US011215499B1

(12) **United States Patent**
Polish

(10) **Patent No.: US 11,215,499 B1**
(45) **Date of Patent: Jan. 4, 2022**

(54) **CALIBRATION APPARATUS AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/377,120**

(22) Filed: **Apr. 5, 2019**

(51) **Int. Cl.**
G01D 18/00 (2006.01)
G01G 23/01 (2006.01)

(52) **U.S. Cl.**
CPC ***G01G 23/01*** (2013.01); ***G01D 18/00*** (2013.01)

(58) **Field of Classification Search**
CPC G01G 23/01; G01D 18/00
USPC 177/1
See application file for complete search history.

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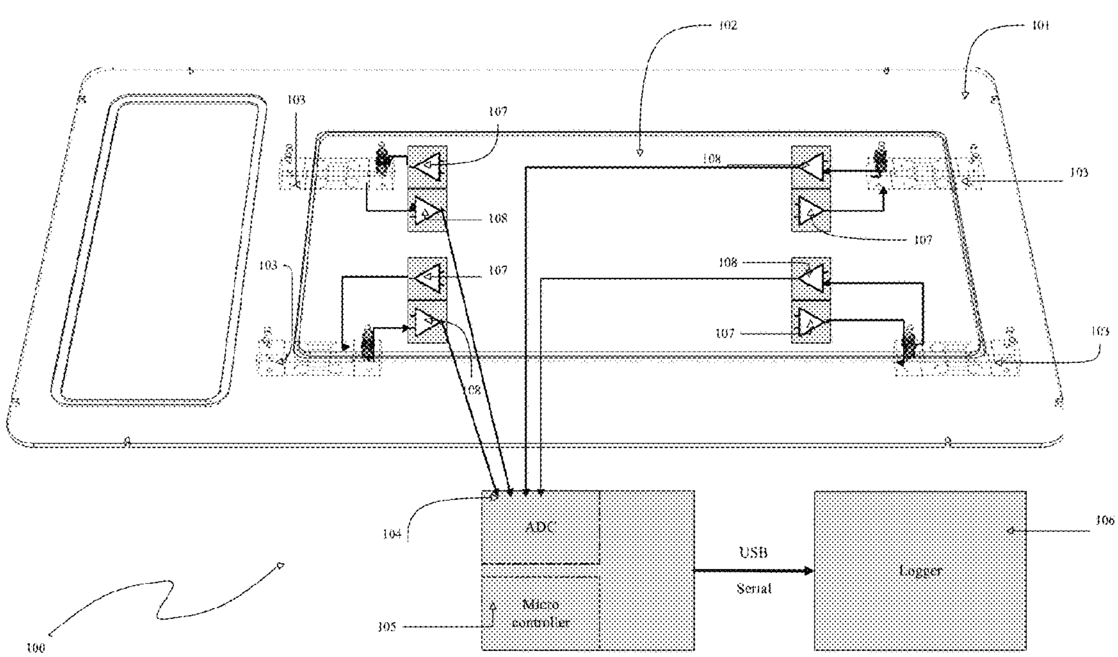
(57) **ABSTRACT**

An electronic measurement device or electronic scale including an arrangement of multiple low-cost sensors to measure a physical property of an object is disclosed. The electronic measurement device or electronic scale utilizes an accurate and effective calibration method that compensates for the idiosyncrasies of using individual sensors. The electronic measurement device positions a plurality of sensors at predetermined observational locations to provide sensor output signals in response to sensing physical characteristics of the physical property of the object to be measured and combines the different sensor output signals by applying a combined calibration transfer function that represents a calibration function for each of the plurality of sensors to provide a cumulative measurement signal that represents the measurement of the physical property of the object.

20 Claims, 6 Drawing Sheets



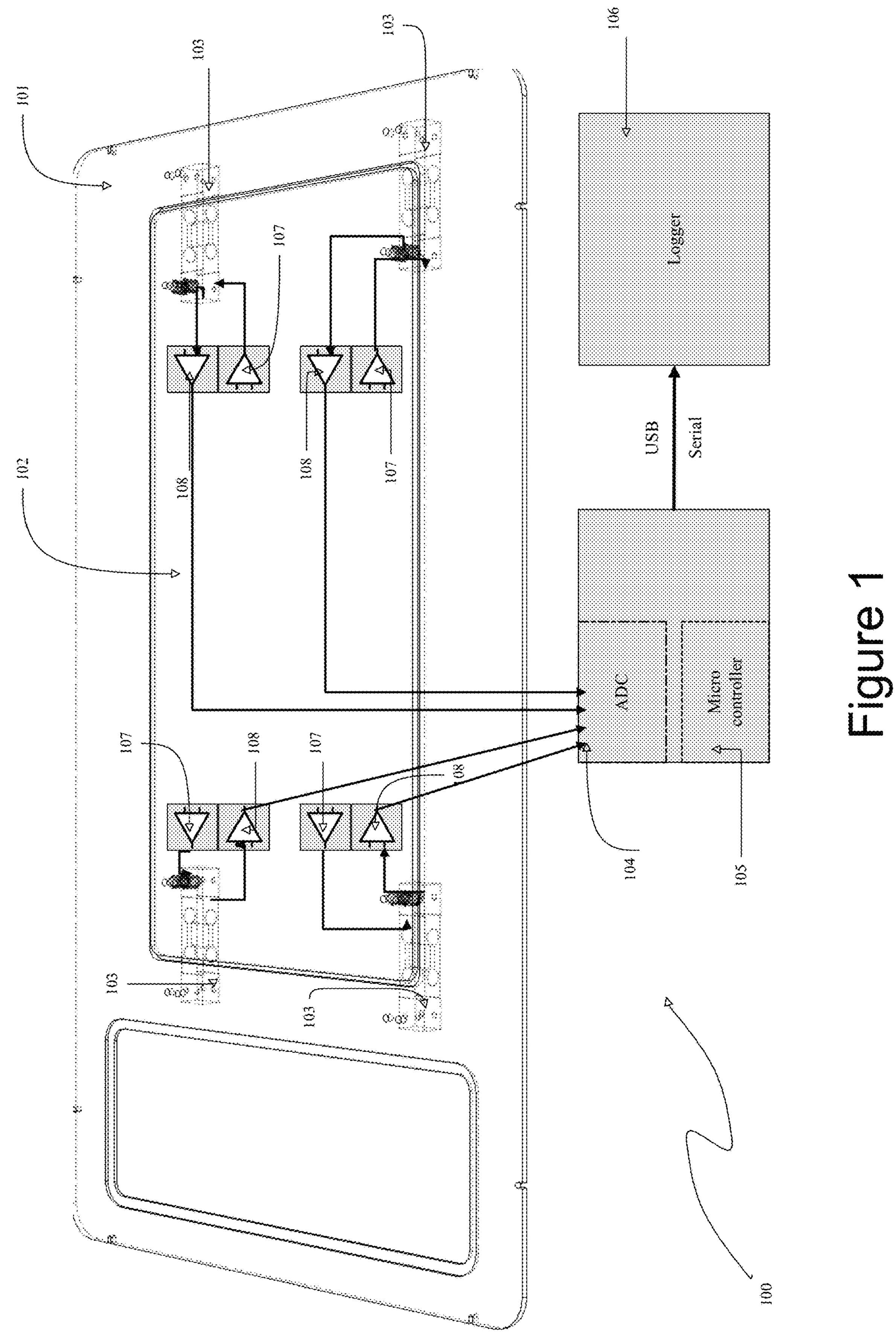

100
101
102
103
104
105
106
107
108
Logger
USB
Serial
ADC
Micro
controller

Figure 1

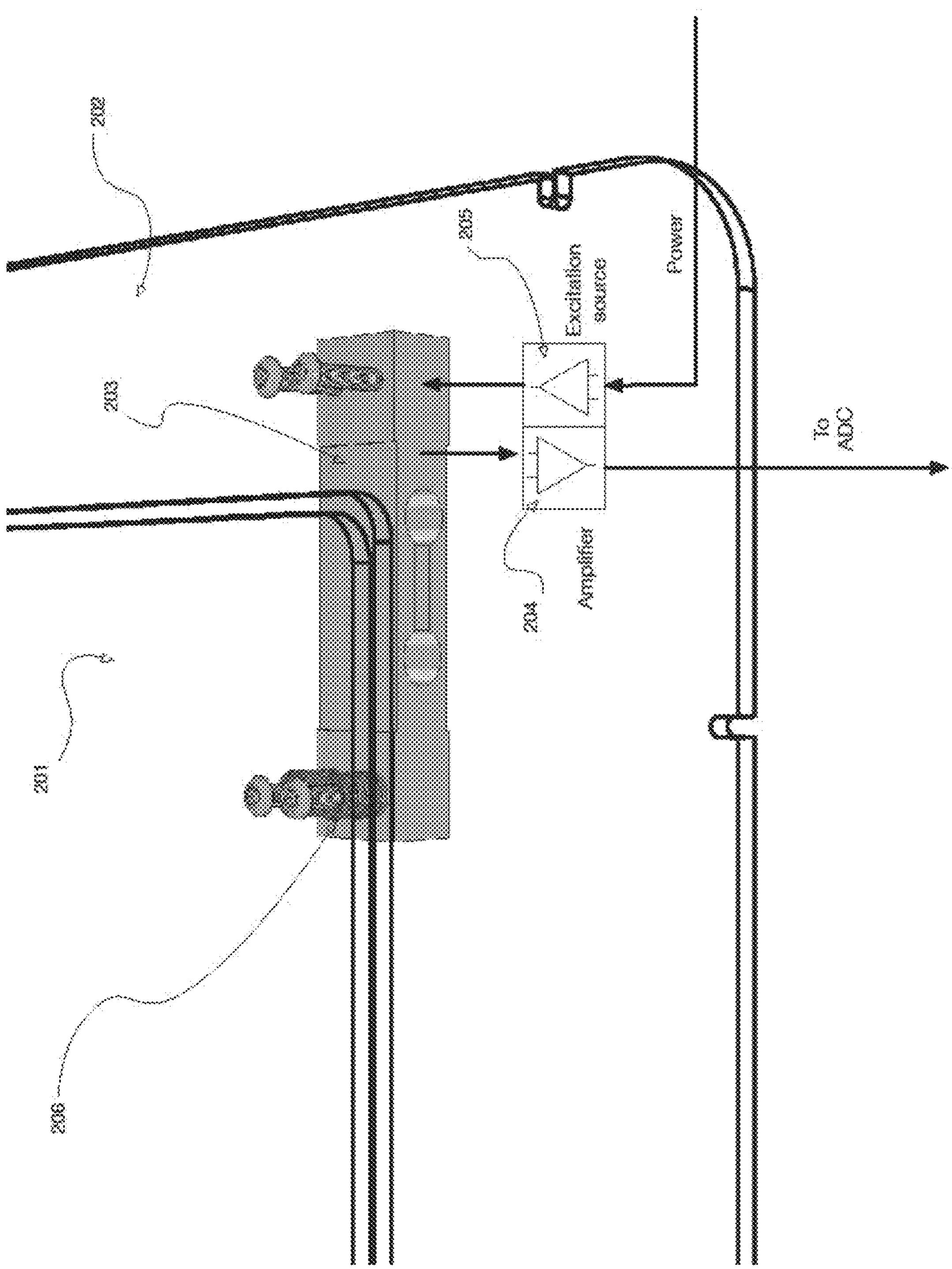
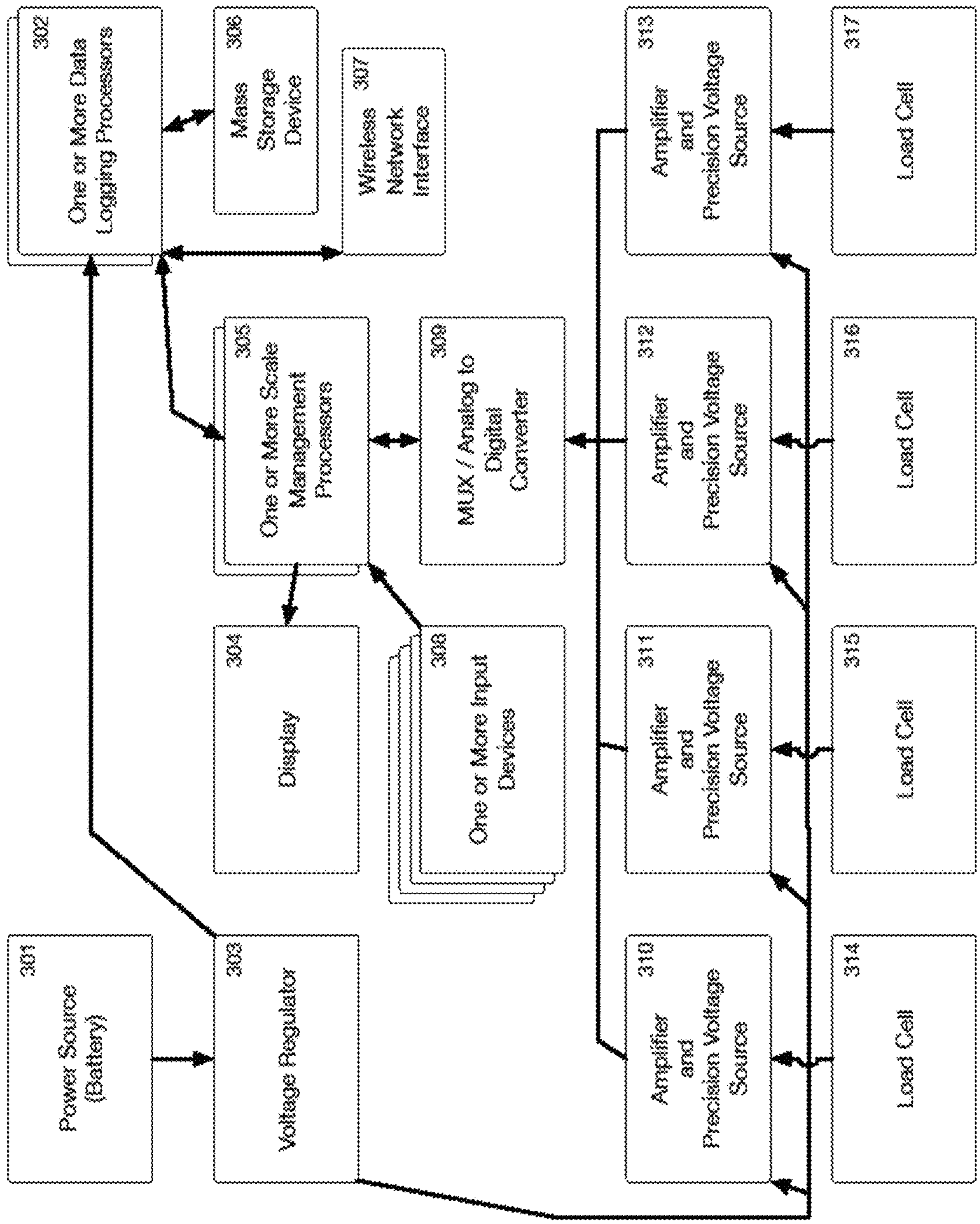

202
203
205
Excitation source
Power
To ADC
Amplifier
204
201
206

Figure 2



302
One or More Data Logging Processors
306
Mass Storage Device
307
Wireless Network Interface
305
One or More Scale Management Processors
309
MUX / Analog to Digital Converter
304
Display
308
One or More Input Devices
301
Power Source (Battery)
303
Voltage Regulator
310
Amplifier and Precision Voltage Source
311
Amplifier and Precision Voltage Source
312
Amplifier and Precision Voltage Source
313
Amplifier and Precision Voltage Source
314
Load Cell
315
Load Cell
316
Load Cell
317
Load Cell

Figure 3

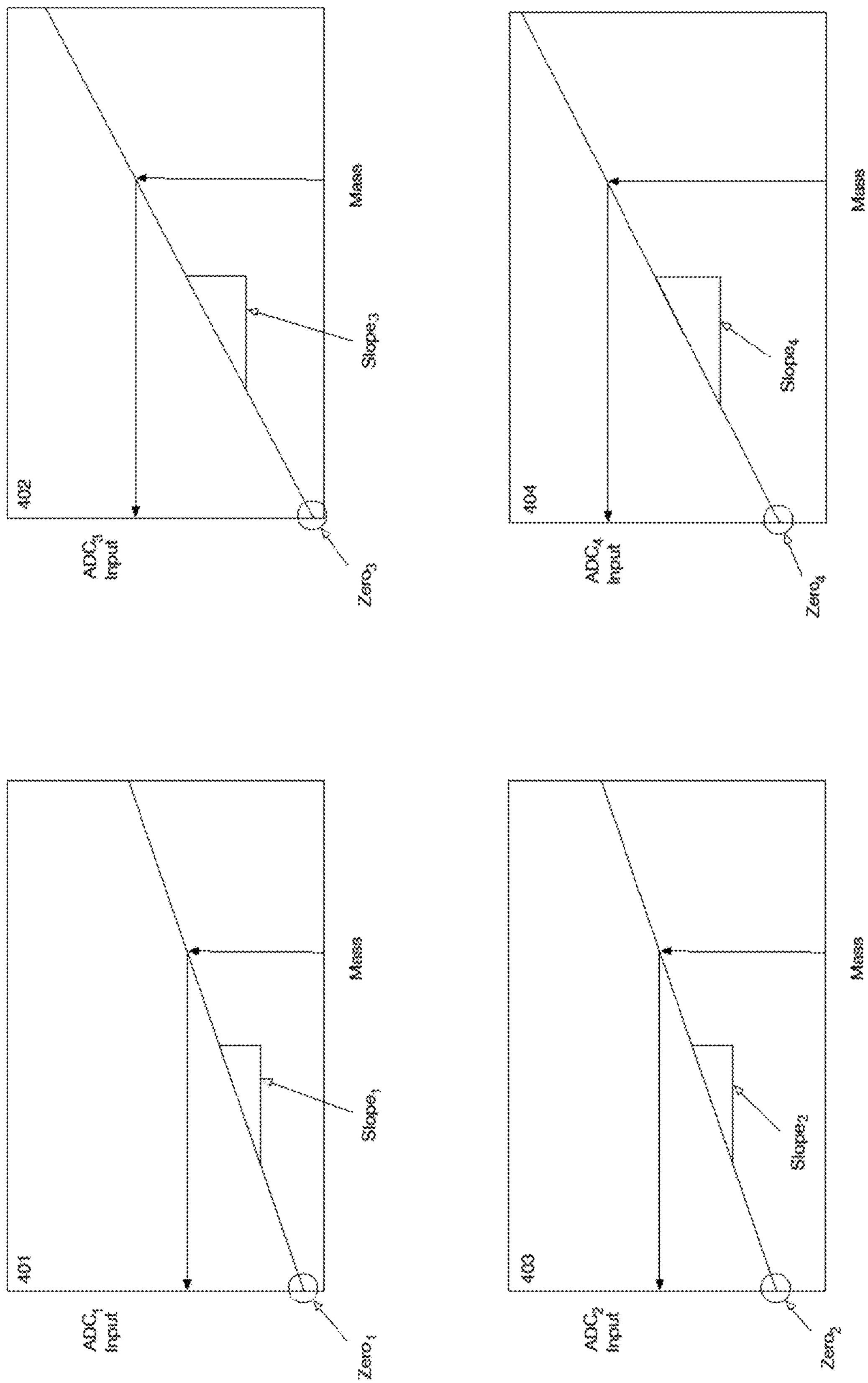

402
ADC3 Input
Zero3
Slope3
Mass
404
ADC4 Input
Zero4
Slope4
Mass
401
ADC1 Input
Zero1
Slope1
Mass
403
ADC2 Input
Zero2
Slope2
Mass

Figure 4

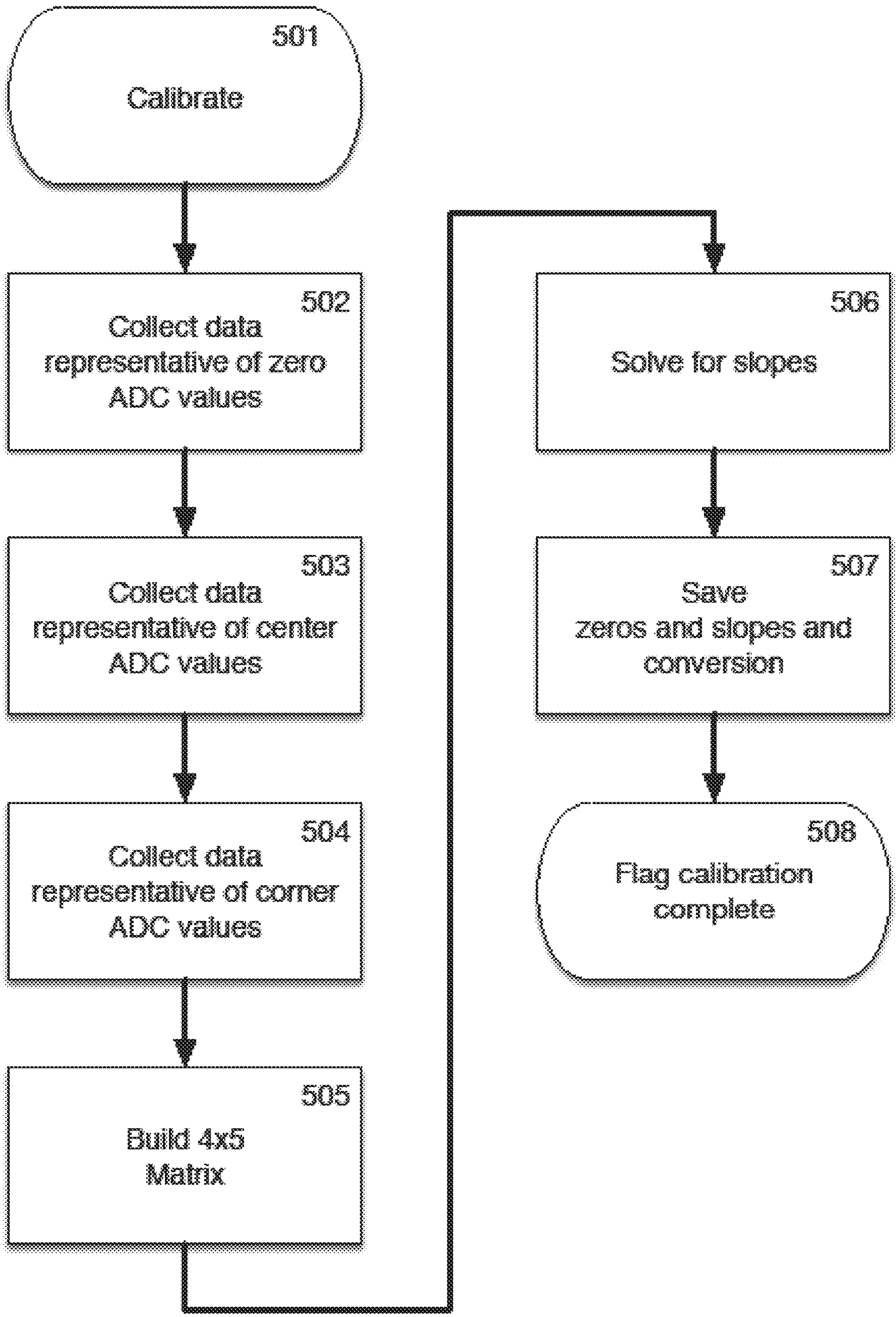

501
Calibrate
502
Collect data representative of zero ADC values
503
Collect data representative of center ADC values
504
Collect data representative of corner ADC values
505
Build 4x5 Matrix
506
Solve for slopes
507
Save zeros and slopes and conversion
508
Flag calibration complete

Figure 5

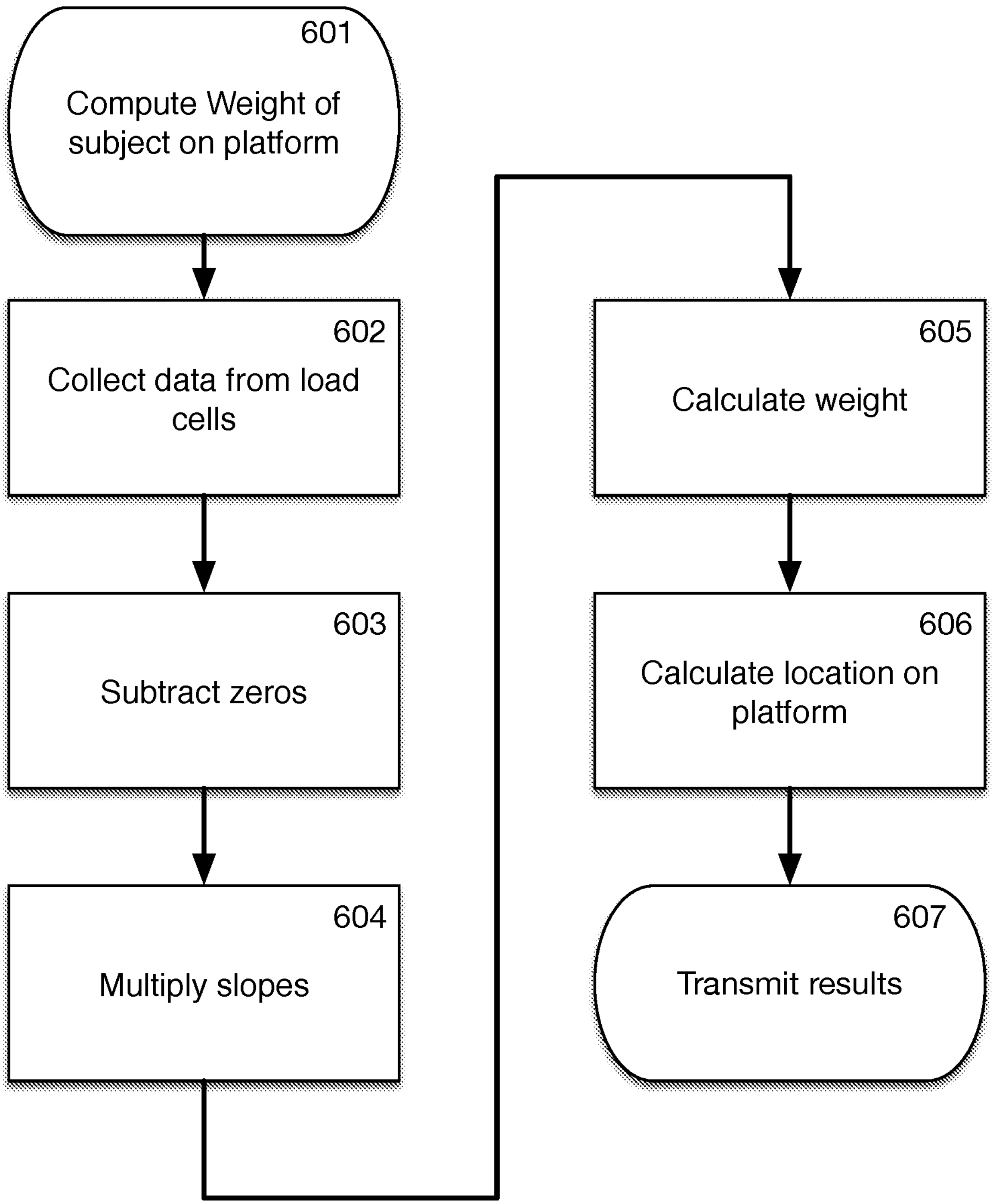

601
Compute Weight of subject on platform
602
Collect data from load cells
603
Subtract zeros
604
Multiply slopes
605
Calculate weight
606
Calculate location on platform
607
Transmit results

Figure 6

CALIBRATION APPARATUS AND METHOD

BACKGROUND

1. Field of the Invention

The present invention relates generally to the field of measurement devices and methods for calibrating them. In particular, the present invention relates to a calibration apparatus, system or device including an arrangement of multiple low-cost sensors to measure a physical property of an object and methods for calibration or measurement using the novel techniques implemented.

2. Description of the Related Art

Measurement devices are common in many industries. Electronic measurement devices or scales as they are otherwise known, are usually constructed of several components, electronic or mechanical. Electronic measurement devices or scales typically have a platform, mostly planar, on which the items or objects to be weighed or measured are placed. A platform for this purpose can range in size and shape depending upon the particular application. The shape and size of these types of platforms can vary over a very wide range. For example, at one end of this wide range, there are kitchen scales configured with two-inch diameter platforms used to weigh ingredients or the like. At the other end of this wide range, there are weigh stations located on highways and configured to weigh passing trucks, with platforms that are tens of feet long. As yet another example, some platforms created for measurement scales used at construction-related sites are shaped to hold loose items such as gravel. Yet other platforms created for scales typically used in hospitals are shaped to hold squirming infants.

A platform in an electronic scale is mechanically coupled to some sort of underlying support structure. The purpose of this support structure is largely to support the weight of the platform and the item placed on or within it that is to be weighed. The support structure must support the weight such that there is no binding action over the support structure's range of motion. Finally, the support structure must transfer the weight to the weighing sensor from some well characterized direction relative to gravity. This direction is typically vertical.

The support structure usually transfers the weight from the platform to the sensor through springs. Springs allow the weight to transfer and to apply to the sensor vertically. These springs typically introduce a low frequency resonance into the scale that is experienced as bounciness or bouncy motion. The non-spring components in the support structure should be extremely rigid in the range of weights that the scale is meant to measure. This is desirable to prevent the support structure from becoming damaged under the weight of any load placed on it such that the support structure itself does not introduce non-linear responses to the weight, which can result in inaccurate readings.

Sometimes in instances when an object to be weighed is very large or massive, it may be desirable to transfer the task of determining the weight to several weight sensors. This distribution serves to reduce the load on any one sensor. This also serves to reduce the stress on some elements of the support structure. However, working with multiple weight sensors in the same system can be complex and therefore, introduces significant calibration difficulties.

One complexity with using multiple weight sensors is that it is nearly impossible to couple the weighing platform to the sensors in a way that evenly distributes the weight among the sensors. This is similar to the problem of a four-legged chair placed on a flat floor. Unless the person seated on the chair exercises some care, the weight of the chair is borne by two diagonally opposed legs and the remaining weight is borne by a single one of the remaining legs. In this example, the chair will have a tendency to rock back and forth between the non-weight bearing legs. In the case of a measurement device or scale, this problem manifests in almost all of the weight being sensed by two sensors, with the remaining sensors receiving unstable results. This problem is typically solved in this example by use of very tight springs configured to couple the scale platform to the weight sensors. These springs as well as "flex" in the platform surface introduce resonances that must be dealt with during calibration and weighing.

The weight sensors are typically load cells that use a strain gauge coupled to a Wheatstone bridge to produce a resistance proportional to weight. A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured. The load cells are usually fabricated from a block of metal such as steel or aluminum. The cells are set up so that they are supported by a fixed structure by bolts on one end. The weight to be measured is coupled to bolt holes at the other end. Over the range of weights that the cell is designed to work with, the block slightly buckles or deforms under the weight.

The deformation of the load cell is measured by a strain gauge, which is a device that is typically implemented with thin structures of graphite that are bonded to the load cell. As the load cell deforms under either weight or stress, the graphite stretches. When the graphite changes shape, its resistance to electrical current changes and this resistance change can be measured.

Since the resistance changes in the strain gauge are very small, the strain gauge is incorporated into a Wheatstone bridge. The Wheatstone bridge has an excitation voltage applied and a resultant output voltage that is proportionate to the excitation voltage as well as the weight applied to the load cell.

When all of these parts of the apparatus are designed and constructed properly, voltage output from the load cell is linearly related to the weight applied. As demonstrated here, there is complexity in this sort of arrangement. The deforming function of the metal of the load cell must be designed so it is linear, and the response of the strain gauge must be designed to also be linear. Lastly, the power supply for the excitation voltage applied must be stable. Also, it should be recognized that most resistive elements such as the strain gauge as well as the other resistors in the Wheatstone bridge have temperature dependencies.

However, these problems that exist with load cells have long been understood and are well compensated for. The result is inexpensive, rugged, and reasonably reliable electronic scales. These systems typically operate well up to about 1% or one part in 100. Therefore, to weigh an object that is 150 pounds, such systems can expect to provide accurate measurements up to about 1.5 pounds. With extreme care exercised during design and manufacturing, it may be possible to construct these types of systems to accomplish accurate measurements up to one part in 1000 or even one part in 5000.

Conventional scales use a single load cell and some sort of spring-loaded system to transfer the weight to the single load cell. In such systems, the scale system typically has to wait until the spring settles down or damps to a low enough variation before a reliable reading can be taken. Eliminating the springs is not a viable option as that can place great stress on the components. Using multiple load cells is one solution. However, the use of multiple load cells introduces the need to balance them so that they all make similar contributions to the total measured weight. Typical state of the art in such balancing is done through adjustment of small resistors in series with the load cells. These resistors are subject to fluctuations from many sources. For example, there is a standard part VKK1-4 from a company called HBM, Inc., that supplies parts for load cell measurements. The VKK1-4 allows the balancing of four load cells using adjustments of small resistors. Determining how to set these resistors is a complex process. Therefore, while the use of multiple load cells can help reduce the need for as many components, in the way of springs, the calibration and balancing problems are difficult.

The support structures that allow for the use of a single load cell on a large-scale panel are deep, complex, mechanical, and difficult to maintain. While it is certainly possible and common to use a single load cell for large loads, the mechanical systems necessary to transfer those loads involve levers that add considerable and often undesirable depth to the existing scale systems. This depth makes such scales difficult to deploy. Also, the pivot points and other moving parts in such systems require regular maintenance to ensure that these systems in use are not distorting the weight being measured.

Many sensors have an almost linear relationship between their signal output and what such sensors are sensing. However, it is common that the exact slope and intercept of the transform function is not well controlled. More expensive sensors are typically be well calibrated and have well controlled characteristics. Inexpensive sensors often demonstrate poorly controlled characteristics.

It is well known and routine to be able to calibrate a single inexpensive sensor. Consider for example a scale. At the time of manufacture, the manufacturing process can include a test that measures sensor outputs at zero weight and at a single known weight. By this test, the exact particular linear transfer function of this particular weight sensor is easily determined. A problem can surface in applications when trying to utilize multiple inexpensive sensors together. One solution in such applications is to try and characterize each of these sensors separately, but that process is complex and involves separating the sensors from each other to individually discover their linear transfer functions. This process can be a time consuming and frustrating exercise.

Applications that involve multiple sensors face problems in field repair. If one of the sensors fails in the field it must be replaced. That task is not simple as multiple sensors must be balanced and calibrated. The replacement sensor should match exactly what it is replacing. Alternatively, such a system can be taken to where it was manufactured to be properly balanced and recalibrated.

For at least these reasons, there exists a dire need for a new method of calibration and a new type of sensor that can be introduced and calibrated in the field with minimal effort and disruption.

SUMMARY OF THE INVENTION

The calibration system and methods in accordance with the present invention introduce a calibration method and a simplified mechanical system of sensors that enables greater precision from sensors than could otherwise be obtained from prior sensing methods and systems. The calibration method in accordance with the present invention uses multi-sensor systems that are much easier to operate than existing sensing systems and are fabricated from lower cost components. In one embodiment, the method and apparatus of the present invention uses multiple load cells with a solution to the problems of balancing the load cells as well as calibrating the load cells with a minimum requirement of test readings. This approach solves multiple problems including making it simpler to use multiple load cells as well as making scales that use fewer mechanical components.

In accordance with one embodiment of the inventive method, the present system allows characterization of multiple linear transfer functions of multiple sensors while they are coupled together in a finished product using a minimum of test measurements or operations. In operation, the method and device of the present invention provides N+2 readings where N is the number of sensors to be characterized.

Any system or apparatus involving coupled, linearly responsive sensors that must be characterized may be calibrated in this fashion. This invention makes it much easier and simpler to use inexpensive poorly controlled sensors in a wide variety of systems in the field or otherwise. Examples of such sensors include load cells for measuring weight or force, pressure transducers, and humidity sensors. This system or apparatus and method may be easily used with a hall-effect sensor typically used in the automotive industry. In some embodiments, the system and method of the present invention may be used with a current sensor, a galvanometer, a hall-effect sensor, a magnetometer, a voltage detector, typically used to measure electric current, electric potential, magnetic or radio data. In other embodiments, the system and method of the present invention may be used with a humistor or a seismometer used to gauge the weather, moisture, humidity and other environmental readings. It may also be used for measuring position, angle, displacement, distance, speed or acceleration in capacitive sensing devices, flex sensors, gravimeter, integrated circuit piezoelectric sensors, photoelectric sensors, and piezoelectric accelerometers. In yet other embodiments, the system and method of the present invention may also be used with a photodetector, a photodiode, and a photoresistor for measuring optical, light, imaging and photon properties. In yet other embodiments, the system or apparatus and method of the present invention may be used for calibrating pressure devices, for example, a piezometer and a pressure sensor. In yet other embodiments, the present invention may be used for calibrating force, density, and level devices, for example, a hydrometer, a force gauge and force sensor, a load cell, a piezoelectric sensor, and a strain gauge. In yet other embodiments, the present invention is used for calibrating thermal, heat, and temperature devices, for example, a thermistor. In yet other embodiments, the present invention is used to calibrate a capacitance sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is illustrated by way of example, and not by way of limitation in the figures of the accompanying drawings in which like reference numerals are used to refer to similar elements.

FIG. **1** is a schematic illustration of one embodiment of the calibration apparatus or device in accordance with the present invention.

FIG. **2** is a schematic representation illustrating the details of example load cells in one embodiment of the calibration apparatus and device to show how the loads cells are mounted.

FIG. **3** is a hi-level block diagram illustrating one embodiment of the overall calibration apparatus or device in accordance with the present invention.

FIG. **4** is a graphical representation illustrating four examples of calibration transfer functions that relate ADC inputs to mass.

FIG. **5** is a flow chart of an example method illustrating the calibration in accordance with the present invention.

FIG. **6** is a flow chart of an example method describing use of calibration constants to compute an actual weight.

DETAILED DESCRIPTION OF THE DRAWINGS

Systems and methods for creating and implementing a calibration apparatus and device are described below. While the systems, methods of the present disclosure are described in the context of a particular device architecture, it should be understood that the device and methods described here can be applied to other architectures and organizations of hardware.

FIG. **1** illustrates a simplified version of the calibration apparatus or device **100**. The calibration apparatus **100** has a non-moving frame **101** and a scale platform **102**. The scale platform **102** is configured to receive the object to be weighed. The scaled platform **102** is configured for the object to be either placed onto it or walk onto it. In one embodiment, the scale platform **102** is supported by four load cells, each of which is designated by the reference numeral **103**. These load cells **103** are attached rigidly on one side to the non-moving frame **101** and attached on the other side to the scale platform **102**. The weight of an object placed on the scale platform **102** is therefore borne by the load cells **103**.

In one embodiment, the load cells **103** are strain gauges connected to a Wheatstone bridge. As one example, "The Art of Electronics by Horowitz and Hill," 3rd edition, pages **297** and **298** illustrates such connections. The Wheatstone bridges are supplied excitation voltage using a precision voltage source **107**. The sense voltage output from each of the load cells **103** are amplified by instrumentation amplifiers **108** and fed to an analog-to-digital converter (ADC) **104**. The output of the ADC **104** is processed by a microcontroller **105**. The output of the microcontroller **105** is sent over a conventional USB connection to a datalogging computer **106**, referred to as "Logger" in FIG. **1**.

In one embodiment, the load cells used may be four inexpensive load cells wired up to a simple multichannel ADC. The calibration method uses a commonly available MAX11254 from Maxim. The system calibrates by weighting a known weight at five locations including the center of the weighing surface. Preferably the four other weighing locations are in the corners as far from each other as possible. Each calibration weighing is used to construct a linear equation of four variables. The center weighing is used as the source of the true weight and thus to provide the sum value of the four equations. The four equations are from the four-corner calibration weighings. This results in four linear equations with four unknowns. The four unknown values are solved for using Gaussian Elimination. This provides the "multiplicative factor" that is applied to each respective load cell.

It is assumed that all of the components of the scale system respond linearly with weight. The signal path from any given load cell consists of at least the following: the scale surface connected to the load cell via a tight and partially compressed spring, the load cell itself which is excited through a stable voltage source, the output signal from the load cell (typically in the tens of millivolt range) is passed through an instrumentation amplifier that applies a several hundred times amplification of the signal, a cable to bring the amplified signal to the ADC, and finally the ADC itself. Note that the voltage source need not be precision only stable and can vary from load cell to load cell. Each of these chains of components need not be matched with each other. All that matters is that the chains of components are linear in their response and consistent over time.

The calibration technique described the system uses an algorithm to compute the zero value or y-intercept of the total linear response curve between the ADC and the scale for each load cell as well as the slope of the linear response curve. Given these two values for each load cell, the algorithm computes the contribution from each load cell to compute the total weight on the scale platform.

It should be recognized that no real-world sensors are perfectly linear. In many cases the sensors can be assumed to be or modeled to be linear if the deviations from linear are small enough to not be significant. This may be varied depending upon the application. In many applications, for example, the noise generated in the system offers a greater contribution to creating an error than the non-linearity of the sensor. However, there are circumstances where the non-linearity is significant. There are can also be hysteresis in the sensor.

In these instances where non-linearity is a significant source of error, the method disclosed herein can be used multiple times at different points along the sensor response curve. For example, the method of the present invention can obtain calibration constants for load cells at 1.000 kg, 5.000 kg, and 10.000 kg in order to map out the response curves across the range of interest. Similarly, in the instance that hysteresis occurs, by this method, the curve may be mapped only in the increasing direction and then again may be mapped only in the decreasing direction. This method may be effectively used as long as a linearity assumption can be made for a small section of the response curve.

Instead of load cells for measuring weight or force, the calibration apparatus or device **100** may alternatively be configured with other examples of sensors such as pressure transducers and humidity sensors. A pressure transducer or pressure transducer is a device that measures the pressure of a fluid, to indicate the force the fluid is exerting on surfaces it is in contact with. Pressure transducers or pressure transmitters convert pressure into an analog electrical signal are used in many control and monitoring applications such as flow, air speed, level, pump systems or altitude. A humidity sensor (or hygrometer) senses, measures and reports both moisture and air temperature. Relative humidity becomes an important factor, when seeking comfort. Humidity sensors work by detecting changes that alter electrical currents or temperature in the air.

The calibration apparatus or device **100** may be easily used with a hall-effect sensor typically used in the automotive industry. A hall effect sensor is a device used to measure the magnitude of a magnetic field. Its output voltage is directly proportional to the magnetic field strength through it. Such sensors are used for proximity sensing, positioning, speed detection, and current sensing applications.

In some embodiments, the calibration apparatus or device **100** may be used with a current sensor, a galvanometer, a hall-effect sensor, a magnetometer, a voltage detector, typically used to measure electric current, electric potential, magnetic or radio data. A current sensor is a device that is typically used to detect electric current in a wire. It generates a signal proportional to that current. The generated signal may be analog voltage or current or even a digital output. In other embodiments, the calibration apparatus or device **100** may be used with a humistor or a seismometer used to gauge the weather, moisture, humidity and other environmental readings. A humistor, sometimes referred to as a humidity sensitive resistor or resistive humidity sensor, is a type of variable resistor whose resistance changes with the change in humidity of the surrounding air. The resistance of the humistor depends on the concentration of absorbed water molecules. When the humidity increases, the water molecules absorbed by the humistor increases and the humistor becomes more electrically conductive. As a result, the resistance of the humistor decreases. On the other hand, when the humidity decreases, the water molecules absorbed by the humistor becomes less electrically conductive. As a result, the resistance of the humistor increases. Likewise, the humistor detects and measures the change in humidity. The calibration apparatus or device **100** may also be used for measuring position, angle, displacement, distance, speed or acceleration in capacitive sensing devices, flex sensors, gravimeter (used to measure gravitational acceleration), integrated circuit piezoelectric (IEPE) sensors (used to measure acceleration, force or pressure), photoelectric sensors (equipment used to discover the distance, absence, or presence of an object by using a light transmitter, e.g. infrared, and a photoelectric receiver), and piezoelectric accelerometers (an accelerometer that uses the piezoelectric effect of certain materials to measure dynamic changes in mechanical variables). In yet other embodiments, the calibration apparatus or device **100** may also be used with a photodetector, a photodiode, and a photoresistor for measuring optical, light, imaging and photon properties. In yet other embodiments, the calibration apparatus or device **100** may be used for calibrating pressure devices, for example, a piezometer and a pressure sensor. In yet other embodiments, the calibration apparatus or device **100** may be used for calibrating force, density, and level devices, for example, a hydrometer, a force gauge and force sensor, a load cell (as described here), a piezoelectric sensor, and a strain gauge. In yet other embodiments, the calibration apparatus or device **100** is used for calibrating thermal, heat, and temperature devices, for example, a thermistor. In yet other embodiments, calibration apparatus or device **100** is used to calibrate a capacitance sensor.

Referring now to FIG. **2**, more details of each of the load cells **103** are shown, in particular, how they are mounted. FIG. **2** illustrates the fixed frame of the scale **202** as well as the scale platform **201** (**102** in FIG. **1**). The load cell **203** (**103** in FIG. **1**) is bolted to the fixed frame **202** by conventional bolts. The other side of the load cells **203** (**103** in FIG. **1**) is bolted to the scale platform **201** (**101** in FIG. **1**) using conventional bolts, however, very stiff springs **206** are used to couple the scale platform **201** to each of the load cells **203** (**103** in FIG. **1**). These springs **206** serve to allow the scale platform **201** (**101** in FIG. **1**) to float over the multiple load cells and distribute their load.

The excitation power for each of the load cells **203** (**103** in FIG. **1**) is provided by an excitation source **205** (also seen as **107** in FIG. **1**). The signal produced by the load cell **203** is typically approximately a few tens of millivolts. This low voltage is amplified with an instrumentation amplifier **204**. Any conventional instrumentation amplifier may be used. For example, there are single package integrated circuits that provide the excitation source as well as the amplification for example from Texas Instruments—the INA125 part that is called "Instrumentation Amplifier with Precision Voltage Reference."

Referring now to FIG. **3**, a high-level overall block diagram of one embodiment of the calibration apparatus is illustrated. This block diagram shows an example of a scale system, which can be calibrated using the method in this disclosure. The scale is powered by a battery **301**, which supplies power to a voltage regulator **303**. The voltage regulator **303** in turn provides power to all devices in the scale.

There are four sets of load cells, a first set designated by reference numeral **314**, a second set designated by reference numeral **315**, a third set designated by reference numeral **316**, and a fourth set designated by reference numeral **317**. Each of these four sets of load cells are connected to an amplifier and precision voltage source. A first one of the four amplifier and precision voltage sources is designated by reference numeral **310**, a second is designated by reference numeral **311**, a third is designated by reference numeral **312**, and a fourth is designated by reference numeral **313**. The output of these sets of amplifier and precision voltage sources **310-313** are sent to an analog-to-digital converter (ADC) **309** (shown **104** in FIG. **1**). This ADC **309** is connected to one or more scale-management processors **305**. Each of the scale-management processors **305** has control buttons and other input devices designated collectively by reference numeral **308** connected to it. The scale-management processor **305** also has a display **304** connected to it to provide user interface and status information.

The scale-management processor **305** is connected to one or more data logging processors **302** ("Logger" in FIG. **1**) that log scale data received into a mass-storage device **306** and communicates results over a wireless network interface **307**.

FIG. **4** shows four examples of calibration transfer functions that relate ADC inputs to mass. A first example calibration transfer function is designated by reference numeral **401**, a second example calibration transfer function is designated by reference numeral **402**, a third example calibration transfer function is designated by reference numeral **403** and a fourth example calibration transfer function is designated by reference numeral **404**. Each of these example calibration transfer functions are illustrated by a graphical representation including an ADC input, a mass of the object to be weighed, a slope and a zero point.

In operation, for calibration, the varying voltages that are produced by the weight sensor or sensors must be converted into a weight measurement to be output to a user (e.g. via the logger **106** in FIG. **1**). An analog-to-digital converter (e.g., ADC **104** in FIG. **1**) is usually used to measure the voltages and provide it to a computer (e.g. microcomputer **106** in FIG. **1**) for further processing. Given that these types of systems are mostly linear, a theoretical line maps a voltage to a weight. This is the linear response curve. Calibration is a process by which the parameters of the line—slope and y-intercept—are discovered. If everything is working perfectly and all elements are behaving linearly and in the case of the use of a single weight sensor the problem of calibration is simply to take and record two measurements with each of two separate and known weights.

Usually this calibration operation is accomplished with a zero weight when the scale is empty (without a physical object placed on its platform) and with a weight (of a physical object placed on its platform) as close as practical to the full-scale capacity of the scale. The line that passes through these two measurements may be easily computed. All further measurements of output voltage can then be computed based on that line.

One additional wrinkle to consider even in the instance of a perfectly functioning single load-cell design is drift. Drift is due to changes in the characteristics of the system over time. Although the slope of the calibration line does not typically change over time, the y-intercept changes. This creates an additive error to the results. This means that when a scale is first powered up to operate, it must be zeroed. At first power up, it is typical to ask the user to remove everything from the scale so that the zero can be determined. It varies from implementation to implementation but this zero is usually valid only for a few minutes before another zero must be obtained.

Another approach to the zero problem is to simply record the changes in the scale reading from when the physical object is placed off the scale to when it is placed on the scale. When we have used this scale system for tracking the weight of wildlife we consider the scale reading shortly before the animal enters the scale as a way to "zero" the scale.

FIG. **5** is a flow chart of an example calibration process. At step **501**, the calibration operation is initiated. At step **502**, data from the ADC (**103** in FIGS. **1** and **309** in FIG. **3**) are collected representative of the voltage values coming from each of the load cells (a first load cell **314**, a second load cell **315**, a third load cell **316**, and a fourth load cell **317**). At step **503**, data are collected from the ADC representing voltages produced by each load cell (a first load cell **314**, a second load cell **315**, a third load cell **316**, and a fourth load cell **317**), when the test weight or object to be weighed is placed in the center of the scale platform **201** (see FIG. **2**). At step **504**, values from the ADC are collected representing voltages from each load cell (a first load cell **314**, a second load cell **315**, a third load cell **316**, and a fourth load cell **317**) for each of the four corners of the scale platform **201** (see FIG. **2**). At step **505**, these corner and center values are used to create a 4 by 5 value matrix. At step **506**, the matrix is then used to compute the slopes of each of the calibration transfer functions (examples illustrated in FIG. **4**). At step **507**, the calibration slopes computed at step **506** and the zeros determined at step **502** are saved for future use. At step **508**, a software flag is created and raised to indicate to the system (e.g., the microcontroller **106** in FIG. **1**/one or more scale-management processors **306**) that the calibration process is complete.

FIG. **6** is a flowchart describing the use of the calibration constants to compute an actual weight. At **601**, the process begins with a trigger to start or initiate an operation to compute the weight of a physical object. At step **602**, the values obtained by the ADC (**104** in FIG. **1**/**309** in FIG. **3**) are collected to represent voltage values from each of the load cells (a first load cell **314**, a second load cell **315**, a third load cell **316**, and a fourth load cell **317**). At step **603**, the zero values collected at step **502** (in FIG. **5**) are subtracted from the corresponding load cell values. At step **604**, the slopes computed at step **506** (in FIG. **5**) are multiplied by the corresponding values obtained from step **603**. At step **605**, these values are summed to compute a final weight. At step **606**, the calibrated weight values obtained from each load cell are used to compute a location on the scale platform **201** (see FIG. **2**). Finally, at step **607**, the results are sent on to the logging processor **302** for storage.

One specific calibration technique to be used for the four load cells coupled on a rigid panel (e.g. scale platform) is described below. First, a user should see what each load cell generates for a zero or unloaded case. It is useful to sample and average load cell readings to average out some of the noise present in the system. The user should call these

readings cellnPowerup where n is 0 to 3. These readings represent the y-intercept of the linear response line.

The next step is to place the known calibration weight at the central point of the scale panel or platform. In accordance with one embodiment, the system of the present invention can use a 1.000 kg weight. The next step is to calculate the difference between the reading in this configuration and the zero case for each load cell. These calculated values may be called CalLocCCellN where N is 0 to 3. Therefore, the algorithm is CalLocCCell0=cell0reading−cell0Powerup. This algorithm produces four values one for each load cell for the example where the calibration weight is placed in the center of the scale platform.

The next step is to move the calibration weight closer to load cell 0. In a similar operation, the difference between the reading in this configuration and the zero case for each load cell should be computed. These calculated values may be referred to as CalLoc0CellN where N is 0 to 3. The algorithm used is CalLocOCell0=cell0reading−cell0Powerup. Further CalLoc0Cell1=cell1reading−cell1Powerup. This produces four values one for each load cell for the example where the calibration weight is at load cell 0.

The next step is to move the calibration weight to near load cell 1. Similarly, the system algorithm calculates the difference between the reading in this configuration and the zero case for each load cell. The algorithm refers to these calculated values as CalLoc1CellN where N is 0 to 3. Therefore, the algorithm computes CalLoc1Cell0=cell0reading−cell0Powerup. Further CalLoc1Cell1=cell1reading−cell1Powerup. These computations provide four values one for each load cell for the case where the calibration weight is at load cell 1.

The next step is to move the calibration weight closer to load cell 2. Similarly, the system algorithms calculate the difference between the reading obtained in this configuration and the zero case for each load cell. These calculated values are called by the algorithm CalLoc2CellN where N is 0 to 3. Therefore, the algorithm for further calculations is CalLoc2Cell0=cell0reading−cell0Powerup. Further, the algorithm step CalLoc2Cell 1=cell1reading−cell1Powerup. This gives us four values one for each load cell for the case where the calibration weight is at load cell 2.

The next step in the calibration process is to move the calibration weight near load cell 3. Similarly, the system algorithm calculates the difference between the reading in this configuration and the zero case for each load cell. These calculated values are CalLoc3CellN where N is 0 to 3. Therefore, CalLoc3Cell0=cell0reading−cell0Powerup. Further CalLoc3Cell1=cell1reading−cell1Powerup. These algorithms produce four values one for each load cell for the case where the calibration weight is at load cell 3.

Each of these four reading at each of the load cells represents a linear equation. The equation is weight0*CalLocNCell0+weight1*CalLocNCell1+ weight2*CalLocNCell2+weight3+ CelLocNCell3=Calibration Weight. In one example determination in accordance with one embodiment of the present invention the Calibration Weight is 1.000 kg. The four unknowns weight0, weight1, weight2, and weight3 can be easily computed with as many equations as there are unknowns. In this example described here, as there are four sets of readings, there are four equations for the four unknowns.

$$(a_1-a_p)x+(b_1-b_p)y+(c_1-c_p)z+(d_1-d_p)q=w$$

$$(a_2-a_p)x+(b_2-b_p)y+(c_2-c_p)z+(d_7-d_p)q=w$$

$$(a_3-a_p)x+(b_3-b_p)y+(c_3-c_p)z+(d_3-d_p)q=w$$

$$(a_4-a_p)x+(b_4-b_p)y+(c_4-c_p)z+(d_4-d_p)q=w$$

Here, the a_n values represent measurements made at load cell a with the test weight at location n, a_p to compute the power up measurement of load cell a with no weight on it. The b, c, and d values are similar. The w value is the weight of the calibration weight.

Following the rules of Linear Algebra, four linear equations with four unknowns can be solved using a technique called Gaussian Elimination. The algorithm uses Gaussian Elimination to compute the four weightN values. These weightNs are the slopes of the respective linear response curves. By using these steps, the slopes of the linear response curves of the respective load cells are determined.

Finally, the conversion factor between the units of the analog-to-digital conversion of the load cells to units of mass may be determined, by using the equation for the center. SamplesPerKilo=(weight0*CalLocCCell0+weight1*CalLocCCell1+weight2*CalLocCCell2+weight3*CalLocCCell3)/Calibration Weight.

To use these values, the system computes the contribution from each load cell by subtracting the cellNPowerup value from the reading and multiplying by the weightN value. The total weight is given by summing these contributions and dividing by the SamplesPerKilo value. The different contributions from the different cells can be used to locate the centroid of the weight applied to the scale panel or platform.

Other calibration techniques may also be used. However, given the assumption of linearity, the above technique and algorithms result in an accurate and excellent calibration with a minimum of calibration readings required making this an effective and efficient process.

It is important to note that the readings are accomplished on the complete system. The load cells do not have to be separated from the measurement system to be calibrated. This is advantageous, as compared to prior systems, because each element has to be separately calibrated and characterized before assembly. This required contributions from all elements to be factored into the calibration process. This calibration technique involves fewer mechanical steps than prior approaches.

Also, it should be recognized that the exact location of the calibration readings is not critical. As long as there are four readings for four separate load cells, a user may obtain four equations that may be then solved for the four slopes. Separating the four readings as far as possible results in determining the most accurate slopes, but their exact placement is not critical. This approach works as long as a user has one center reading and one additional reading for each load cell—four in the example described above.

The general version of this method views each reading involving multiple sensors as a linear equation where the weighted linear sum adds to the calibration value. As many equations as sensors may be used to provide N linear equations with N unknowns. These N unknowns are the slopes of the linear transfer functions of the N sensors. It should be recognized that Gaussian Elimination is one example, other approaches may be used to solve this system of linear equations.

This calibration technique has helped create a unique and efficient measurement scale, which may be effectively used for weighing moving objects, for example animals as they move. With four load cells, large springs are not required to bring the weight to a single load cell. This makes the overall scale very thin, resilient, and very responsive to rapidly changing loads. The present measurement scale can effectively weigh penguins as they run across it. By avoiding the use of big springs, the measurement scale does not bounce as the penguins run across it. This simple calibration techniques make field calibration easy and field repair possible.

In the above description, for purposes of explanation, numerous specific details were set forth. It will be apparent, however, that the disclosed technologies can be practiced without any given subset of these specific details. In other instances, structures and devices are shown in block diagram form. For example, the disclosed technologies are described in some implementations above with reference to particular hardware.

Reference in the specification to "one implementation" or "an implementation" means that a particular feature, structure, or characteristic described in connection with the implementation is included in at least one implementation of the disclosed technologies. The appearances of the phrase "in one implementation" in various places in the specification are not necessarily all referring to the same implementation.

Some portions of the detailed descriptions above were presented in terms of processes and symbolic representations of operations on data bits within a computer memory. A process can generally be considered a self-consistent sequence of steps leading to a result. The steps may involve physical manipulations of physical quantities. These quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. These signals may be referred to as being in the form of bits, values, elements, symbols, characters, terms, numbers or the like.

These and similar terms can be associated with the appropriate physical quantities and can be considered labels applied to these quantities. Unless specifically stated otherwise as apparent from the prior discussion, it is appreciated that throughout the description, discussions utilizing terms for example "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, may refer to the action and processes of a controller, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the controller's registers and memories into other data similarly represented as physical quantities within the controller memories or registers or other such information storage, transmission or display devices.

The disclosed technologies also relate to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, or it may include a general-purpose computing element selectively activated or reconfigured by computer instructions stored in the computing element. Such computer instructions may be stored in a computer readable storage medium, for example, but not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, flash memories including USB keys with non-volatile memory or any type of media suitable for storing electronic instructions, each coupled to a computer system bus.

The disclosed technologies can take the form of an entirely hardware implementation, an entirely software implementation or an implementation containing both hardware and software elements. In some implementations, the technology is implemented in software, which includes but is not limited to firmware, resident software, microcode, etc.

Furthermore, the disclosed technologies can take the form of a computer program product accessible from a nontransitory computer-usable or computer-readable medium providing program code for use by or in connection with a computer or any instruction execution system. For the purposes of this description, a computer-usable or computer-readable medium can be any apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

A computing or data processing component suitable for storing and/or executing program code will include at least one processor (e.g., a hardware processor) coupled directly or indirectly to memory elements through a system bus. The memory elements can include local memory employed during actual execution of the program code, bulk storage, and cache memories which provide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution.

Input/output or I/O devices (including but not limited to keyboards, displays, pointing devices, etc.) can be coupled to the calibration apparatus or device either directly or through intervening I/O controllers.

Network adapters may also be coupled to the calibration apparatus or device to enable it to become coupled to other data processing systems or remote printers or storage devices through intervening private or public networks. Modems, cable modems and Ethernet cards are just a few of the currently available types of network adapters.

Finally, the processes and displays presented herein may not be inherently related to any particular computer or other apparatus. Various general-purpose components may be used with programs in accordance with the teachings herein to substitute for the more specialized apparatus of the present invention to perform the required method steps. The required structure to create a variety of these systems appears in the description above. In addition, the disclosed technologies are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement any portion of the teachings of the technologies as described herein.

The foregoing description of the implementations of the present techniques and technologies has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the present techniques and technologies to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the present techniques and technologies be limited not by this detailed description. The present techniques and technologies may be implemented in other specific forms without departing from the spirit or essential characteristics thereof. Likewise, the particular naming and division of the modules, routines, features, attributes, methodologies and other aspects are not mandatory or significant, and the mechanisms that implement the present techniques and technologies or its features may have different names, divisions and/or formats. Furthermore, the modules, routines, features, attributes, methodologies and other aspects of the present technology can be implemented as software, hardware, firmware or any combination of the three. Also, wherever a component, an example of which is a module, is implemented as software, the component can be implemented as a standalone program, as part of a larger program, as a plurality of separate programs, as a statically or dynamically linked library, as a kernel loadable module, as a device driver, and/or in every and any other way known now or in the future in computer programming. Additionally, the present techniques and technologies are in no way limited to implementation in any specific programming language, or for any specific operating system or environment. Accordingly, the disclosure of the present techniques and technologies is intended to be illustrative, but not limiting.

What is claimed is:

1. A calibration method for measuring a physical property of an object, comprising:

placing the object to be measured on a platform in a specific location on the platform;

positioning a plurality of individual sensors at predetermined observational locations of the platform in a multi-sensor arrangement, further comprising:

1) positioning a first sensor at a first predetermined observational location, said first sensor configured to provide a first sensor output signal that represents a first sensor reading in response to sensing a first physical characteristic of said physical property of said object to be measured with said object positioned on said specific location on the platform; and

2) positioning a second sensor at a second predetermined observational location, said second sensor configured to provide a second sensor output signal that represents a second sensor reading in response to sensing the physical characteristic of said physical property of said object to be measured with said object positioned on said specific location on the platform; and

combining the first sensor output signal and the second sensor output signal by a combined calibration transfer function that represents a calibration function for each of said first sensor and said second sensor to provide a cumulative measurement signal that represents the measurement of the physical property of the object configured to give two readings in 1) and 2) with locating the object to be measured at the same position on a receiving component.

2. A calibration method according to claim **1**, further comprising:

mapping a non-linear transfer function for said multi-sensor arrangement through multiple calibrations.

3. A calibration method according to claim **1**, wherein the first sensor is a first load cell and the second sensor is a second load cell.

4. A calibration method according to claim **3**, wherein the first load cell and the second load cell are coupled via at least one rigid spring.

5. A calibration method according to claim **1**, wherein at least one of said first and second sensors is at least one of a group of: a hall effect sensor, a current sensor, a galvanometer, a magnetometer, a voltage detector, a humistor, a seismometer, a capacitive sensor, a flex sensor, a gravimeter, an integrated circuit piezoelectric sensor, a photoelectric sensor, a piezoelectric accelerometer, a photodetector, a photodiode, a photoresistor, a piezometer, a pressure sensor, a hydrometer, a force gauge and force sensor, a load cell, a piezocacitive pressure sensor, a piezoelectric sensor, a strain gauge, a thermistor, and a capacitance sensor.

6. A calibration method according to claim **1**, wherein said first and second sensors are from a group of: a hall effect sensor, a current sensor, a galvanometer, a magnetometer, a voltage detector, a humistor, a seismometer, a capacitive sensor, a flex sensor, a gravimeter, an integrated circuit piezoelectric sensor, a photoelectric sensor, a piezoelectric accelerometer, a photodetector, a photodiode, a photoresistor, a piezometer, a pressure sensor, a hydrometer, a force gauge and force sensor, a load cell, a piezocacitive pressure sensor, a piezoelectric sensor, a strain gauge, a thermistor, and a capacitance sensor.

7. A calibration method according to claim **1**, further comprising:

using an analog-to-digital converter to read the first and second sensors.

8. A calibration method according to claim **1**, wherein the calibration function is automatically performed.

9. A calibration system, comprising:

a platform receiving an object to be measured, wherein said object to be measured is placed on a specific location on said platform;

a plurality of individual sensors in a multi-sensor arrangement positioned on said platform at predetermined observational locations, the multi-sensor arrangement further comprising:

1) a first sensor positioned at a first predetermined observational location on said platform and configured to provide a first sensor output to represent a first sensor reading in response to sensing a physical characteristic of a physical property of said object to be measured with said object positioned on said specific location on the platform; and

2) a second sensor positioned at a second predetermined observational location on said platform and configured to provide a second sensor output signal to represent a second sensor reading in response to sensing the physical characteristic of said physical property of said object to be measured with said object positioned on said specific location on the platform; and

3) a processor coupled to said multi-sensor arrangement and configured to use a combined calibration transfer function to combine the first sensor output and the second sensor output, wherein the combined calibration transfer function represents a calibration function for each of said first sensor and said second sensor to provide a cumulative measurement signal that represents the measurement of the physical property of the object.

10. A calibration system according to claim **9**, wherein said multi-sensor arrangement is calibrated by mapping a non-linear transfer function for said multi-sensor arrangement through multiple calibrations.

11. A calibration system according to claim **9**, wherein the first sensor is a first load cell and the second sensor is a second load cell.

12. A calibration system according to claim **11**, wherein the first load cell and the second load cell are coupled via at least one rigid spring.

13. A calibration system according to claim **9**, wherein said first and second sensors are one of a group of: a hall effect sensor, a current sensor, a galvanometer, a magnetometer, a voltage detector, a humistor, a seismometer, a capacitive sensor, a flex sensor, a gravimeter, an integrated circuit piezoelectric sensor, a photoelectric sensor, a piezoelectric accelerometer, a photodetector, a photodiode, a photoresistor, a piezometer, a pressure sensor, a hydrometer, a force gauge and force sensor, a load cell, a piezocacitive pressure sensor, a piezoelectric sensor, a strain gauge, a thermistor, and a capacitance sensor.

14. A calibration system according to claim **9**, further comprising:

an analog-to-digital converter to read the first sensor and the second sensor.

15. A calibration system according to claim **9**, wherein the calibration is automatically performed.

16. A calibration system, comprising:

a platform for receiving an object to be measured, wherein said object to be measured is placed on a specific location on said platform;

means for arranging a plurality of individual sensors to create a multi-sensor arrangement on a platform, the multi-sensor arrangement comprising:

1) a first means for sensing and providing a first sensor output to represent a first sensor reading in response to sensing a physical characteristic of a physical property of said object from a first observational point on said platform with said object positioned on said specific location on the platform; and

2) a second means for sensing and providing a second sensor output to represent a second sensor reading in response to sensing the physical characteristic from a second observational point on said platform with said object positioned on said specific location on the platform; and

3) means for combining the first sensor output and the second sensor output by applying a combined calibration transfer function that represents a calibration function for each of said first sensor and said second sensor to provide a cumulative measurement signal that represents the measurement of the physical property of the object.

17. A calibration system according to claim **16**, further comprising:

means for mapping a non-linear transfer function for said multi-sensor arrangement through multiple calibrations.

18. A calibration system according to claim **16**, wherein the first sensor is a first load cell and the second sensor is a second load cell.

19. A calibration system according to claim **18**, wherein the first load cell and the second load cell are coupled via at least one rigid spring.

20. A calibration system according to claim **16**, wherein at least one of said first and second sensors is at least one of a group of: a hall effect sensor, a current sensor, a galvanometer, a magnetometer, a voltage detector, a humistor, a seismometer, a capacitive sensor, a flex sensor, a gravimeter, an integrated circuit piezoelectric sensor, a photoelectric sensor, a piezoelectric accelerometer, a photodetector, a photodiode, a photoresistor, a piezometer, a pressure sensor, a hydrometer, a force gauge and force sensor, a load cell, a piezocacitive pressure sensor, a piezoelectric sensor, a strain gauge, a thermistor, and a capacitance sensor.

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