The cost of these precision temperature references is relatively high and they take up terminal space that could be used for other devices and accordingly a typical I/O module will use one or two cold junction compensation circuits at most.

SUMMARY OF THE INVENTION

The present inventors have determined that there can be a significant temperature variation across the terminals of the I/O module in use (up to 3°C) that can substantially affect the accuracy of thermocouple measurements. Embodiments of ~~T~~the present invention seek to addresses~~s~~ this problem by providing multiple built-in auxiliary temperature sensors positioned at ~~a~~ temperature sensing terminals. The use of these multiple sensors is enabled in various embodiments by a compensation system that corrects for the distance between the built-in sensors and the terminals, a multiplexer that accommodates the additional signal burden produced by the sensors, and a compensation system that allows low-cost sensors to be used and calibrated to as little as a single high accuracy sensor.

~~Specifically then~~ According to an aspect of the present invention, ~~Provides~~there is provided an I/O circuit for use with an industrial control system including a terminal block having ~~terminals~~at least one first terminal for releasably receiving leads of at least one first temperature sensor and a multiplicity of second ~~temperatures~~temperature sensors permanently affixed in thermal communication with ~~the~~each of the at least one first terminals of the terminal block. The I/O circuit further comprises of at least one second terminal for connecting at least one third temperature sensor having a higher accuracy than the multiplicity of second temperature sensors. Input circuitry electrically connects to ~~the~~each of the at least one first terminals, the second temperature sensors, and each of the at least one second terminals ~~and to the second temperature sensors~~ for receiving temperature signals from each of the at least one first temperature sensors, the second temperature sensors, and ~~second~~each of the at least one third temperature sensors, wherein the input circuitry ~~operating~~is operable to compensate the temperature signal received ~~temperature signals~~ from each of the at least one first temperature sensors using temperature signals from the second temperature sensors and from each of the at least one third temperature sensors.

It is thus a feature of at least one embodiment of the invention to provide a system that greatly reduces errors caused by unpredictable terminal-to-terminal temperature variation.

According to another aspect of the invention, there is provided a method of measuring temperature using an I/O circuit having a terminal block having terminals for releasably receiving leads of first temperature sensors and having a multiplicity of second temperature sensors permanently affixed in thermal communication with the terminals of the terminal block, the method comprising the steps of: receiving temperature signals from the first temperature sensors and second temperature sensors; receiving a temperature signal from a third temperature sensor having a higher accuracy than the multiplicity of second temperature sensors; and compensating the received temperature signals from the first temperature sensors using temperature signals from the second temperature sensors and the third temperature sensor.

The terminal block may be attached to a printed circuit board and the multiplicity of second temperature sensors are soldered to the printed circuit board.

It is thus a feature of at least one embodiment of the invention to provide a simple method of incorporating multiple compensation sensors into a terminal block system.

A housing covering a portion of the terminal block and the multiplicity of second temperature sensors may be covered by at least one of the housing and terminal block.

It is thus a feature of at least one embodiment of the invention to provide high accuracy cold junction compensation which is invisible to the user and does not interfere with the use of the terminal block.

As mentioned above, ~~T~~the I/O circuit ~~may~~ further includes terminals for connecting at least one third temperature sensor having a higher accuracy than the multiplicity of second temperature sensors,~~, and~~ ~~T~~the input circuitry may also electrically connect to the terminals for connecting the third temperature sensor for receiving a temperature signal from the third temperature sensor, the input circuitry operating to compensate the multiplicity of second temperature sensors using the temperature signal from the third temperature sensor.

It is thus a feature of at least one embodiment of the invention to permit the use of commercially practical low-cost sensors to provide for the multiple temperature sensing points needed for terminal-to-terminal corrections.

The multiplicity of second temperature sensors are RTD sensors.

It is thus a feature of at least one embodiment of the invention to provide low-cost temperature sensors readily available in integrated circuit packages.

The I/O circuit may execute a stored program to use a thermal model to extend the temperature signals of the second temperature sensors to an estimated cold junction temperature at the terminals.

It is thus a feature of at least one embodiment of the invention to permit practical mounting of the cold junction compensation sensors at practical distances from the terminals.

An embodiment of ~~T~~the invention may include the steps of: (1) determining a temperature at a third location using the third temperature sensor; (2) using at least one second temperature sensor at a second location to determine a temperature difference between the second location and the third location; (3) using a thermal model and the temperature difference to calculate a corrected temperature at the second location; (4) using the corrected temperature at the second location to estimate a cold junction temperature at a terminal for releasably receiving leads of a first temperature sensor; and (5) estimating a first temperature sensor temperature using a first temperature sensor reading and the cold junction temperature estimate.

It is thus a feature of at least one embodiment of the invention to synergistically combine high accuracy and low accuracy cold junction compensation to provide for correction of terminal-to-terminal temperature variations.

An embodiment of ~~T~~the invention may include a multiplexer circuit having inputs connected to at least two temperature sensors and an output connected to the analog to digital converter.

It is thus a feature of at least one embodiment of the invention to manage the additional I/O burden and power consumption of the precision power reference presented by multiple cold junction compensators.

These particular objects and advantages may apply to only some embodiments falling within the claims and thus do not define the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of an I/O circuit per the present invention showing optional four thermocouples and an optional cold junction compensation device attached to two terminal blocks of the I/O circuit for temperature measurement;

Fig. 2 is a front perspective view of a portion of the I/O circuit of Fig. 1 showing one terminal block and a housing;

Fig. 3 is a rear perspective view the terminal block of Fig. 2 without the housings showing two cold-junction compensation sensors associated with the terminals holding the thermocouples;

Fig. 4 is a block diagram of a multiplexer of the I/O circuit switching among the cold junction compensation temperature sensors; and

Fig. 5 is a flow chart of a program executed by the present invention within the I/O circuit or elsewhere;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to Fig. 1, an I/O circuit 10 may provide for processing electronics 12 having connections, for example, to two terminal blocks 14, 16. The terminal blocks 14, 16 have screw terminals 28 or similar design to permit releasable attachment to leads of temperature sensors 30 such as thermocouples, resistance temperature detectors (RTD), thermistors, and solid-state temperature sensors of a type used for sensing temperatures as part of an industrial control process. In addition, the screw terminals 28 may releasably receive a removable cold junction compensation (CJC) temperature sensor, typically a highly accurate resistive temperature device of a type known in the art.

CLAIMS

What we claim is:

1. An I/O circuit for use with an industrial control system comprising:

a terminal block having terminals for releasably receiving leads of at least one first temperature sensor;

a multiplicity of second temperatures sensors permanently affixed in thermal communication with the terminals of the terminal block; and

input circuitry electrically connected to the terminals and to the second temperature sensors for receiving temperature signals from the first temperature sensors and second temperature sensors, the input circuitry operating to compensate the received temperature signals from the first temperature sensors using temperature signals from the second temperature sensors.

2. The I/O circuit of claim 1, wherein the terminal block is attached to a printed circuit board and the multiplicity of second temperature sensors are soldered to the printed circuit board.

3. The I/O circuit of claims 1 or 2, further including a housing covering a portion of the terminal block and wherein the multiplicity of second temperature sensors are covered by at least one of the housing and terminal block.

4. The I/O circuit of any one of the previous claims, further including terminals for connecting at least one third temperature sensor having a higher accuracy than the multiplicity of second temperature sensors wherein the input circuitry is also electrically connected to the terminals for connecting the third temperature sensor for receiving a temperature signal from the third temperature sensor, the input circuitry operating to compensate the multiplicity of second temperature sensors using the temperature signal from the third temperature sensor.

5. The I/O circuit of any one of the previous claims, wherein the multiplicity of second temperature sensors are RTD sensors.

6. The I/O circuit of any one of the previous claims, wherein the input circuitry includes a microprocessor executing a stored program to compensate the received temperature signals from the first temperature sensors using temperature signals from the second temperature sensors.

7. The I/O circuit of claim 6 wherein the stored program provides communication with an industrial control system executing control instructions to control an industrial process in real-time.

8. The I/O circuit of any one of claims 4-7, wherein there is one second compensation temperature sensor for each terminal releasably receiving leads of first temperature sensors.

9. The I/O circuit of claim 8, wherein there is one second prime temperature sensor for each third temperature sensor.

10. The I/O circuit of any one of claims 6-9, wherein the microprocessor further executes the stored program to use a thermal model and the temperature signals of the second temperature sensors to estimate a cold junction temperature at the terminals.

11. The I/O circuit of claim 9 further comprising:

a microprocessor executing a stored program to compensate a first temperature sensor by estimating the temperature of its cold junction at a first location by:

(1) determining a temperature at a third location using the third temperature sensor;

(2) using one second prime temperature sensor and one second compensation temperature sensor to determine a temperature difference;

(3) using the temperature at the third location and the temperature difference to determine a cold junction temperature at the first location; and

(4) compensating the thermocouple reading connected to a cold junction at a first location to determine a thermocouple temperature.

12. The I/O circuit of claim 11 wherein determining the temperature difference utilizes a thermal model comprising one selected from a group consisting of a look-up table, and an equation with at least one coefficient

13. The I/O circuit of any one of the previous claims, further comprising a multiplexer circuit having inputs connected to at least two temperature sensors and an output connected to the input circuitry.

14. The I/O circuit of claim 13 further comprising a multiplexer selectively connecting power and input lines to the plurality of second temperature sensors in a predetermined sequence.

15. A method of measuring temperature using an I/O circuit having a terminal block having terminals for releasably receiving leads of first temperature sensors and having a multiplicity of second temperatures sensors permanently affixed in thermal communication with the terminals of the terminal block, the method comprising the steps of:

(1) receiving temperature signals from the first temperature sensors and second temperature sensors; and

(2) compensating the received temperature signals from the first temperature sensors using temperature signals from the second temperature sensors.

16. The method of claim 15 wherein the terminal block is attached to a printed circuit board and the multiplicity of second temperature sensors are soldered to the printed circuit board and further including a housing covering a portion of the terminal block and wherein the multiplicity of second temperature sensors are covered by at least one of the housing and terminal block.

17. The method of one of claims 15 or 16, including receiving a temperature signal from a third temperature sensor having a higher accuracy than the multiplicity of second

temperature sensors and compensating the first temperature sensors using the temperature signal from the third temperature sensor and the second temperature sensors.

18. The method of any one of claims 15-17, wherein the multiplicity of second temperature sensors are RTD sensors and at least one first temperature sensor is a thermocouple.

19. The method of claim 19 having a prime RTD proximate to the third temperature sensor, and compensation RTDs proximate to first temperature sensor terminals further including the step of using a subtracting prime RTD and compensation RTD readings to determine a difference temperature and using the difference temperature and the third temperature sensor reading to estimate temperature of first temperature sensor terminals proximate to compensation RTD.

20. The method of any one of claims 15-19, further including the step of sequentially connecting at least two temperature sensors to power such that they are energized for a period of time, and the step of sequentially connecting the at least two temperature sensor outputs to a single digitizing input in communication with a microprocessor.

CLAIMS

What we claim is:

1. An I/O circuit for use with an industrial control system comprising:

a terminal block having at least one first terminal for releasably receiving leads of at least one first temperature sensor;

a multiplicity of second temperature sensors permanently affixed in thermal communication with each of the at least one first terminals of the terminal block;

at least one second terminal for connecting at least one third temperature sensor having a higher accuracy than the multiplicity of second temperature sensors; and

input circuitry electrically connected to each of the at least one first terminals, the second temperature sensors, and each of the at least one second terminals for receiving temperature signals from each of the at least one first temperature sensors, the second temperature sensors, and each of the at least one third temperature sensors, wherein the input circuitry is operable to compensate the temperature signal received from each of the at least one first temperature sensors using temperature signals from the second temperature sensors and from each of the at least one third temperature sensors.

2. The I/O circuit of claim 1 wherein the terminal block is attached to a printed circuit board and the multiplicity of second temperature sensors are soldered to the printed circuit board.

3. The I/O circuit of claims 1 or 2 further including a housing covering a portion of the terminal block and wherein the multiplicity of second temperature sensors are covered by at least one of the housing and terminal block.

4. The I/O circuit of any one of the previous claims, wherein there is one second compensation temperature sensor for each of the at least one first terminals releasably receiving leads of first temperature sensors.

5. The I/O circuit of claim 4 wherein one of the second temperature sensors is defined as a prime temperature sensor and wherein there is one prime temperature sensor for each third temperature sensor.

6. The I/O circuit of claim 5 further comprising:

a microprocessor executing a stored program to compensate a first temperature sensor by estimating the temperature of its cold junction at a first location by:

(1) determining a temperature at a third location using one of the at least one third temperature sensors;

(2) using one prime temperature sensor and one second compensation temperature sensor to determine a temperature difference;

(3) using the temperature at the third location and the temperature difference to determine a cold junction temperature at the first location; and

(4) compensating the thermocouple reading connected to a cold junction at the first location to determine a thermocouple temperature.

7. The I/O circuit of claim 6 wherein determining the temperature difference utilizes a thermal model comprising one selected from a group consisting of a look-up table, and an equation with at least one coefficient.

8. The I/O circuit of any one of the previous claims, wherein the multiplicity of second temperature sensors are RTD sensors.

9. The I/O circuit of any one of claims 1-5, wherein the input circuitry includes a microprocessor executing a stored program to compensate the temperature signal received from each of the at least one first temperature sensors using temperature signals from the second temperature sensors.

10. The I/O circuit of claim 9 wherein the stored program provides communication with an industrial control system executing control instructions to control an industrial process in real-time.

11. The I/O circuit of claims 9 or 10 wherein the microprocessor further executes the stored program to use a thermal model and the temperature signals of the second temperature sensors to estimate a cold junction temperature at each of the at least one first terminals.

12. The I/O circuit of any one of the previous claims further comprising a multiplexer circuit having inputs connected to at least two temperature sensors and an output connected to the input circuitry.

13. The I/O circuit of claim 12 further comprising a multiplexer selectively connecting power and input lines to the plurality of second temperature sensors in a predetermined sequence.

14. A method of measuring temperature using an I/O circuit having a terminal block having terminals for releasably receiving leads of first temperature sensors and having a multiplicity of second temperature sensors permanently affixed in thermal communication with the terminals of the terminal block, the method comprising the steps of:

receiving temperature signals from the first temperature sensors and second temperature sensors;

receiving a temperature signal from a third temperature sensor having a higher accuracy than the multiplicity of second temperature sensors; and

compensating the received temperature signals from the first temperature sensors using temperature signals from the second temperature sensors and the third temperature sensor.

15. The method of claim 14 wherein the terminal block is attached to a printed circuit board and the multiplicity of second temperature sensors are soldered to the printed circuit board and further including a housing covering a portion of the terminal block and wherein the multiplicity of second temperature sensors are covered by at least one of the housing and terminal block.

16. The method of one of claims 14 or 15, wherein the multiplicity of second temperature sensors are RTD sensors and at least one first temperature sensor is a thermocouple.

17. The method of any one of claims 14-16 having a prime RTD proximate to the third temperature sensor and compensation RTDs proximate to first temperature sensor terminals further including the step of subtracting prime RTD and compensation RTD readings to determine a difference temperature and using the difference temperature and the third temperature sensor reading to estimate temperature of first temperature sensor terminals proximate to compensation RTD.

18. The method of any one of claims 14-17, further including the step of sequentially connecting at least two temperature sensors to power such that they are energized for a period of time, and the step of sequentially connecting the at least two temperature sensor outputs to a single digitizing input in communication with a microprocessor.