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(54) **Title**: A MULTI-SENSE ENVIRONMENTAL MONITORING DEVICE AND METHOD

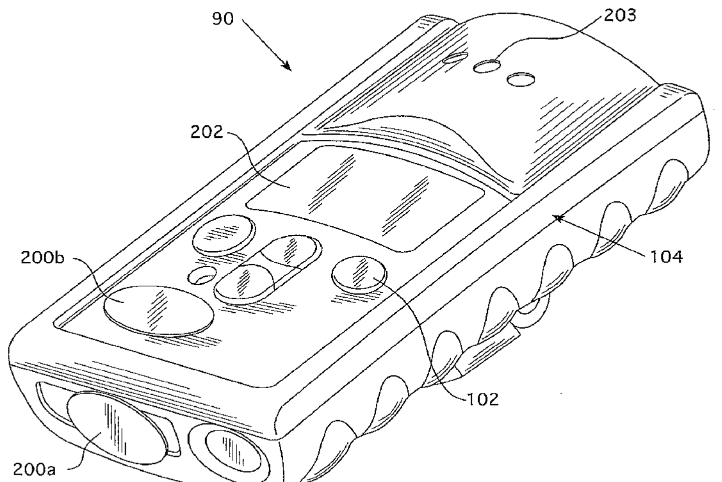

FIG. 1C

(57) **Abstract**: An environmental monitoring device for detecting and warning users of unhealthy levels of a given substance is disclosed having more than one sensor for each substance to be detected. Each sensor for each substance detected may be positioned in more than one plane or surface on the device. The device may be capable of auto or self calibration. Methods for reading substance levels and auto calibrating are also disclosed.

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A MULTI-SENSE ENVIRONMENTAL MONITORING DEVICE AND METHOD

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to U.S. Provisional Patent Application No: 61/358,729 filed June 25, 2010.

FIELD OF THE INVENTION

[0002] Embodiments of the present invention generally relate to environmental monitoring devices.

BACKGROUND OF THE INVENTION

[0003] In a number of industrial work environments workers are at risk of being exposed to a variety of hazardous environmental substances such as toxic or highly combustible gases, oxygen depleted environments, or radiation, etc. that pose a serious threat to worker safety. In order to keep workers safe, specialized environmental monitoring devices are used to alert workers of dangerous changes in their immediate environment.

[0004] Current practice involves using fixed point monitoring devices that monitor the environment around where they are deployed or portable monitoring devices that are carried by the workers to monitor their immediate vicinity. Fixed point monitoring devices are typically used around potential hazard locations such as confined spaces to warn workers of the environment before they enter. Portable monitoring devices are often used for personal protection. These monitoring devices may have a single sensor to monitor one specific substance or multiple sensors (typically two to six) each monitoring a distinct substance.

[0005] Given that these environmental monitoring devices are life critical, it is important the device functions properly and accurately. Current practice involves periodic bump testing and calibration of monitoring devices to guarantee proper functioning. Bump tests involve exposing the monitoring device to a measured quantity of gas and verifying that the device responds as designed, i.e. it senses the gas and goes into alarm. Calibration involves exposing the device to a measured quantity of gas and adjusting the gain of the sensors so it reads the quantity of gas accurately. The purpose of calibration is to maintain the accuracy of the monitoring device over time.

[0006] Current best practice followed by leading manufacturers of environmental monitors recommends bump testing the monitoring device before every days work and calibrating the device once at least every thirty days. While a number of manufacturers sell automated docking stations that automatically perform calibration and bump testing when a monitoring device is docked, there are still a number of disadvantages to the current practice.

[0007] A fixed bump and calibration policy, such as currently practiced, does not take into account the actual state of the sensors or the environmental monitoring device. Such a fixed policy (bump test every day and calibrate every thirty days) by its very nature is a compromise that is too stringent in many cases and too liberal in many others.

[0008] Given that the docking operation requires the user to bring the monitor to a central location, which typically is outside the work area, to perform the bump test and calibration, there is value in minimizing/optimizing this operation as much as possible without compromising safety.

[0009] Threshold limit values (TLV), namely the maximum exposure of a hazardous substance repeatedly over time which causes no adverse health effects in most people is constantly being reduced by regulatory authorities as scientific understanding and evidence grows and we accumulate more experience. Often these reductions are quite dramatic as in the case of the recent (February 2010) reduction recommended by the American Congress of Governmental Industrial Hygienists (ACGIH) for H2S exposure. The ACGIH reduced the TLV for H2S from a time weighted average (TWA) of 10ppm to 1 ppm TWA averaged over eight hours. The effect of such reductions puts a premium on accuracy of measurements. Current practice of a fixed calibration policy, such as calibrate every thirty days, may not be enough to guarantee the level of accuracy to meet the more stringent emerging TLV's. While a blanket reduction in the frequency of the calibration interval, i.e. from thirty days, will help to improve accuracy, it would add significant cost to the use and maintenance of the environmental monitoring devices.

[00010] One solution to this problem, pursued by some, is to use newer and more advanced technology sensors with a higher degree of accuracy and tolerance to drift that minimize the need for calibration and bump testing. While there certainly is value in this approach, the cost of these emerging sensor often preclude its widespread use, particularly in personal monitoring applications where a large number of these monitors need to be deployed.

[00011] For all the aforementioned reasons there is value in developing monitors that use current low cost sensor technologies while still meeting emerging TLV regulations and allow for a more adaptive calibration/bump policy that takes into account the state of the sensors and monitoring devices.

SUMMARY OF THE INVENTION

[00012] In one general aspect, embodiments of the present invention generally pertain to a monitoring device having at least two sensors for each substance to be detected, a display, a processing unit, and an alarm. The sensors may be positioned on more than one plane or surface of the device. The processing unit may auto or self calibrate the sensors. Another embodiment relates to a network of monitoring devices. Other embodiments pertain to methods of monitoring a substance with a monitoring device having at least two sensors for that substance and auto or self calibrating the sensors.

[00013] Those and other details, objects, and advantages of the present invention will become better understood or apparent from the following description and drawings showing embodiments thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[00014] The accompanying drawings illustrate examples of embodiments of the invention. In such drawings:

[00015] Figures 1A, 1B and 1C illustrate monitoring devices having two sensors that detect the same substance and positioned on different planes or surfaces of the device, and Figure 1D shows a monitoring device having three sensors according to various embodiments of the present invention;

[00016] Figure 2 shows a block diagram illustrating a few of the components of the monitoring device according to various embodiments of the present invention;

[00017] Figure 3 illustrates a flowchart of an example AI logic according to various embodiments of the present invention; and

[00018] Figure 4A illustrates a monitoring device with the plurality of sensors housed in multiple housings and connected to a central processing unit and Figure 4B illustrates a network of monitoring devices according to various embodiments of the present invention.

DETAILED DESCRIPTION

[00019] Various embodiments of the present invention pertain to a monitoring device and methods used for environmental monitoring of substances, such as, for example and without limitation, gases, liquids, nuclear radiation, etc.

[00020] In an embodiment, as illustrated in Figures 1A-C, the monitoring device 90 has at least two sensors, 200a and 200b, which detect the same substance. The sensors may be positioned in more than one plane or surface of the device 90. The device 90 also has a display 202; a user interface 102, such as, for example and without limitation, at least one key or key pad, button, or touch screen, for control and data entry; an alarm 203, shown in Figures 1C and 1D, such as, for example and without limitation, audio, visual, or vibration; and a housing 104. The monitoring device 90 may have a user panic button 106, shown in Figures 1A and 1B, that allows the user to trigger an alarm mechanism. In an example, as shown in Figures 1A and 1B, sensor 200a and 200b are on opposite sides of the device 90. In another example, as shown in Figure 1C, sensor 200a is on the front of the device 90 and sensor 200b on the top. In yet another example, as shown in Figure 1D, the device 90 has three sensors, 200a-c, sensing the same substance and positioned in different planes or surfaces of the device 90. The position of the sensors 200 in different and multiple planes greatly reduces the likelihood of more than one sensor failing, for example by being clogged by debris from the device 90 being dropped. The monitoring device 90 may have more than one sensor 200 for each substance to be detected, i.e. the device 90 may detect more than one substance. The sensors 200 for each substance may be positioned on more than one plane or surface of the device 90. For example, the device 90 may have two sensors 200a and 200b for H2S positioned on different surfaces or planes, e.g. one on the top and one on the side, of the device 90 and two sensors 200c and 200d for oxygen positioned on different surfaces or planes of the device 90, e.g. one on top and one on the side.

[00021] In another embodiment the monitoring device 90, as shown in Figure 2, has a plurality of sensors 200a-n that detect the same substance. One benefit of using more than one sensor 200 for each substance to be detected is reduction in the frequency of bump testing and calibration of the monitoring devices. As an example, in practice monitoring device types typically used for gas detection have been found to fail at a rate of 0.3% a day based on field analysis data and thus daily bump tests have been mandated; however, equivalent safety may be gained with two sensors by bump testing every week, thereby reducing bump testing by seven fold.

[00022] In further embodiments, the monitoring device 90, as shown in Figure 2, has a processing unit 201; a plurality of sensors 200a-n that sense the same substance, such as, for example and without limitation, a gas; a display 202; an alarm 203 that would generate an alarm, for example and without limitation, an audio, visual, and/or vibratory alarm; and a memory 204 to store, for example and without limitation, historic sensor and calibration/bump test data. The processing unit 201 interfaces with the sensors 200a-n and determines the actual reading to be displayed. The actual reading may be, for example and without limitation, the maximum, minimum, arithmetic, mean, median, or mode of the sensor 200a-n readings. The actual reading may be based on artificial intelligence (AI) logic. The AI logic mechanism takes into account, for example and without limitation, the readings from the plurality of sensors 200a-n, historic sensor performance data in the memory 204, span reserve of the sensor 200, gain of the sensor 200, temperature, etc., to determine the actual reading. In another example, as an alternative to the displayed actual reading being the maximum of the aggregate of the n sensors 200a-n, the displayed actual reading may be calculated as follows, where R denotes the displayed reading and R_i denotes the reading sensed by sensor i:

$R = \frac{\sqrt[k]{\sum_{i=0}^{n} R_i^k}}{n}$. Then, the processing unit may display possible actions that need to be taken based on the actual reading derived, for example and without limitation, activate the alarm, request calibration by user, indicate on the display that the sensors are not functioning properly, indicate the current reading of gas or other substance in the environment, auto calibrate sensors that are out of calibration, etc.

[00023] One example of the artificial intelligence logic method would be for the greater readings of the two sensors 200a and 200b or the greater readings of a multitude of sensors 200a-n to be compared with a threshold amount, and if the sensor reading crosses the threshold amount, an alarm mechanism would be generated. Another example of AI logic entails biasing the comparison between the sensor readings and the threshold amount by weights that are assigned based on the current reliability of the sensors 200a-n, i.e. a weighted average. These weights can be learned, for example and without limitation, from historic calibration and bump test performance. Standard machine learning, AI, and statistical techniques can be used for the learning purposes. As an example, reliability of the sensor 200 may be gauged from the span reserve or alternatively the gain of the sensor 200. The higher the gain or lower the span reserve, then the sensor 200 may be deemed less reliable. Weights may be assigned appropriately to bias the aggregate substance concentration reading (or displayed reading) towards the more reliable sensors 200a-n. Consider R to denote the displayed reading, R_i to denote the reading sensed by sensor I, and w_i to denote the weight associated by sensor i:

$R = \frac{\sum_{i=1}^{n} w_i * R_i}{n}$ where the weight $w_i (0 < w \geq 1)$ is proportional to span reading of sensor i or inversely proportional to the gain G_i. Alternatively, w_i can be derived from historical data analysis of the relationship between the gain w_i and span reserve or gain G_i. Historical data of bump tests and calibration tests performed in the field, for example and without limitation, can be used to derive this data.

[00024] In addition, as illustrated in Figure 3, if the difference in readings between any two or more sensors 200 is greater than some threshold value t_c, which could be determined in absolute terms or relative percentage terms and may vary by substance, then the monitoring device 90 would generate an alarm or visual indication in the display

202 requesting a calibration by docking on a docking station or manually be performed on the device 90. Further, if the difference in readings is greater than some higher threshold value t_f, the monitoring device 190 would generate an alarm and or indicate on the display 202 a message indicating a sensor failure.

[00025] In some circumstances, for example and without limitation, in the case of an oxygen sensor, the minimum reading of a multitude of sensors 200a-n may be used to trigger an alarm to indicate a deficient environment.

[00026] In another embodiment, the monitoring device 90 may have an orientation sensor, such as, for example and without limitation, an accelerometer, that would allow the artificial intelligence logic to factor in relative sensor orientation to account for the fact that heavier than air gases, for example, would affect sensors in a lower position more than on a higher position and lighter than air sensors would. The degree of adjustment to the reading based on orientation can be learned, for example and without limitation, from the calibration data, field testing, distance between sensors, etc. and used to adjust readings from multiple positions on the device 90 to give the most accurate reading at the desired location, such as the breathing area of a user or a specific location in a defined space using the environmental monitoring device 90 as a personnel protection device.

[00027] Another embodiment pertains to a network 500 having the plurality of sensors 200a-n that detect a single substance housed in separate enclosures, placed in the vicinity of one another, e.g. from inches to feet depending on the area to be monitored, and communicate with one another directly and/or the central processing unit through a wireless or wired connection. See Figures 4A and 4B. Each of the housings 104 may have a separate processing unit 201, memory 204, and AI processing logic, as shown in Figure 4B. Alternatively, or in combination, sensor units would share a central processing unit 201 and memory 204, as shown in Figure 4A.

[00028] Based on the plurality of sensor readings 200a-n, the processing unit, using standard AI and machine learning techniques, etc., will adjust the gain of the sensors 200a-n to match closer to the majority of sensors 200a-n for each substance, i.e. minimize variance among the sensors. The variance may be, for example and without limitation, a statistical variance, other variance metrics such as Euclidean distance, or

calculated from the average, weighted average, mean, median, etc. readings of the sensors. This would allow auto or self calibration of outlying sensors 200a-n without the use of calibration gas using a manual method or a docking station. In an example, if n sensors 200a-n sensing a particular gas, such as H2S, are considered and R_i is the reading that represents the concentration of H2S sensed by sensor i and M is the median value of the reading among the n sensors, then the gain, given by $G_{i,}$, of each sensor can be adjusted so that the reading R_i moves towards the median value by a small amount given by weight w($0 < w \geq 1$). For each sensor i in (1,n): $G_i = G_i * \left(w * \frac{R_i}{M}\right)$
Performing such gain adjustment whenever the monitoring device 90 is exposed to a substance in the field, for example, as part of day- to-day operation will reduce the frequency of calibrations required, thus saving money both directly from the reduction in calibration consumption, such as gas, and also costs involved in taking time away to perform the calibration. Current monitoring devices that use a single gas sensor for detecting each gas type require a more frequent calibration schedule, thereby incurring significant costs.

[00029] While presently preferred embodiments of the invention have been shown and described, it is to be understood that the detailed embodiments and Figures are presented for elucidation and not limitation. The invention may be otherwise varied, modified or changed within the scope of the invention as defined in the appended claims.

EXAMPLE

[00030] The following discussion illustrates a non-limiting example of embodiments of the present invention.

[00031] A single gas monitor that is used as a small portable device worn on the person and used primarily as personal protection equipment may be used to detect the gases within the breathing zone of the bearer of the device. The gas monitor is designed to monitor one of the following gases:

Measuring Ranges:	Gas	Symbol	Range	Increments
	Carbon Monoxide	CO	0-1,500	1 ppm
	Hydrogen Sulfide	H_2S	0-500 ppm	0.1 ppm
	Oxygen	O_2	0-30% of volume	0.1%
	Nitrogen Dioxide	NO_2	0-150 ppm	0.1 ppm
	Sulfur Dioxide	SO_2	0-150 ppm	0.1 ppm

[00032] The sensors are placed on two separate planes of the monitoring device, for example as depicted in Figures 1A-C. The gas concentration of the reading is calculated in the following manner:

$$reading = \frac{\sqrt{SensorReading1^5 + SensorReading2^5}}{2}$$

[00033] If the reading is higher (or lower in the case of oxygen) than a user defined alarm threshold, then an audio and visual alarm is generated.

[00034] Further, if $reading > 0.5 * abs(alarmThreshold - normalReading)$ and if $0.3 \leq \frac{abs(sensorReading1 - sensorReading2)}{\max(sensorReading1, sensorReading2)} \leq 0.5$ then an auto calibrate function based on gain as described below is performed. The auto calibration may be done, based on a user defined setting in the monitoring device, without further input from the user of the monitoring device, and/or the user will be informed that the gas monitor has detected an anomaly and requests permission to auto calibrate.

[00035] If $\frac{abs(sensorReading1 - sensorReading2)}{\max(sensorReading1, sensorReading2)} > 0.5$ then a message is displayed to the user to calibrate the gas monitor immediately using a calibration gas.

[00036] Gain of each of the sensors is modified as follows in the auto or self calibration process:

$$sensorGain^{new} = sensorGain^{old} + 0.1 * \frac{max(sensorReading1, sensorReading2)}{min(sensorReading1, SensorReading2)}$$

What is claimed is:

1. A monitoring device comprising:

   at least two sensors for each substance to be detected;

   a display;

   an alarm;

   a user interface; and

   a processing unit with memory.

2. The monitoring device of claim 1, wherein the at least two sensors are positioned in more than one plane or surface of the device.
3. The monitoring device of claim 1 or 2, wherein the user interface is at least one of a button, key, or touch screen.
4. The monitoring device of any one of the preceding claims, wherein the processing unit interfaces with the sensors and alarm.
5. The monitoring device of any one of the preceding claims, wherein the alarm is at least one of vibration, visual, or audio.
6. The monitoring device of any one of the preceding claims, further comprising a user panic button.
7. The monitoring device of any one of the preceding claims, further comprising an orientation sensor.
8. The monitoring device of any one of the preceding claims, wherein the processing unit comprises a means to determine an actual reading to be displayed based on the amount of substance detected by the sensors.
9. The monitoring device of claim 8, further comprising a means to instruct or trigger the alarm if the actual reading is greater than or lesser than a threshold amount.
10. The monitoring device of any one of claims 1-7, wherein the processing unit comprises a means to auto or self calibrate the sensors.
11. The monitoring device of any one of claims 1-7, wherein the processing unit comprises a means to instruct a user to perform a calibration with a measured quantity of substance.

12. The monitoring device of any one of claims 1-7, wherein the processing unit comprises a means to request a user to allow auto or self calibration of the sensors.
13. The monitoring device of any one of the preceding claims, wherein the sensors are connected to the processing unit through a wired or wireless connection.
14. A network comprising at least two monitoring devices of claim 1.
15. The network of claim 14, wherein the monitoring devices are connected through a wired or wireless connection.
16. A method for monitoring at least one substance with a monitoring device having at least two sensors specific for each substance, the method comprising:
    calculating an actual reading to be displayed based on the amount of the substance detected by the sensors;
    determining if the actual reading is greater than a threshold limit; and
    instructing an alarm if the actual reading is greater or lesser than the threshold limit.
17. The method of claim 16, wherein the step of calculating the actual reading of the substance comprises determining the maximum reading detected by the sensors for the substance.
18. The method of claim 16, wherein the step of calculating the actual reading of the substance comprises determining the minimum reading detected by the sensors for the substance.
19. The method of claim 16, wherein the step of calculation the actual reading of the substance comprises compensating for orientation of the device.
20. The method of claim 16, wherein the step of calculating the actual reading of the substance comprises determining the average or weighted average of the readings detected by the sensors for the substance.
21. The method of any one of claims 16-20, further comprising determining if the reading detected by one sensor deviates by a threshold amount compared to the other sensors specific for the same substance and if so instructing a user to calibrate with a measured quantity of substance, requesting the user to auto or self calibrate, automatically calibrating, or indicate sensor failure.

22. The method of any one of claims 16-21, further comprising auto or self calibrating the sensors.
23. The method of claim 22, wherein self or auto calibrating comprises adjusting a gain of the sensors that deviate by a threshold amount to minimize variance among the sensors for the substance.
24. A method for auto calibrating a monitoring device having at least two sensors for detecting a substance, the method comprising adjusting a gain of the sensors that deviate by a threshold amount to minimize variance among the sensors for the substance.

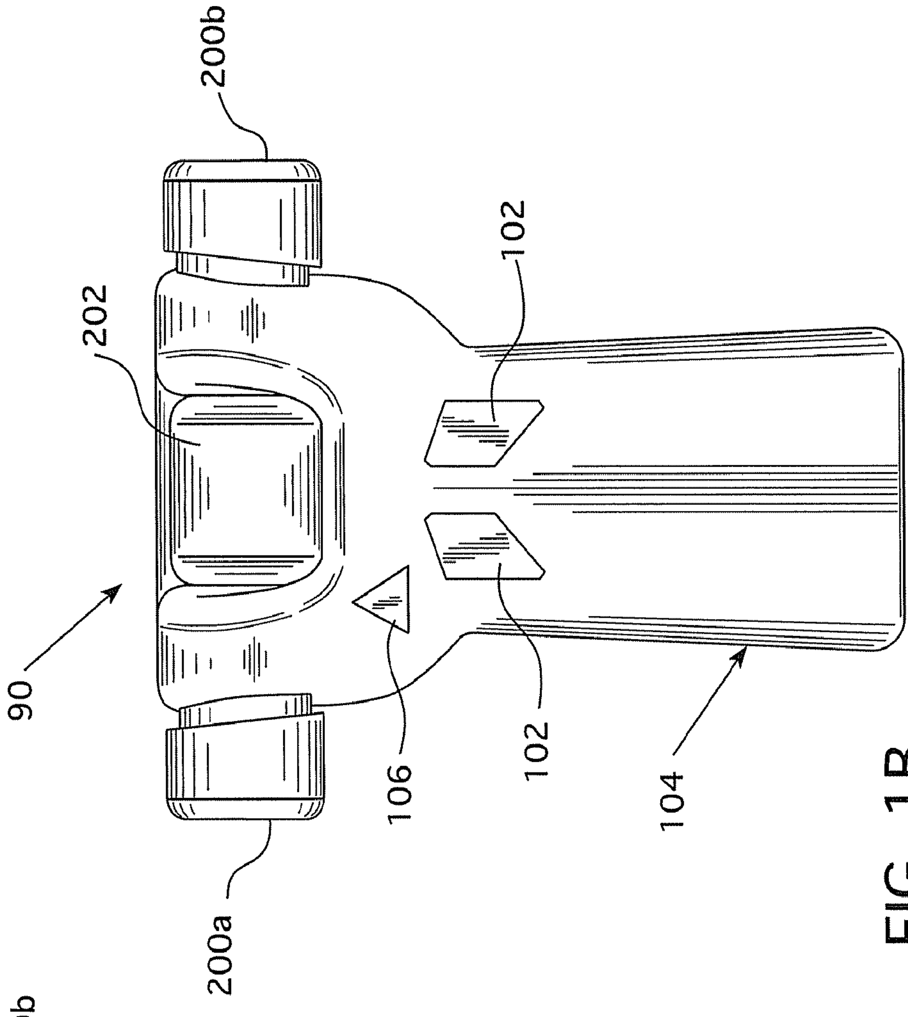

200b
202
102
90
102
106
102
104
200a

FIG. 1B

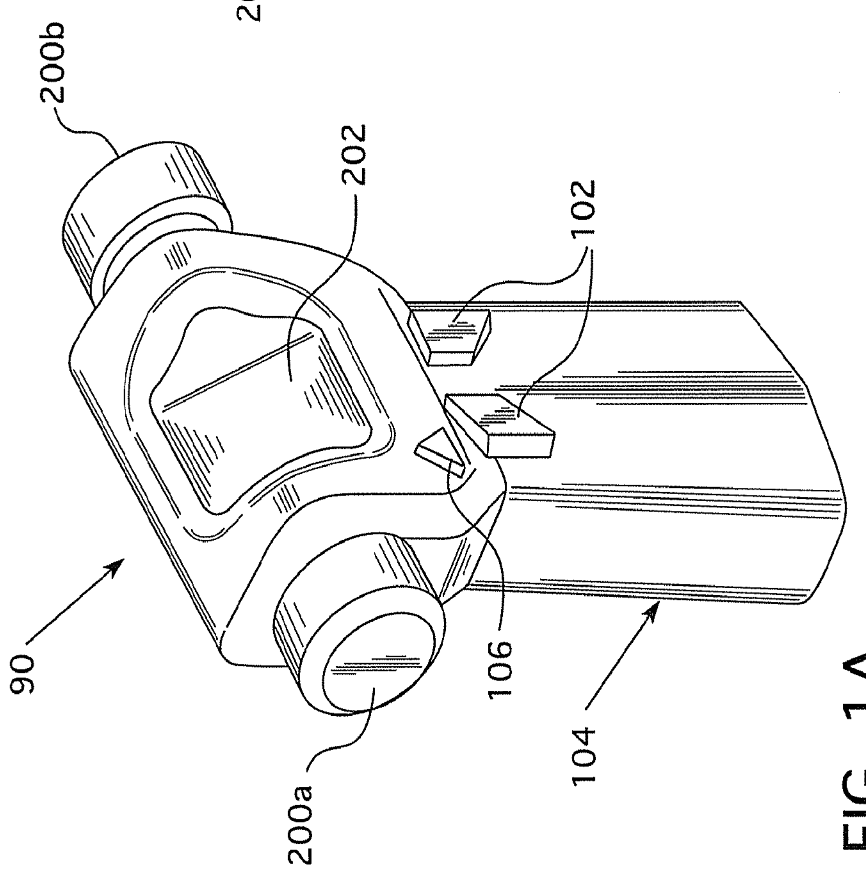

200b
202
102
90
106
104
200a

FIG. 1A

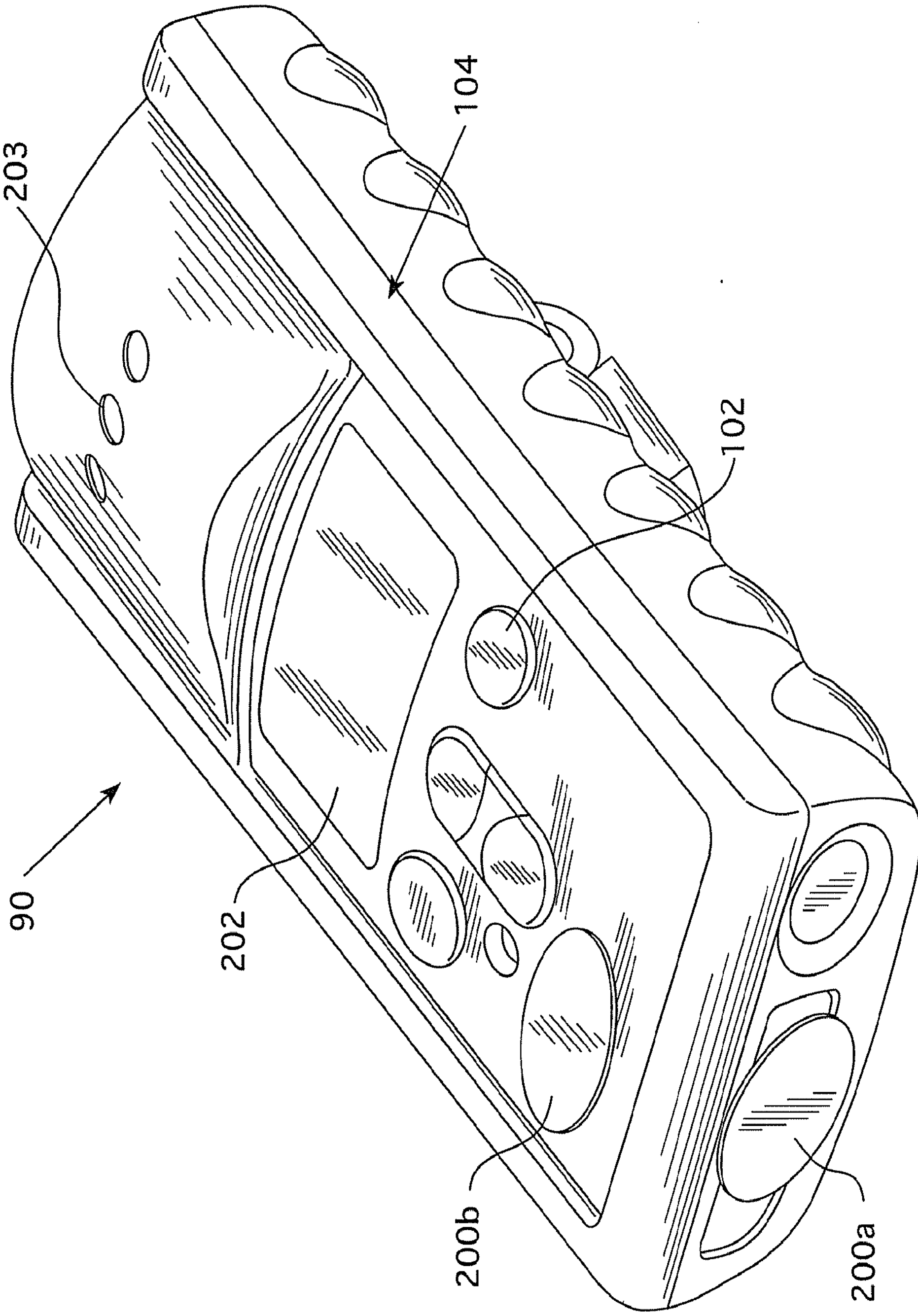


FIG. 1C

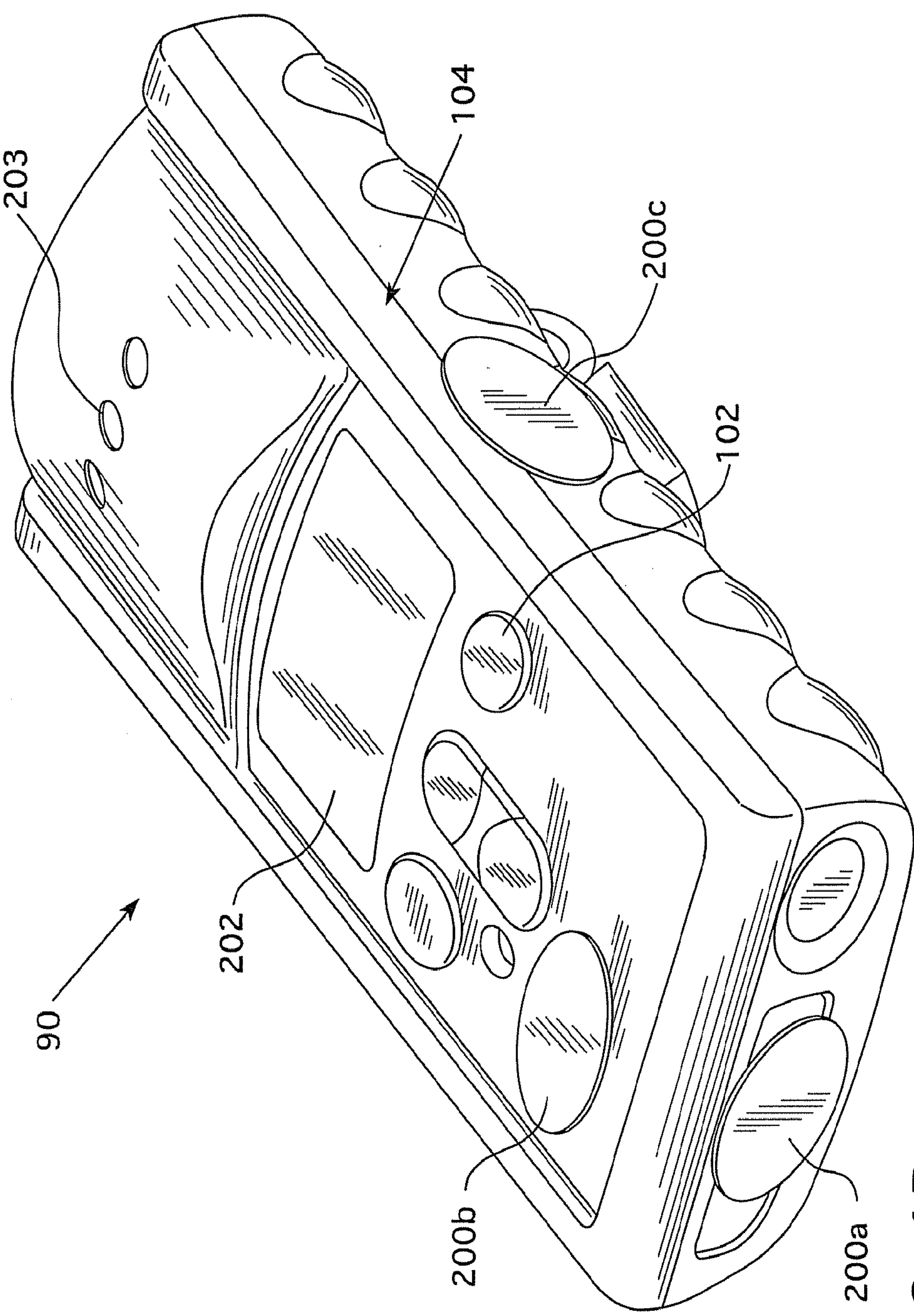


FIG. 1D

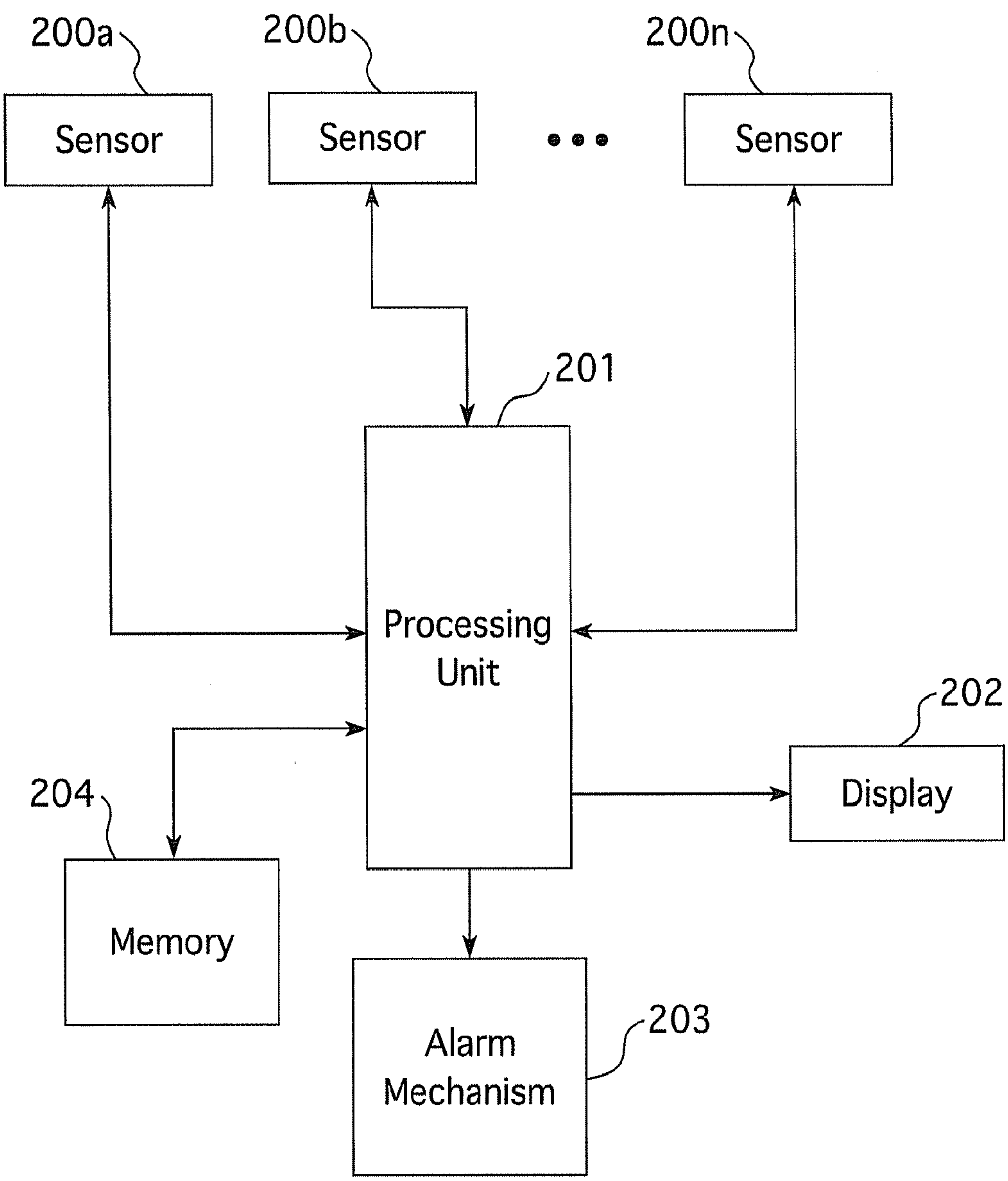

200a
200b
200n
Sensor
Sensor
Sensor
201
Processing Unit
202
Display
204
Memory
Alarm Mechanism
203

FIG. 2

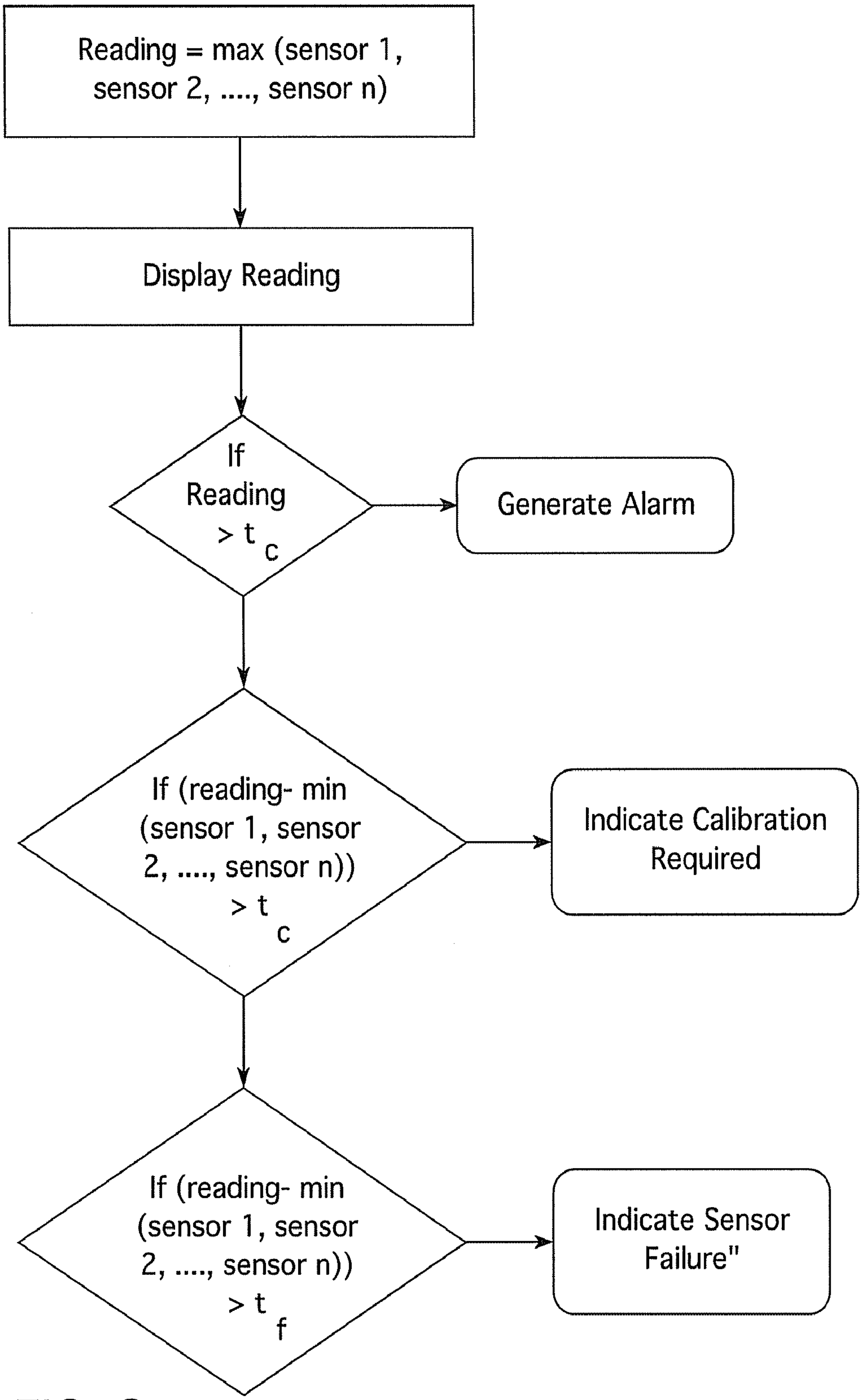

Reading = max (sensor 1, sensor 2, ..., sensor n)
Display Reading
If Reading > t c
Generate Alarm
If (reading- min (sensor 1, sensor 2, ..., sensor n)) > t c
Indicate Calibration Required
If (reading- min (sensor 1, sensor 2, ..., sensor n)) > t f
Indicate Sensor Failure"

FIG. 3

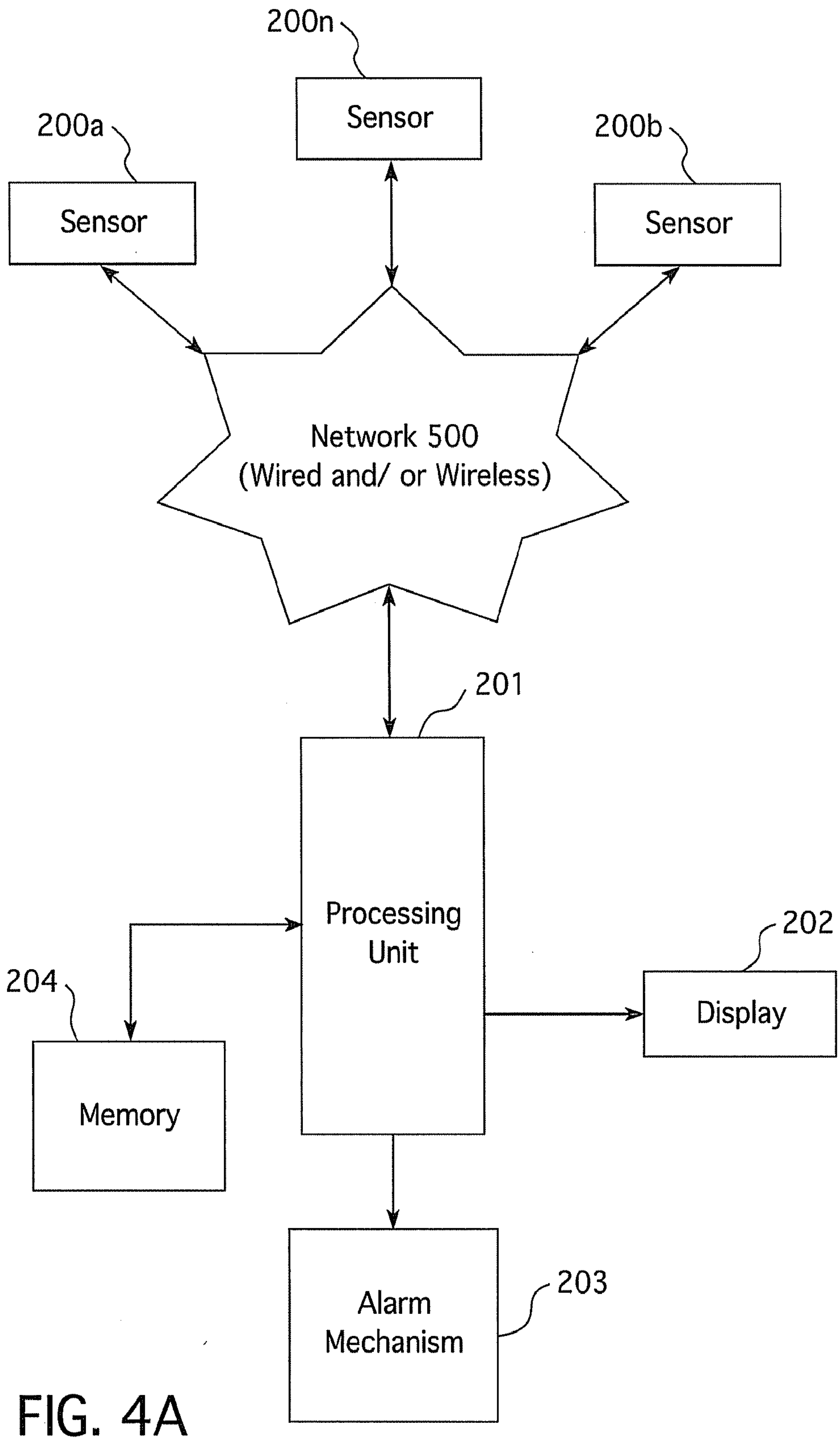
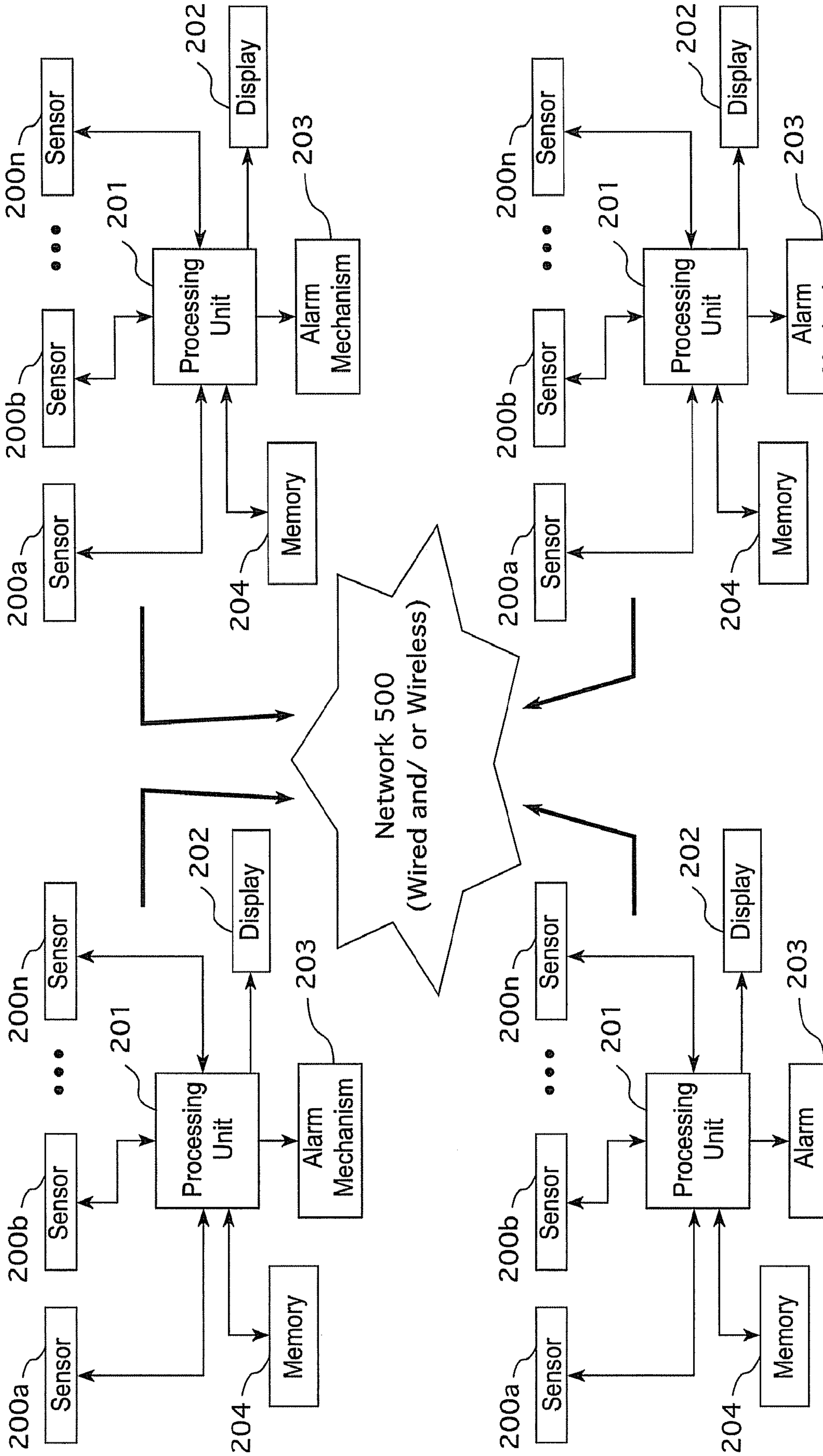

200n
Sensor
200a
Sensor
200b
Sensor
Network 500
(Wired and/ or Wireless)
201
Processing
Unit
202
Display
204
Memory
Alarm
Mechanism
203

FIG. 4A



200a
Sensor
200b
Sensor
200n
Sensor
201
Processing Unit
202
Display
203
Alarm Mechanism
204
Memory
Network 500
(Wired and/ or Wireless)

FIG. 4B

A. CLASSIFICATION OF SUBJECT MATTER

INV. G08B21/14 G08B21/16 G08B29/16 G08B29/24 G01N35/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G08B G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	ANONYMOUS: "Solaris Multigas Detector", SOLARIS MULTIGAS MANUAL,, 1 January 2005 (2005-01-01), pages 1-54, XP007919417, the whole document pages 2-1,2-2, pages 2-8,2-9 pages 2-14,2-5 pages 3-2 - pages 3-4 manual of solaris instrument, generic instrument known at time of application.; pages 4-1 - pages 4-5; figures 7-1; tables 7-1 ----- -/--	1-5, 8-13, 16-18, 20-22 23

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 September 2011	28/09/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Wright, Jonathan

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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