIG. 2 shows a schematic diagram illustrating a method of manufacturing a temperature calibration sensor according to various embodiments;

5 FIG. 3A shows a schematic diagram illustrating a method of calibrating temperature sensor according to various embodiments;

FIG. 3B shows a schematic diagram illustrating a method of calibrating a temperature sensor according to various embodiments;

10 FIG. 4 shows a schematic diagram of a temperature sensor calibrator according to various embodiments;

FIG. 5 shows a perspective view of a temperature sensor calibrator according to various embodiments;

FIG. 6A shows the liquid bath assembly of the temperature sensor calibrator of FIG. 5 according to various embodiments;

15 FIG. 6B shows a first portion of the liquid bath assembly of FIG. 6A;

FIG. 6C shows a second portion of the liquid bath assembly of FIG. 6A;

FIGs. 7A to 7C show various cavity configurations of the first chamber of the temperature sensor calibrator of FIG. 5;

20 FIG. 8 shows a schematic diagram of the electronic module of the temperature sensor calibrator of FIG. 5 according to various embodiments;

FIG. 9 shows a graph illustrating a multiple temperature points calibration program for use with the temperature sensor calibrator of FIG. 5 according to various embodiments;

25 FIG. 10 shows a graph illustrating a comparison between the temperature difference at two locations in the inner chamber of the liquid bath assembly with only the outer chamber, and that in the inner chamber of the liquid bath assembly with both the outer chamber and the stirrer during calibration;

30 FIG. 11 shows a graph illustrating a comparison of the errors of temperature calculated by traditional three-points calibration and the multi-points calibration following the procedure shown in FIG. 9 according to various embodiments;

FIG. 12 shows a table illustrating a comparison between original coefficients of the thermistor, coefficients calculated by traditional three-point

calibration method, and coefficients calculated by multi-point least square algorithm according to various embodiments.

Detailed description

5 **[0013]** Embodiments described below in context of the apparatus are analogously valid for the respective methods, and vice versa. Furthermore, it will be understood that the embodiments described below may be combined, for example, a part of one embodiment may be combined with a part of another embodiment.

[0014] It should be understood that the terms “on”, “over”, “top”, “bottom”,
 10 “down”, “side”, “back”, “left”, “right”, “front”, “lateral”, “side”, “up”, “down” etc., when used in the following description are used for convenience and to aid understanding of relative positions or directions, and not intended to limit the orientation of any device, or structure or any part of any device or structure. In addition, the singular terms “a”, “an”, and “the” include plural references unless
 15 context clearly indicates otherwise. Similarly, the word “or” is intended to include “and” unless the context clearly indicates otherwise.

[0015] Various embodiments seek to provide a portable temperature calibrator and novel time-saving calibrating method for field calibration of temperature sensors such as thermistors, which are typically utilized for HVAC system. Various
 20 embodiments seek to improve the accuracy as well as realize fast calibration by focusing on one or more of the factors that affect calibration end-to-end accuracy. These factors include temperature uniformity of liquid bath, temperature stability of liquid bath, the accuracy of reference thermometer, the resistance uncertainty of data acquisition unit, and the mathematical model of Temperature T_i (°C) vs.
 25 Resistances R_i (Ohms).

[0016] According to various embodiments, a temperature sensor calibrator may include two separate liquid chambers and a stirrer such that the calibrator may be configured for “two-step” temperature tuning to increase the vertical and horizontal temperature homogeneity of the liquid bath. The calibrator may include a high
 30 precision data acquisition unit with multiple channels. The calibrator may further include one master processor configured to be utilized by the unit to control multiple dedicated microprocessors assembled for each channel so that multiple data may be recorded simultaneously. Synchronized sampling interval may be

utilized to decrease the error induced by temperature stability of liquid bath. Reference temperature may be acquired using a high accuracy thermometer. Multiple temperature points rather than the traditional three-points may be recorded for modeling of mathematical relationship between T_i and R_i . Multi-point least square algorithm, which may be built in the master processor, may be utilized for coefficients identification. According to various embodiments, the liquid bath, the high accuracy reference thermometer, and the high precision data acquisition unit may be integrated into a portable device for field calibration purposes. Various embodiments may be able to realize fast calibration by heating the outer chamber fluid without waiting for the liquid in the outer chamber to be fully stable, and simultaneously recording liquid reference temperature and resistance for the to-be-calibrated temperature sensor at each temperature point. According to various embodiments, the method may also be able to increase the end-to-end accuracy by decreasing the error induced by liquid bath stability. The calibrator may finish the field calibration in one hour with end-to-end accuracy of $\pm 0.01^\circ\text{C}$.

[0017] According to various embodiments, by using the two chambers configuration, a normal performance liquid bath may be used to realize higher temperature uniformity. The total cost may be reduced although one more chamber is required. This is because, the conventional commercial control unit and heating/cooling element of high performance water bath with equally uniformity and stability may be far more expensive than that of a normal performance liquid bath used in the various embodiments. According to various embodiments, the integration of resistance readout unit and master processor with in-built algorithm may waive the utilization of extra readout and an external computer, which may simplify the system as well as reduce the cost.

[0018] FIG. 1A shows a schematic diagram of a temperature sensor calibrator 100 according to various embodiments. The temperature sensor calibrator 100 may include a first chamber 110. The first chamber 110 may be configured to receive a temperature sensor, such as a thermistor or a reference thermometer, in a liquid. According to various embodiments, the first chamber 110 may be configured to receive a plurality of temperature sensors in the liquid. The plurality of temperature sensors may include a reference thermometer and a plurality of to-be-calibrated temperature sensor, such as a plurality of thermistors. Accordingly, the first

chamber 110 may be configured to contain a liquid such that the temperature sensor received in the first chamber 110 may be immersed into the liquid contained in the first chamber 110.

[0019] According to various embodiments, the calibrator 100 may include a
5 second chamber 120 separate from the first chamber 110. Accordingly, the second chamber 120 may be independent of the first chamber 110 such that the second chamber 120 and the first chamber 110 are set apart from each other and are not in fluid communication with each other. Thus, a liquid contained in the first chamber 110 may be separated from a liquid contained in the second chamber 120 such that
10 the liquid in the first chamber 110 is not in physical connection with the liquid in the second chamber 120. In this arrangement, the stability of the liquid in the first chamber 110 may be independent of the stability of the liquid in the second chamber 120. Thus, when the liquid in the second chamber 120 is being agitated or disturbed, the liquid in the first chamber 110 may remain still or undisturbed.
15 Consequently, stability of the liquid in the second chamber 120 may not be a factor influencing the calibration of the temperature sensor inserted into the liquid of the first chamber 110. The separate second chamber 120 may be configured to surround the first chamber 110. Accordingly, the second chamber 120 may encircle the first chamber 110 such that the second chamber 120 may form an outer chamber and the
20 first chamber 110 may form an inner chamber. In this configuration, an efficient exchange of thermal energy may occur between the second chamber 120 and the first chamber 110.

[0020] According to various embodiments, the calibrator 100 may include a temperature-regulating component 130 configured to adjust a temperature of a
25 liquid received in the second chamber 120. Accordingly, the temperature-regulating component 130 may heat and/or cool the liquid in the second chamber 120 to adjust the temperature of the liquid. According to various embodiments, the temperature-regulating component 130 may be connected to the second chamber 120 such that the temperature-regulating component 130 may provide direct or indirect
30 heating/cooling to the liquid contained in the second chamber 120.

[0021] According to various embodiments, the temperature-regulating component 130 may include a heating component, or a cooling component, or a combination of a heating component and a cooling component, or a heating and

cooling component. The heating component may generate heat to warm up the liquid in the second chamber 120. The heating component may include metal wires (Nichrome, Resistance wire, Etched foil), ceramic (Molybdenum disilicide (MoSi₂), PTC Ceramic), or composite. The cooling component may remove heat from the liquid in the second chamber 120 to cool down the liquid. The cooling component may include vapor-compression based refrigeration or refrigerant-based cooling technologies.

[0022] According to various embodiments, the combination of the heating component and the cooling component may refer to a physical combination of at least one heating component and at least one cooling component. Accordingly, the heating component and the cooling component may be separate and independent from each other such that they independently provide heating or cooling respectively to the second chamber 120. For example, the heating component may include metal wires and the cooling component may include a vapor-compression based refrigeration. Accordingly, two output channels of one controller may be used to control the two separate components.

[0023] According to various embodiments, the heating and cooling component may include a single component that may be utilized to heat and/or cool the liquid in the second chamber 120 depending on the temperature requirement. For example the heating and cooling component may heat and/or cool the liquid in the second chamber 120 depending on the temperature difference between the actual temperature of the liquid in the second chamber 120 and the desired temperature for the liquid. Accordingly, the liquid contained in the second chamber 120 may be heated up by the heating and cooling component when the desired temperature is higher than the actual temperature. The heating and cooling component may also cool the liquid contained in the second chamber 120 when the desired temperature is lower than the actual temperature. According to various embodiments, the heating and cooling component may include a Peltier based thermal semiconductor, which can be used either for heating and/or for cooling. According to various embodiments, to effectively control the temperature of the liquid in the second chamber 120, both heating and cooling may be required. Advantageously, using the Peltier based thermal semiconductor may allow both heating and cooling to be done

via one single component, which may reduce the number of components in the calibrator 100 and enhance the portability of the calibrator 100.

[0024] According to various embodiments, the calibrator 100 may further include a temperature-homogenizing component 140 disposed in the second chamber 120. The temperature-homogenizing component 140 may be configured to enhance temperature uniformity of a liquid in the second chamber 120. The temperature-homogenizing component 140 may be configured to increase mixing of the liquid in the second chamber 120 such that temperature uniformity of the liquid in the second chamber 120 may be enhanced. The temperature-homogenizing component 140 may also be configured to provide uniform heating/cooling across the second chamber 120 such that temperature uniformity of the liquid in the second chamber 120 may be enhanced. With the temperature uniformity of the liquid in the second chamber 120 enhanced, a uniform heating/cooling of the first chamber 110, by the liquid in the second chamber 120 which surrounds the first chamber 110, may be achieved.

[0025] FIG. 1B shows a temperature sensor calibrator 101 according to various embodiments. The temperature sensor calibrator 101 may, similar to the temperature sensor calibrator 100 of FIG. 1A, include a first chamber 110 configured to receive a temperature sensor in a liquid. The temperature sensor calibrator 101 may, similar to the temperature sensor calibrator 100 of FIG. 1A, further include a second chamber 120 separate from the first chamber 110, the second chamber 120 surrounding the first chamber 110. The temperature sensor calibrator 101 may, similar to the temperature sensor calibrator 100 of FIG. 1A, further include a temperature-regulating component 130 configured to adjust a temperature of a liquid received in the second chamber 120. The temperature sensor calibrator 101 may, similar to the temperature sensor calibrator 100 of FIG. 1A, include a temperature-homogenizing component 140 configured to enhance temperature uniformity of the liquid in the second chamber 120.

[0026] According to various embodiments, the temperature-homogenizing component 140 may include an agitator 142. The agitator 142 may be configured to set the liquid in the second chamber 120 into motion to increase mixing of the liquid within the second chamber 120 such that temperature uniformity of the liquid in the second chamber 120 may be enhanced. According to various embodiments,

the agitator 142 may be configured to generate a tangential flow in the liquid contained in the second chamber 120. According to an implementation, the agitator 142 may include an anchor type agitator that may generate tangential flow. Advantageously, tangential flow of the liquid may enhance the temperature
5 uniformity of the liquid in the second chamber 120, which encircles the first chamber 110. According to various embodiments, the agitator 142 may be configured to generate a steady-flow profile in the liquid contained in the second chamber 120. Accordingly, the agitator 142 may be rotated at a suitable speed such that the liquid in the second chamber 120 may have a steady-flow profile and avoid
10 any turbulence. Without generating any turbulence, the temperature uniformity of the liquid in the second chamber 120 may be enhanced. According to various embodiments, the agitator 142 may be shaped to generate tangential flow in the liquid in the second chamber 120 and may be configured to rotate at a suitable speed to generate steady-flow profile.

15 **[0027]** According to various embodiments, the agitator 142 may include a mechanical stirrer. The mechanical stirrer may be moved through the liquid in the second chamber 120 to create a stirring motion to set the liquid in the second chamber 120 into motion. The stirring motion of the mechanical stirrer may generate a tangential flow in the liquid in the second chamber 120. The mechanical
20 stirrer may also create a steady-flow profile for the liquid in the second chamber 120.

[0028] According to various embodiments, the agitator 142 may be disposed in the second chamber 120 and the agitator 142 may be configured to circle around the first chamber 110 for mixing the liquid in the second chamber 120. For example,
25 when the agitator 142 includes a mechanical stirrer, the mechanical stirrer may include a blade disposed in the second chamber 120. The blade may include a vertical blade. The blade may be configured to circle around the first chamber 110 such that the liquid in the second chamber 120 surrounding the first chamber 110 may be stirred to increase mixing of the liquid so as to achieve enhanced
30 temperature uniformity of the liquid in the second chamber 120. The circling of the vertical blade around the first chamber 110 may generate a tangential flow as well as a steady flow in the liquid in the second chamber 120. Various configurations of the blade and various number of blades may be possible. For example, in an

implementation, the mechanical stirrer may include four vertical blades disposed in the second chamber 120 and spaced equally apart around the first chamber 110. The mechanical stirrer may be in the form of an anchor-type stirrer.

[0029] According to various embodiments, the calibrator 101 may include a motor connected to the agitator 142. The motor may be configured to drive the agitator 142. When the agitator 142 includes the mechanical stirrer in the form of a blade, the blade may be connected to the motor such that rotation of the motor shaft may move the blade through the liquid in the second chamber 120 in a circular motion around the first chamber 110.

[0030] According to various embodiments, the temperature-homogenizing component may include a plurality of inlets 144 and a plurality of outlets 146. The plurality of outlets 146 may draw the liquid from the second chamber 120 and flow the liquid to the temperature-regulating component 130 for heating or cooling. The plurality of inlets 144 may then supply the heated/cooled liquid from the temperature-regulating component 130 into the second chamber 120. Accordingly, the liquid in the second chamber 120 may be circulated between the temperature-regulating component 130 and the second chamber 120 for heating/cooling. The plurality of inlets 144 and the plurality of outlets 146 may be configured and disposed in the second chamber 120 such that heated/cooled liquid may be supplied into the second chamber 120 and liquid in the second chamber 120 may be drawn out in an optimized manner to enhance temperature uniformity of the liquid in the second chamber 120.

[0031] According to various embodiments, the plurality of inlets 144 and the plurality of outlets 146 may be distributed along a height of the second chamber 120 such that a vertical temperature uniformity of the liquid in the second chamber 120 may be enhanced. Various other configuration and distribution of the plurality of inlets 144 and the plurality of outlets 146 may be possible to achieve a desired temperature uniformity of the liquid in the second chamber 120.

[0032] According to various embodiments, the first chamber 110 may include heat conducting fins. The heat conducting fins may be assembled within the first chamber 110. The heat conducting fins may be configured to enhance temperature uniformity of the liquid contained in the first chamber 110.

[0033] According to various embodiments, the first chamber 110 may be defined by a cavity within a container. Accordingly, the cavity in the container may form the first chamber 110. The container may be configured to include various types of cavities such as a plurality of elongated cavity, an annular cavity or a plurality of flabellate cavities. The container may be made of thermal conductivity materials, including by not limited to copper, silver and aluminum etc.

[0034] According to various embodiments, the first chamber 110 may be configured into various shapes and profiles for receiving the temperature sensor depending on the calibration requirement. The first chamber 110 may include one or more cavities. The one or more cavities may be in various dimensions, shapes, profiles and configurations. The one or more cavities may be symmetric or asymmetric depending on the calibration requirement.

[0035] According to various embodiments, the first chamber 110 may include a plurality of elongated cavities. Each of the elongated cavities may be configured to receive an elongated temperature sensor. The temperature sensor received may be a reference thermometer or a to-be-calibrated thermistor.

[0036] According to various embodiments, the first chamber 110 may include an annular cavity. The annular cavity may be configured to receive a plurality of temperature sensors including reference thermometer and to-be-calibrated thermistors.

[0037] According to various embodiments, the first chamber 110 may include a plurality of flabellate cavities. Each of the plurality of flabellate cavities may be configured to receive a plurality of temperature sensors including reference thermometer and to-be-calibrated thermistors.

[0038] According to various embodiments, the second chamber 120 may be surrounded by thermal isolation layer. The thermal isolation layer may prevent heat loss to or heat gain from the surrounding, and thus maintain the temperature of the liquid in the second chamber 120 for acting as a heat source or cooling source for the first chamber 110.

[0039] According to various embodiments, the calibrator may further include a lid 150 configured to cover a top of the first chamber 110 and the second chamber 120. The lid 150 may include a through-hole configured to receive the temperature sensor for inserting into the first chamber. Accordingly, inserting the temperature

sensor through the through-hole may introduce a portion of the temperature sensor into the first chamber 110. When the first chamber 110 contains a liquid, the temperature sensor may then be immersed into the liquid contained in the first chamber 110. Depending on the calibration requirements, the lid 150 may include a plurality of through holes arranged and configured to receive a plurality of temperature sensors for immersing into the liquid in the first chamber 110.

[0040] According to various embodiments, the calibrator may include a rubber plug 160 configured to be fitted into the through-hole in the lid 150 of the calibrator. The rubber plug 160 may couple the temperature sensor to the lid 150 such that the temperature sensor may be held by the lid 150. Accordingly, the rubber plug 160 may be sandwiched between the temperature sensor and the through-hole such that the temperature sensor may be held with a desired length inserted into the first chamber 110. By using the rubber plug 160 to couple the temperature sensor to the through-hole of the lid 150, the temperature sensor may be inserted at a desired insertion length. Accordingly, the insertion length of the temperature sensor may be adjusted depending on the calibration requirements.

[0041] According to various embodiments, the temperature-regulating component 130 may be separate from the second chamber 120. Accordingly, the temperature-regulating component 130 may be located or positioned outside the second chamber 120. The external temperature-regulating component 130 may be connected to the second chamber 120 via conduits. The temperature-regulating component 130 may maintain fluid communication with the second chamber 120 via the conduits for circulating of the liquid from the second chamber 120 to the temperature-regulating component 130. The liquid in the second chamber 120 may be pumped to the temperature-regulating component 130 for heating or cooling, and the heated/cooled liquid may be subsequently pumped back into the second chamber 120. With the temperature-regulating component 130 located outside of the second chamber 120, the temperature-regulating component 130 would not be in direct contact with the second chamber 120. Thus, the second chamber 120 may avoid non-uniform temperature distribution of the liquid in the second chamber 120.

[0042] According to various embodiments, the calibrator 101 may further include an electronic module 170. The electronic module 170 may be built-in to the

calibrator 101. The built-in electronic module 170 may perform the functions of interfacing with the user, collecting calibration data from the to-be-calibrated temperature sensors and reference temperature sensor, processing the calibration data and providing calibration result to the user. With the built-in electronic module 170, the calibrator 101 may be used for conducting field calibration on-site and may provide calibration results on-site. Accordingly, the calibrator 101 may provide a all-in-one solution for performing high accuracy calibration on-site and providing calibration results on-site without requiring additional computational equipments or connection to external devices.

10 **[0043]** According to various embodiments, the electronic module 170 may include a user interface 172 configured to receive instructions from the user and/or to display information. The user interface 172 may include a touch panel configured to receive user inputs and/or to display calibration information.

[0044] According to various embodiments, the electronic module 170 may include an input channel 174 configured to be connectable to the temperature sensor. The input channel 174 may be configured to receive a resistance R_i measurement of the to-be-calibrated temperature sensor, such as a thermistor. The input channel 174 may also be configured to receive a temperature T_i measurement from the reference temperature sensor, such as a reference thermometer. According to various embodiments, the electronic module 170 may include a plurality of input channels 174. The plurality of input channels 174 may be configured to receive resistance R_i measurement of the to-be-calibrated temperature sensor, and to receive a temperature T_i measurement from the reference temperature sensor.

25 **[0045]** According to various embodiments, each input channel 174 or each of the plurality of input channels 174 may include a microprocessor 184 and a memory 186. The dedicated microprocessor 184 and the dedicated memory 186 for each input channel 174 may be configured to receive or obtain a desired parameter or data from the temperature sensor connected to that input channel 174.

30 **[0046]** According to various embodiments, the electronic module 170 may include a data acquisition unit 182 configured to acquire the data from the input channel 174. The data acquisition unit 182 may be configured to acquire the data with high precision. According to various embodiments, the data acquisition unit 182 may be configured to acquire data simultaneously from the plurality of input

channels 174. Accordingly, the data acquisition unit 182 may be configured to synchronously sample data from the plurality of input channels 174. This may be possible due to the dedicated microprocessor 184 and memory 186 for each of the plurality of input channels 174. Advantageously, with the data acquisition unit 182 and the plurality of input channels 174, the calibrator 101 may be used to calibrate multiple temperature sensors simultaneously in a synchronized manner. This may significantly enhance the efficiency of the calibrator 101.

[0047] According to various embodiments, the electronic module 170 may include a master processor 180. The master processor 180 may be configured to control the dedicated microprocessor 184 for each input channel 174 such that the master processor 180 may simultaneously instruct each of the dedicated microprocessor 184 of the plurality of input channels 174 to record data at synchronized time interval.

[0048] According to various embodiments, the master processor 180 may be configured to include inbuilt algorithm for performing onboard calibration and calculation using the data acquired by the data acquisition unit 182. According to various embodiments, the master processor 180 may be configured to identify Steinhart-hart coefficients for the calibration of the to-be-calibrated temperature sensor. According to various embodiments, the master processor 180 may be configured to process the data acquired by the data acquisition unit 182 based on mathematical modeling of Temperature Vs Resistance. The master processor 180 may then be configured to determine the Steinhart-hart coefficient based on a multi-point fitting algorithm. The multi-point fitting algorithm may include multi-point least square algorithm

[0049] According to various embodiments, the electronic module 170 may include a controller 176 configured to control the temperature-regulating component 130 and/or the temperature-homogenizing component 140. Depending on the temperature points required for the calibration of the temperature sensor, the electronic module 170 may control the temperature of the liquid of the first chamber 110 via controlling the temperature-regulating component 130 and/or the temperature-homogenizing component 140 to control the temperature of the liquid in the second chamber 120 for heating/cooling the first chamber 110.

[0050] According to various embodiments, the electronic module 170 may include an electronic port 178 configured to be connectable with external electronic devices such as processors or display devices. The electronic port 178 may include USB port etc. for connections with an external computer for processing of the data, or downloading of the data and results etc.

[0051] FIG. 2 shows a schematic diagram illustrating a method 200 of manufacturing a temperature calibration sensor. At 202, a first chamber configured to receive a temperature sensor in a liquid is provided. At 204, a second chamber is provided to surround the first chamber. The second chamber may be separate from the first chamber. At 206, a temperature-regulating component configured to adjust a temperature of a liquid received in the second chamber is provided. At 208, a temperature-homogenizing component is provided in the second chamber. The temperature-homogenizing component may be configured to enhance temperature uniformity of the liquid in the second chamber.

[0052] FIG. 3A shows a schematic diagram illustrating a method 300 of calibrating a temperature sensor. At 302, the temperature sensor is inserted into a liquid in a first chamber. At 304, a liquid in a second chamber surrounding a first chamber, wherein the second chamber is separate from the first chamber, is adjusted, i.e. heated or cooled. At 306, the liquid in the second chamber is mixed to enhance temperature uniformity of the liquid in the second chamber. At 308, a temperature of the liquid in the first chamber is measured by means of the temperature sensor. At 310, the temperature sensor is calibrated based on a measurement result. In the above method, since the second chamber is surrounding the first chamber, when the liquid in the second chamber is being heated, the liquid in the second chamber may provide heat to the first chamber and act as a heat source for heating the liquid contained in the first chamber in which the temperature sensor is received. Conversely, when the liquid in the second chamber is being cooled, the liquid in the second chamber may remove heat from the first chamber and act as a cooling source for cooling the liquid contained in the first chamber. Accordingly, mixing the liquid in the second chamber may provide substantially uniform heating or cooling to the liquid in the first chamber. Further, since the stability of the liquid in the first chamber is independent of the stability of the liquid in the second chamber, when the liquid in the second chamber is being mixed, the

liquid in the first chamber may remain undisturbed. Thus, calibration measurement for the temperature sensor received in the first chamber may be taken almost immediately when the desired temperature is reached as the stability of the liquid in the first chamber is not influenced by the mixing of the liquid in the second chamber. Accordingly, calibration measurement for the temperature sensor may be collected without waiting for the liquid in the second chamber to be fully stabilized.

[0053] According to various embodiments, mixing the liquid in the second chamber at 306 may further include mixing with an agitator. The agitator may be a mechanical stirrer. According to various embodiments, mixing the liquid in the second chamber at 306 may include circulating the liquid in the second chamber through a plurality of inlets and a plurality of outlets disposed along a height of the second chamber.

[0054] According to various embodiments, measuring a temperature of the liquid in the first chamber at 308 may include simultaneously measuring a liquid reference temperature of a reference temperature sensor inserted in the first chamber and a resistance of a to-be-calibrated temperature sensor inserted in the first chamber. Advantageously, simultaneously measuring of the liquid reference temperature and the resistance of the to-be-calibrated temperature sensor may enhance calibration accuracy as well as realize fast calibration.

[0055] According to various embodiments, simultaneously measuring the liquid reference temperature of the reference temperature sensor and measuring the resistance of the to-be-calibrated temperature sensor may be via an electronic module having a data acquisition unit and a plurality of input channels, wherein each of the plurality of input channels is connected to either the reference temperature sensor or the to-be-calibrated temperature sensor. Thus, simultaneously measuring may include synchronized sampling of reference temperature data of the reference temperature sensor and resistance data of the to-be-calibrated temperature sensor with the electronic module having the data acquisition unit and the plurality of input channels. Accordingly, the method may include synchronized sampling of data by the data acquisition unit with the plurality of input channels. Advantageously, the synchronized sampling of data by the data acquisition unit may enhance the efficiency of simultaneously measuring of the liquid reference temperature and the resistance of the to-be-calibrated temperature sensor.

[0056] According to various embodiments, simultaneous measuring may be performed at more than three temperature points. Simultaneous recording may be performed by an electronic module comprising a processor. Advantageously, performing measurements at more than three temperature points may improve the end-to-end accuracy of the calibration method.

[0057] According to various embodiments, calibrating the temperature sensor at 310 may include determining Steinhart-hart coefficient based on a multi-point fitting algorithm. Determination of the Steinhart-hart coefficient may be performed by a processor.

[0058] According to various embodiments, the multi-point fitting algorithm may include multi-point least square algorithm.

[0059] FIG. 3B shows a schematic diagram illustrating a method 350 of calibrating a temperature sensor. At 352, the temperature sensor may be inserted into a controllable temperature source. At 354, readings from the temperature sensor at more than three temperature points may be obtained. At 356, the temperature sensor may be calibrated based on the readings obtained from the temperature sensor. According to various embodiments, calibrating the temperature sensor may include calculating Steinhart-hart coefficient based on the readings from the temperature sensor. Advantageously, by using multiple temperature points for calibrating the temperature sensor, the calibration method may have an improved end-to-end accuracy.

[0060] FIG. 4 shows a schematic diagram of a portable temperature sensor calibrator 400 according to various embodiments. The temperature calibrator 400, may be configured for the calibration of thermistor in HVAC system. As shown in FIG. 4, the calibrator 400 may include a liquid bath assembly 402 with two separate liquid chambers 410, 420 for high temperature homogeneity, electronic module 470 (such as IC board) for controlling and simultaneously recording data of the temperature sensors (such as a high accuracy reference thermometer 404 and to-be-calibrated thermistors 406), display 472 and computer communication interfaces 478, and master processor 480 with inbuilt multi-point calibrating program and coefficients identification algorithms for field time-saving calibration of thermistor. According to an implementation, the calibrator 400 may be configured to calibrate temperature sensor in the range of 0°C - 40°C.

[0061] As shown in FIG. 4, the temperature sensor calibrator may include a liquid bath assembly 402. The liquid bath assembly 402 may include a first chamber 410 (e.g. inner chamber) configured to receive at least one temperature sensor in a liquid. The first chamber 410 may be defined by a cavity 412 within a container 414. The first chamber 410 may be cylindrical shaped. The container 414 may be made of thermal conductivity materials, including but not limited to copper, silver and aluminum etc. The liquid bath assembly 402 may further include a second chamber 420 (e.g. outer chamber) separate from the first chamber 410. The second chamber 420 may surround the first chamber 410. The second chamber 420 may be surrounded by thermal isolation layer. The temperature sensor calibrator 400 may further include a temperature-regulating component 430 configured to adjust a temperature of a liquid received in the second chamber 420. The temperature sensor calibrator 400 may include a temperature-homogenizing component 440 disposed in the second chamber 420. The temperature-homogenizing component 440 may be configured to enhance temperature uniformity of the liquid in the second chamber 420.

[0062] The temperature-homogenizing component 440 may include an agitator 442 in the form of a mechanical stirrer. The mechanical stirrer may be moved through the liquid in the second chamber 420 in a circular motion around the first chamber 410 for stirring the liquid in the second chamber 420. The mechanical stirrer may include a blade 443 disposed in the second chamber 420. The blade 443 may be moved around the first chamber 410 such that the liquid in the second chamber 420 surrounding the first chamber 410 may be stirred to increase mixing of the liquid in the second chamber 420 so as to enhance temperature uniformity of the liquid in the second chamber 420. With enhanced temperature uniformity, the liquid in the second chamber 420 may provide uniform heating/cooling to a liquid contained in the first chamber 410.

[0063] The temperature-homogenizing component 440 may include a plurality of inlets 444 and a plurality of outlets 446. The plurality of outlets 446 may draw the liquid from the second chamber 420 and flow the liquid to the temperature-regulating component 430 for heating or cooling. The plurality of inlets 444 may then supply the heated/cooled liquid from the temperature-regulating component 430 into the second chamber 420. As shown, the plurality of inlets 444 and the

plurality of outlets 446 may be distributed along a height of the second chamber 420 such that a vertical temperature uniformity of the liquid in the second chamber 420 may be enhanced.

[0064] The temperature-regulating component 430 may be separate from the second chamber 420 such that the temperature-regulating component 130 may be located or positioned outside the second chamber 420. Accordingly, the external temperature-regulating component 430 may be connected to the second chamber 420 via conduits 432. A pump or a circulator 434 may be connected along the conduits 432 for circulating the liquid from the second chamber 420 to the temperature-regulating component 430. The liquid in the second chamber 420 may be pumped to the temperature-regulating component 430 for heating or cooling and the heated/cooled liquid may be subsequently pumped back into the second chamber 420. In this arrangement, the second chamber 420 may avoid non-uniform temperature distribution of the liquid in the second chamber 420.

[0065] As shown in FIG. 4, the calibrator 400 may further include a built-in electronic module 470. The electronic module 470 may include a user interface 472 in the form of a touch panel for receiving user inputs and/or to display calibration information. The electronic module 470 may include a plurality of input channels 474 configured to be connectable to a plurality of temperature sensors including a reference thermometer 404 and a plurality of to-be-calibrated thermistors 406. The plurality of input channels 474 may be configured to receive resistance R_i measurements of the to-be-calibrated thermistors 406, and to receive a temperature T_i measurement from the reference thermometer 404.

[0066] The electronic module 470 may include a master processor 480. The master processor 480 may be configured to simultaneously record data from the plurality of temperature sensor at synchronized time interval.

[0067] The master processor 480 may be configured to identify Steinhart-hart coefficients for the calibration of the to-be-calibrated thermistors 406. The master processor 480 may be configured to process the data collected based on mathematical modeling of Temperature Vs Resistance. The master processor 480 may then be configured to determine the Steinhart-hart coefficient based on a multi-point fitting algorithm 482. The multi-point fitting algorithm 482 may include multi-point least square algorithm.

[0068] The electronic module 470 may include a controller 476 configured to control the temperature-regulating component 430. Accordingly, the electronic module 470 may indirectly control the temperature of the liquid in the first chamber 410 via controlling the temperature-regulating component 430 to control the temperature of the liquid in the second chamber 420 for heating or cooling the first chamber 410.

[0069] The electronic module 470 may also include an electronic port 478 configured to be connectable with external electronic devices such as processors or display devices. The electronic port 478 may include USB port etc. for connections with an external computer for processing of the data, or downloading of the data and results etc.

[0070] FIG. 5 shows a perspective view of the portable temperature sensor calibrator 500 according to various embodiments. As shown, the temperature sensor calibrator 500 may include a liquid bath assembly 502. The liquid bath assembly 502 of the temperature sensor calibrator 500 may, similar to the temperature sensor calibrator 400 of FIG. 4, include a first chamber configured to receive a temperature sensor in a liquid. The temperature sensor may include a reference thermometer 504 or a to-be-calibrated thermistor 506. The liquid bath assembly may, similar to the temperature sensor calibrator 400 of FIG. 4, further include a second chamber separate from the first chamber. The second chamber may surround the first chamber. The temperature sensor calibrator 500 may, similar to the temperature sensor calibrator 400 of FIG. 4, further include a temperature-regulating component configured to adjust a temperature of a liquid received in the second chamber via heating and/or cooling. The temperature sensor calibrator 500 may, similar to the temperature sensor calibrator 400 of FIG. 4, include a temperature-homogenizing component disposed in the second chamber. The temperature-homogenizing component may be configured to enhance temperature uniformity of the liquid in the second chamber.

[0071] The temperature sensor calibrator 500 may, similar to the temperature sensor calibrator 400 of FIG. 4, include an electronic module 570. The electronic module 570 may be similar to the electronic module 470 of the temperature sensor calibrator 400 of FIG. 4. For example, as shown in FIG. 5, the electronic module 570 may include a plurality of input channels 574 configured to be connectable to a

plurality of temperature sensors including a reference thermometer 504 and a plurality of to-be-calibrated thermistors 506. The electronic module 570 may also include a user interface 572 in the form of a touch panel.

[0072] FIG. 6A shows the liquid bath assembly 502 of the temperature sensor calibrator 500 of FIG. 5. FIG. 6B shows a first portion of the liquid bath assembly 502. FIG. 6C shows a second portion of the liquid bath assembly 502. According to various embodiments shown, two chambers 510, 520 filled with separate liquid may be adopted as “two-step” temperature tuning to improve vertical and horizontal temperature homogeneity. The second chamber or the outer chamber 520, surrounded by thermal isolation layer, may be covered by thermal isolating material manufactured lid 550 where a DC Gear Motor 552 may be assembled. A plurality of inlets 544 and outlets 546, which are vertically distributed on the shell of outer chamber 520, may be used for circulating of fluid 522 in the outer chamber 520 with improved vertical temperature uniformity. A long motor pole 554 may pass through the central through hole of inner chamber 510 and connect to a special designed stirrer 542 where four vertical blades 548 may be fixed to rotate around the first chamber or the inner chamber 510 for accelerating the mixing of outer chamber fluid 522. The liquid in the outer chamber 522, whose temperature is controlled by primary heating/cooling source – Peltier based thermal semiconductor, surrounds the inner chamber 510 as the secondary heating/cooling source to adjust the temperature of liquid 512 inside inner chamber 510.

[0073] Referring to FIGs. 6C and 7A, the container 514 forming the inner liquid chamber 510 may be manufactured by different high thermal conductivity materials including but not limited to copper, silver, and aluminum etc. as per the calibration requirement. The inner liquid chamber 510 in the form of liquid cavity may be made into various configurations as per the calibration requirement for the insertion of thermistors 506, including but not limited to independent multiple cavities configuration 511 shown in FIG. 7A, an annular cavity configuration 513 shown in FIG. 7B, and 2 or more flabellate cavities configuration 515 shown in FIG. 7C. In the independent multiple cavities configuration 511, each of the to-be-calibrated temperature sensor may be inserted into each of the independent cavity. In the annular cavity configuration 513, all the to-be-calibrated temperature sensor may be inserted into the annular cavity. In the 2 or more flabellate cavities

configuration 515, some of the to-be-calibrated temperature sensor may be inserted into each of the 2 or more flabellate cavities. The dimension of cavity may be varied and the arrangement of the liquid cavities may be symmetric or asymmetric according to the calibration requirement. According to various embodiments, heat-conducting fins 516 may be assembled within the annular cavity and/or the flabellate cavities. The inner chamber 510 and the lid 550 may be connected and fixed by screwing a screw into the threaded hole 518 in the container 514. Rubber plugs 560 with through hole where the temperature sensor may be inserted and plugged in the lid 550 to hold the reference thermometer 504 and the to-be-calibrated thermistors 506 as well as to adjust the respective insertion length.

[0074] FIG. 8 shows a schematic diagram of the electronic module 570 of the temperature sensor calibrator 500 according to various embodiments. Referring to FIGs. 5 and 8, the electronic module 570 (or IC board) with control panel or touch panel 572 may be integrated with the liquid bath assembly 502. The electronic module 570 may include a control unit 576 (or controller) for the liquid bath assembly 502 and the motor 552, high precision data acquisition unit 582 with multiple input channels 574 for collecting the data of the reference thermometer 504 and the to-be-calibrated thermistors 506, master processor 580 for controlling sub-systems of the electronic module 570 and calculating coefficients based on in-built algorithm 590, and communication interfaces 578 for exporting the calibration coefficients to a computer. Each input channel 574 (input channel 574 for reference thermometer 504 and input channels 574 for the to-be-calibrated thermistors 506) may be connected to a corresponding data acquisition module 575 with dedicated microprocessor and inner memory. Each of the data acquisition module 575 may be controlled by the master processor 580 to simultaneously record data from all the input channels 574.

[0075] FIG. 9 shows a graph 901 illustrating a multiple temperature points calibration program for use with the temperature sensor calibrator 500 of FIG. 5 according to various embodiments. In FIG. 9, multiple temperature points over a range of 0°C-40°C rather than the traditional three fixed-points calibration may be adopted. Fast calibration may be realized by heating the outer chamber fluid 522 at a constant temperature increment and continuously stirring the fluid 522 without waiting for it to fully stabilize. When the temperature of liquid 522 in the outer

chamber 520 reaches one selected temperature point, the liquid bath assembly 502 stops heating for few minutes and temperature values and resistances values (T_i and R_i) are recorded simultaneously for the reference thermometer 504 and the to-be-calibrated thermistors 506 inserted in the inner chamber 510 during this period. After that, the liquid bath assembly 502 continues to heat the liquid 522 in the outer chamber 520 to the next selected temperature point until the liquid temperature reaches 40°C. Least Square Algorithm, as an example, which is faster in computing and higher in accuracy for nonlinear fitting of multiple points may be built in the master processor 580 for Steinhart-hart coefficients identification.

[0076] FIG. 10 shows a graph 1001 illustrating a comparison between the temperature difference at two locations in the liquid bath with only the outer chamber, and that in the liquid bath assembly 502 with both two chambers (the inner chamber 510 and the outer chamber 520) and the stirrer 542 when the temperature varies from 25°C to 30°C during calibration. It can be seen that, with the two chambers and the stirrer 542 configuration, the temperature uniformity can be reduced from -0.035°C ~0.045°C to -0.004°C~0.01°C during heating process, and be reduced from -0.015°C ~0.015°C to -0.004°C ~0.005°C during heat holding process.

[0077] FIG. 11 shows a graph 1101 illustrating a comparison of the errors of temperature calculated by traditional three-points calibration and the multi-points calibration following the procedure shown in FIG. 9. The results demonstrate that the deviation between temperature calculated by the calibrated coefficients obtained from the multi-point calibration according to various embodiments and temperature calculated by original coefficients is less than 0.005°C. The error of the multi-point calibration is also less than the error of traditional three-point calibration.

[0078] FIG. 12 shows a table 1201 illustrating a comparison between original coefficients of the thermistor, coefficients calculated by traditional three-point calibration method, and coefficients calculated by multi-point least square algorithm according to various embodiments. As shown, the coefficient calculated by multi-point least square algorithm is closer to the original coefficients of the thermistor as compared to the coefficients calculated by traditional three-point calibration method.

[0079] Various embodiments thus have provided a portable temperature calibrator and novel calibrating method for fast field calibration of thermistors which are typically utilized for HVAC system. As the calibration accuracy mainly depends on several factors, including but not limited to temperature uniformity of liquid bath, temperature stability of liquid bath, the accuracy of reference thermometer, the resistance uncertainty of data acquisition unit, and the mathematical model of Temperature T_i ($^{\circ}\text{C}$) vs. Resistance R_i (Ohms). Several unique and inter-related methods may be adopted according to each factor to meet accuracy requirement of field calibration as well as to realize time-saving. Various embodiments may utilize two liquid chambers and stirrer system for “two-step” temperature tuning so as to increase the uniformity of liquid bath. High precision data acquisition unit with multi-channels may use one master processor to control multiple dedicated microprocessors for each channel so that liquid temperature and resistances at this temperature can be recorded simultaneously. The unit with synchronized sampling interval may be used to decrease the error induced by liquid bath stability. The reference temperature may be acquired by a high accuracy thermometer. Various embodiments may be able to realize fast calibration by heating the outer chamber fluid without waiting for it to fully stabilize, and recording both T_i ($^{\circ}\text{C}$) and R_i (Ohms) at multiple temperature points simultaneously. To improve the uncertainty induced by modeling, multiple points rather than traditional three-points may be used for determining the mathematical relationship of T_i vs. R_i , and least square algorithm which may be built-in to the master processor may be utilized for coefficients identification.

[0080] Compared with traditional field calibration system, various embodiments have the below advantages:

[0081] Fast calibration with high end-to-end accuracy: The calibrator may be able to finish calibration in one hour with end-to-end accuracy of $\pm 0.01^{\circ}\text{C}$. By using the two chamber structure and data acquisition unit which is capable of recording T_i & R_i simultaneously, a normal performance bath (which is usually used for calibration with end-to-end accuracy of $>\pm 0.2^{\circ}\text{C}$) may be used for high accuracy calibration, and the effect induced by stability of the liquid bath may be removed. Moreover, the calibration procedure from 0°C - 40°C may be finished within one hour, which is faster than conventional calibration system (the whole

conventional calibration procedure typically requires at least one and half hour, and only measures data for 3 temperature points with at least 30 min required for each temperature point).

[0082] Portability for field calibration: Various embodiments may integrate liquid bath, reference thermometer, resistance readout into one portable device, and program the coefficient identification algorithm, which is conventionally conducted by an external computer, into the master microprocessor. The calculated coefficients may be displayed on the control panel or touch panel. Although the overall size and weight of the calibrator according to various embodiments may be similar to conventional liquid bath used in the industry, a resistance readout device and an external computer are not required in the calibration procedure for the calibrator according to various embodiments, which simplify the system and improve the portability for field calibration.

[0083] Low cost: Various embodiments may utilize a normal performance liquid bath to realize higher temperature uniformity. The cost of a conventional liquid bath that can achieve substantially equal temperature uniformity and stability as compared to the calibrator according to various embodiments is far more expensive than that of a normal performance liquid bath used in the calibrator of the various embodiments. Thus, the total cost may be reduced.

[0084] Accordingly, various aspect and embodiments may be set out in the following.

[0085] According to various embodiments, a portable temperature calibrator for time-saving field calibration of thermistor used for HVAC system may include a high accuracy reference thermometer, high precision resistance readout for thermistors to be calibrated, display and computer communication interfaces, liquid bath with improved temperature uniformity, and inbuilt coefficients identification program for field calibration of thermistor in the range of 0°C - 40°C with end-to-end accuracy $\pm 0.01^\circ\text{C}$.

[0086] The calibrator may also include two separate liquid chambers (an inner chamber and an outer chamber) with stirrer to accelerate the mixing of temperature controllable fluid in the outer chamber and improve the temperature homogeneity in the inner chamber for the temperature range of 0°C - 40°C.

[0087] The calibrator may also include the IC board (or electronic module) with control panel such as touch panel (or user interface) for control and data acquisition, of which high precision data acquisition unit with multiple input channels for reference thermometer and thermistors to be calibrated. Dedicated
 5 microprocessor, which is assembled for each channel, may be controlled by the master MCU (or master processor) for synchronized time intervals to ensure the temperature of the fluid (T_i) and the resistance (R_i) of the thermistors at different temperatures can be recorded simultaneously. By doing so, the calibration can be conducted without waiting for the liquid bath to be fully stabilized, which speeds up
 10 the procedure as well as decrease the error induced by stability of liquid bath.

[0088] The calibrator may also include fast and multiple temperature points calibrating program with multi-point least square fitting algorithm which may be built in the Master MCU for calibration coefficients identification. The coefficients may be directly calculated in the master processor and displayed on the touch panel.
 15 Hence, the use of an external computer may be optional.

[0089] According to various embodiments, two separate liquid chambers may be used to realize “two-step” liquid temperature tuning for higher temperature homogeneity and fast calibration. The liquid, which may be heated or cooled inside heat exchanger by the primary heat source –Peltier based semiconductor, may be
 20 pumped into the outer chamber and surrounds the inner chamber as the secondary heat source to heat the temperature of liquid inside inner chamber. The outer chamber may be made by low thermal conductivity material with thermal insulation to prevent thermal leaking. The heating/cooling element (semiconductor) may not directly touch with outer chamber so as to avoid non-uniform temperature
 25 distribution in outer chamber.

[0090] According to various embodiments, the liquid via heat exchanger may be pumped into the outer chamber through a series of vertically aligned inlet and outlet, which may be used for circulating of fluid with controllable temperature, so that vertical temperature uniformity of liquid in outer chamber may be improved.

[0091] According to various embodiments, the material of inner liquid chamber
 30 may be selected from different high thermal conductivity materials as per the calibration requirement. The material of inner liquid chamber may include but is not limited to copper, silver, and aluminum.

[0092] According to various embodiments, the liquid cavity of inner liquid chamber may be made into various configurations as per the calibration requirement for the insertion of thermistors. The various configurations may include but are not limited to independent multiple cavities for each sensor, annular
 5 cavities for all the sensors, and 2 or more flabellate cavities for some of the sensors to be calibrated.

[0093] According to various embodiments, the dimension of cavity may be optional and the arrangement of the liquid cavities may be symmetric or asymmetric according to the calibration requirement. The heat-conducting fins may
 10 be assembled within the annular cavities and flabellate cavities.

[0094] According to various embodiments, the stirrer with four vertical blades may be driven by a DC gear motor to rotate around the inner chamber for accelerating the mixing of fluid in outer chamber.

[0095] According to various embodiments, the IC board (or electronic module)
 15 with control panel such as touch panel may include control unit of liquid bath and motor, multiple input channels data acquisition unit with high precision for collecting the data of reference thermometer and thermistors to be calibrated, master processor with in-built coefficients identification algorithm, and communication interfaces. Extra readout and external computer may be optional,
 20 which simplify the system for field calibration purposes.

[0096] According to various embodiments, each input channel of data acquisition unit may have dedicated microprocessor and inner memory. The dedicated microprocessors may be controlled by the master processor for synchronized time intervals to simultaneously record data from all the input
 25 channels. By doing so, the calibration may be conducted without waiting liquid bath to be fully stabilized, which speeds up the procedure as well as decrease the error induced by stability of liquid bath.

[0097] According to various embodiments, multiple temperature points over a range of 0°C-40°C rather than the traditional three fixed-points calibration may be
 30 adopted. The fast calibration may be realized by heating the outer chamber fluid temperature at a constant increment and continuously stirring the fluid without waiting the fully stabilization of bath. The calibration procedure from 0°C-40°C may be finished within one hour, which is faster than conventional calibration

system. According to various embodiments, the inbuilt algorithm in the master processor for Steinhart-hart equation coefficients identification may include but is not limited to Least Square Algorithm which is faster in computing for master processor and higher in accuracy for nonlinear fitting of multiple temperature points.

[0098] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes, modification, variation in form and detail may be made therein without departing from the scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

- 5 1. A temperature sensor calibrator, comprising:
a first chamber configured to receive a temperature sensor in a liquid;
a second chamber separate from the first chamber, the second chamber
surrounding the first chamber;
a temperature-regulating component configured to adjust a temperature of a
10 liquid received in the second chamber; and
a temperature-homogenizing component disposed in the second chamber,
the temperature-homogenizing component configured to enhance temperature
uniformity of the liquid in the second chamber,
wherein the temperature homogenizing component further comprises a
15 plurality of inlets and a plurality of outlets distributed along a height of the second
chamber.
2. The calibrator as claimed in claim 1, wherein the temperature-homogenizing
component comprises an agitator.
- 20 3. The calibrator as claimed in claim 2, wherein the agitator is disposed in the
second chamber, and configured to circle around the first chamber.
4. The calibrator as claimed in claim 2 or 3, further comprising a motor
25 connected to the agitator, and wherein the motor is configured to drive the agitator.
5. The calibrator as claimed in any one of claims 1 to 4, wherein the first
chamber comprises heat conducting fins.
- 30 6. The calibrator as claimed in any one of claims 1 to 5, wherein the first
chamber is defined by a cavity within a container, and wherein the container is
made of thermal conductivity materials.

7. The calibrator as claimed in claim 6, where the cavity comprises a plurality of elongated cavities, an annular cavity, or a plurality of flabellate cavities.

8. The calibrator as claimed in any one of claims 1 to 7, wherein the second
5 chamber is surrounded by thermal isolation layer.

9. The calibrator as claimed in any one of claims 1 to 8, further comprising a lid and a rubber plug, wherein the rubber plug is configured to be fitted into a through hole in the lid for coupling the temperature sensor to the lid.

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10. The calibrator as claimed in any one of claims 1 to 9, wherein the temperature-regulating component is separate from the second chamber, and wherein the temperature-regulating component is connected to the second chamber via conduits.

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11. The calibrator as claimed in any one of claims 1 to 10, further comprising a built-in electronic module.

12. The calibrator as claimed in claim 11, wherein the electronic module
20 comprises a user interface.

13. The calibrator as claimed in claim 11 or 12, wherein the electronic module comprises a plurality of input channels.

25 14. The calibrator as claimed in claim 13, wherein each of the plurality of input channels comprises a microprocessor and a memory.

15. The calibrator as claimed in claim 13 or 14, wherein the electronic module comprises a data acquisition unit configured to acquire data from the plurality of
30 input channels.

16. The calibrator as claimed in claim 15, wherein the data acquisition unit is configured to synchronously sample data from the plurality of input channels.

17. The calibrator as claimed in any one of claims 11 to 16, wherein the electronic module comprises a master processor configured to identify Steinhart-hart coefficients.

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18. The calibrator as claimed in any one of claims 11 to 17, wherein the electronic module comprises a controller configured to control the temperature-regulating component and the temperature-homogenizing component.

10 19. The calibrator as claimed in any one of claims 11 to 18, wherein the electronic module comprises an electronic port configured to be connectable with external processor.

20. A method of manufacturing a temperature sensor calibrator, the method
15 comprising:

providing a first chamber configured to receive a temperature sensor in a liquid;

providing a second chamber to surround the first chamber, wherein the second chamber is separate from the first chamber;

20 providing a temperature-regulating component configured to adjust a temperature of a liquid received in the second chamber; and

providing a temperature-homogenizing component in the second chamber, wherein the temperature-homogenizing component is configured to enhance temperature uniformity of the liquid in the second chamber,

25 wherein the temperature homogenizing component further comprises a plurality of inlets and a plurality of outlets distributed along a height of the second chamber.

21. A method of calibrating a temperature sensor, the method comprising:

30 inserting the temperature sensor into a liquid in a first chamber;

adjusting a temperature of a liquid in a second chamber surrounding the first chamber to regulate a temperature of the liquid in the first chamber, wherein the second chamber is separate from the first chamber;

mixing the liquid in the second chamber to enhance temperature uniformity of the liquid in the second chamber;

measuring the temperature of the liquid in the first chamber by means of the temperature sensor; and

5 calibrating the temperature sensor based on a measurement result,

wherein mixing the liquid in the second chamber comprises circulating the liquid in the second chamber through a plurality of inlets and a plurality of outlets disposed along a height of the second chamber.

10 22. The method as claimed in claim 21, wherein mixing the liquid in the second chamber comprises mixing with an agitator.

23. The method as claimed in claim 21 or 22, wherein measuring a temperature of the liquid in the first chamber comprises simultaneously measuring a liquid
15 reference temperature of a reference temperature sensor inserted in the first chamber and a resistance of a to-be-calibrated temperature sensor inserted in the first chamber.

24. The method as claimed in claim 23, wherein simultaneously measuring
20 comprises synchronized sampling of reference temperature data of the reference temperature sensor and resistance data of the to-be-calibrated temperature sensor with an electronic module having a data acquisition unit and a plurality of input channels.

25 25. The method as claimed in claim 23 or 24, wherein simultaneous measuring is performed at more than three temperature points.

26. The method as claimed in claim 25, wherein calibrating the temperature sensor comprises determining Steinhart-hart coefficient based on a multi-point
30 fitting algorithm.

27. The method as claimed in claim 26, wherein the multi-point fitting algorithm comprises multi-point least square algorithm.