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(54) **CAPACITANCE SENSOR AND ROBOT SYSTEM**

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(52) **U.S. Cl.**

CPC ***G01D 5/2405*** (2013.01); ***B25J 9/1676*** (2013.01); ***G01R 27/2605*** (2013.01)

(57) **ABSTRACT**

A capacitance sensor is capable of correcting an object detection result irrespective of changes in ambient air conditions and capable of simplifying a configuration for the correction. The capacitance sensor includes a detection sensor including a detection electrode and configured to output a sensed value representing a capacitance created between the detection electrode and an object such as a human worker. The sensor includes a reference electrode provided to face the detection electrode and coupled to a reference potential via a switch. The sensor also includes a processing device that controls opening/closing of the switch to transition between a first state in which the reference electrode is opened and a second state in which the reference electrode is coupled to the reference potential.

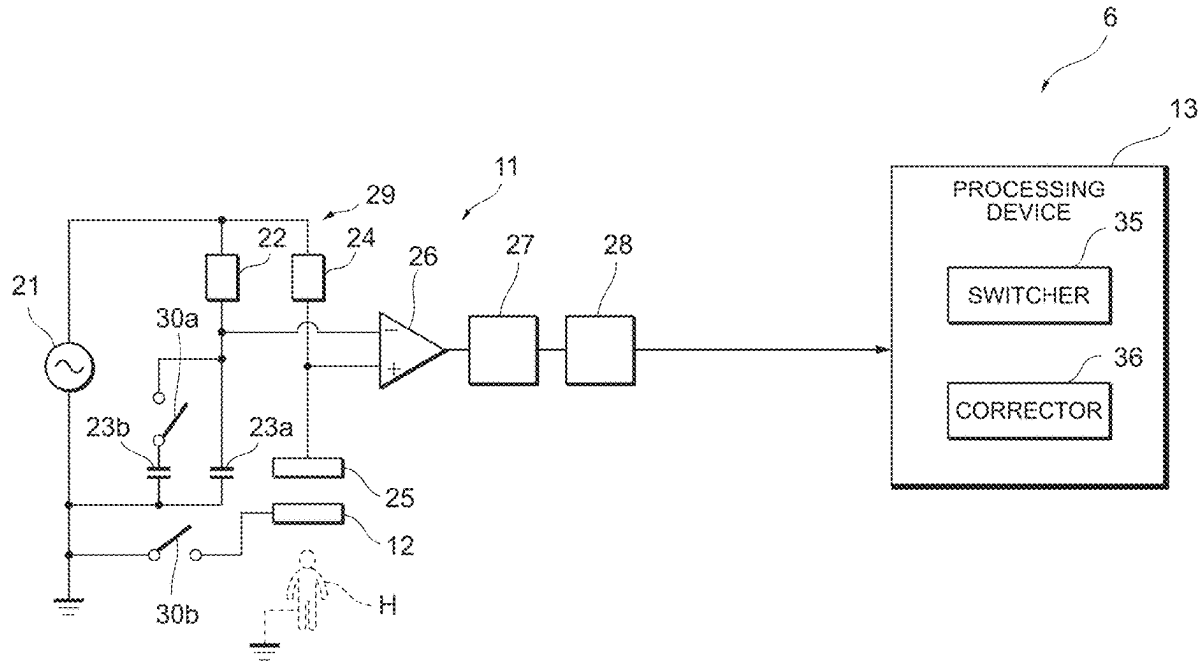


FIG. 1

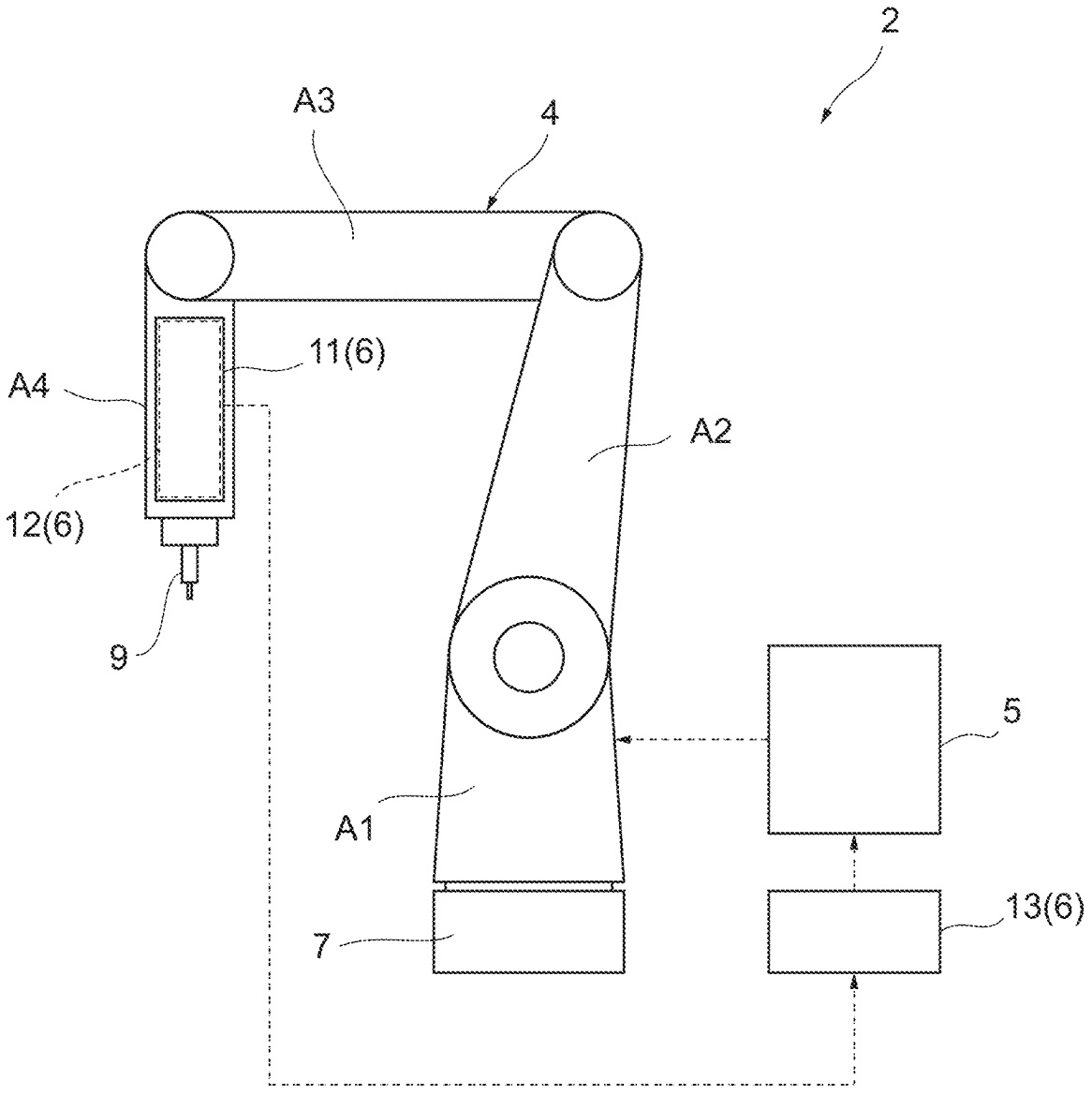


FIG. 2

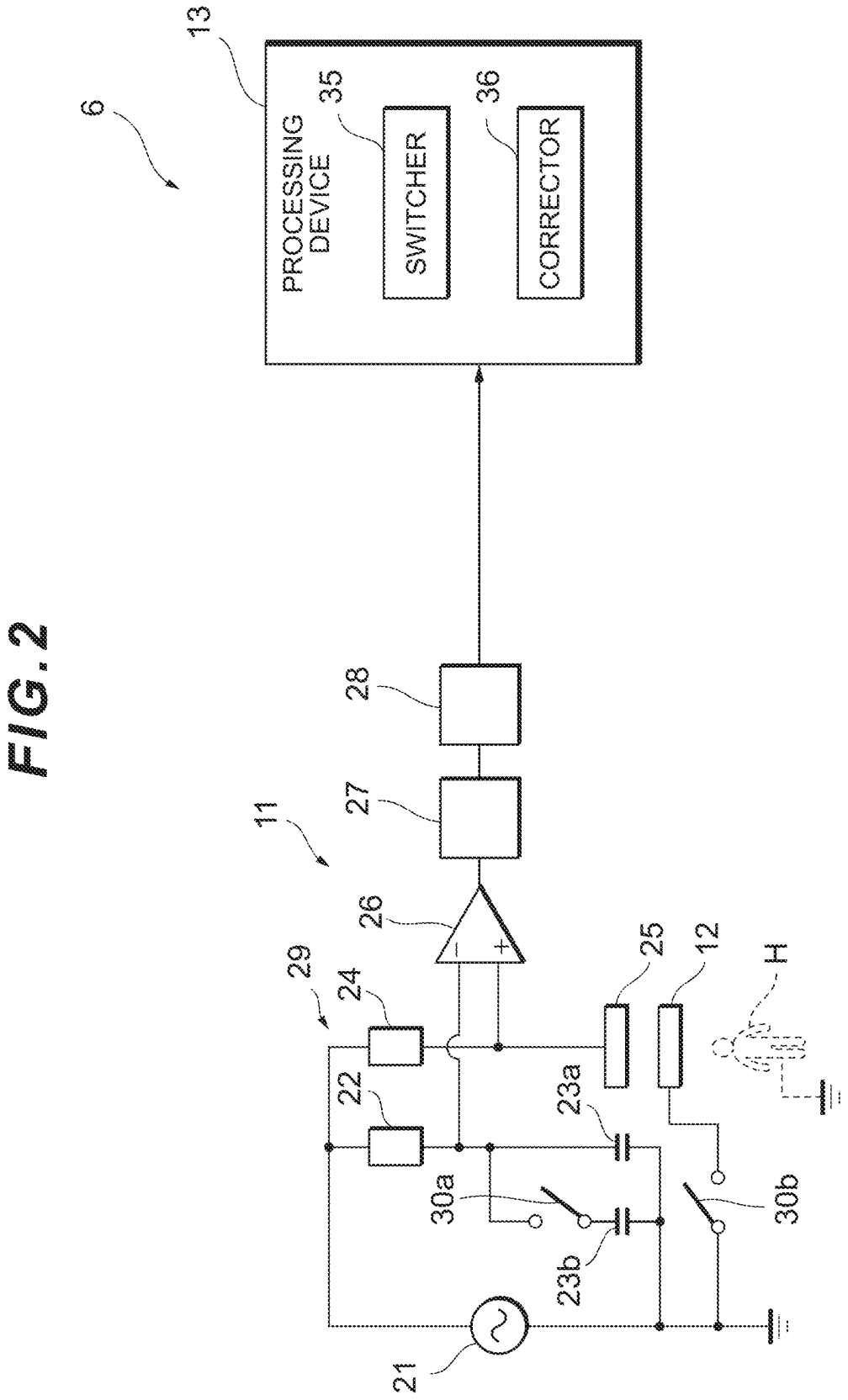

6
13
PROCESSING DEVICE
35
SWITCHER
36
CORRECTOR
11
28
27
26
29
24
22
25
12
H
23a
30a
30b
23b
21

FIG. 3

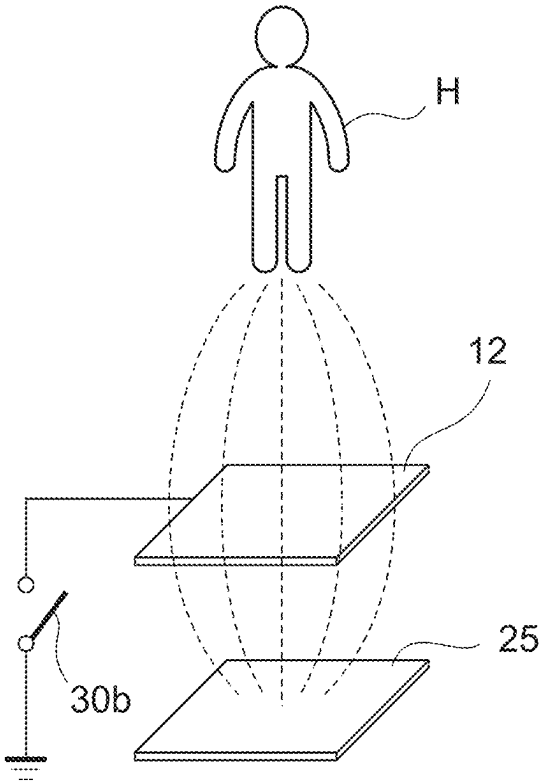


FIG. 4

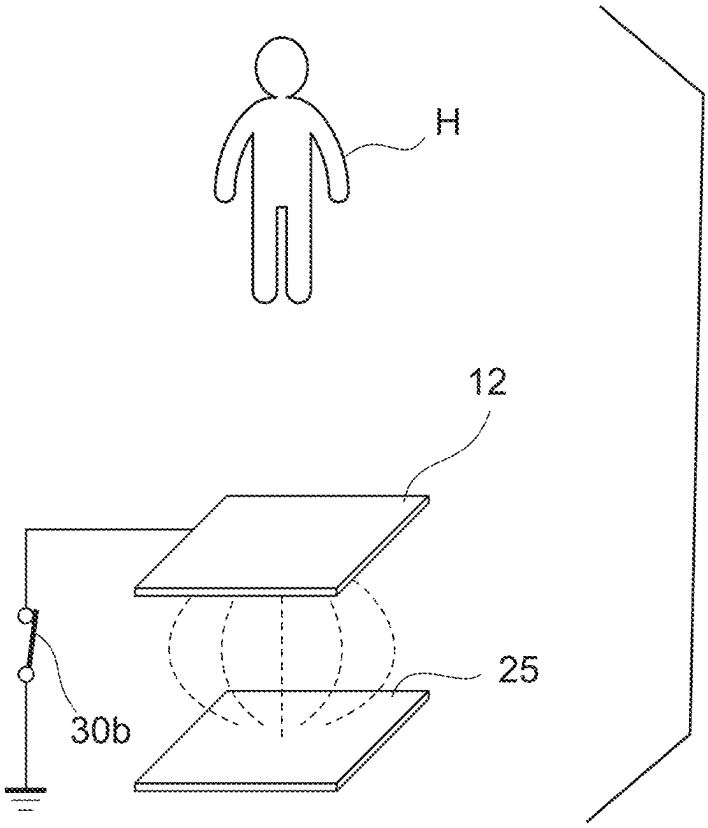


FIG. 5

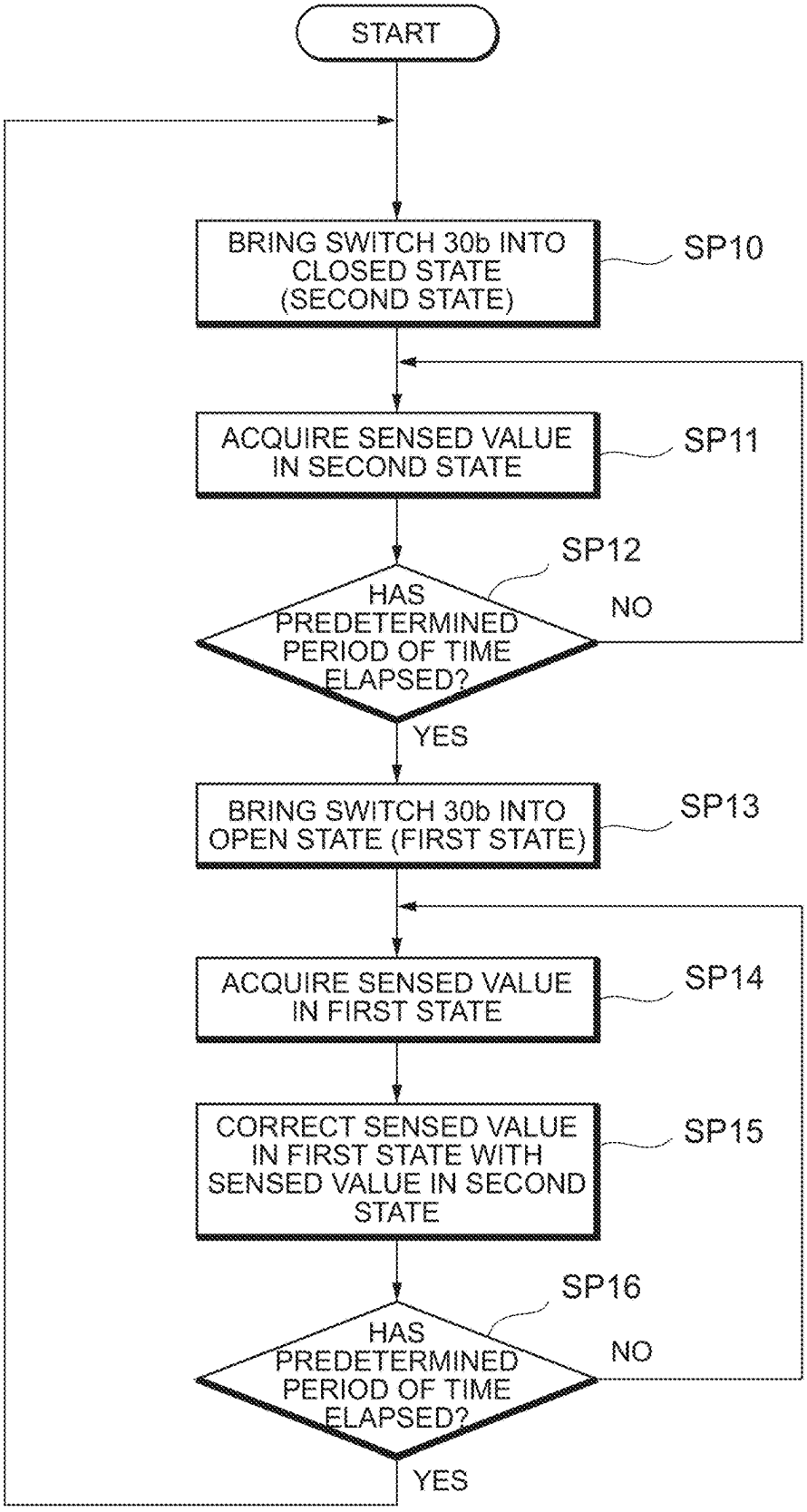

START
BRING SWITCH 30b INTO CLOSED STATE (SECOND STATE)
SP10
ACQUIRE SENSED VALUE IN SECOND STATE
SP11
SP12
HAS PREDETERMINED PERIOD OF TIME ELAPSED?
NO
YES
BRING SWITCH 30b INTO OPEN STATE (FIRST STATE)
SP13
ACQUIRE SENSED VALUE IN FIRST STATE
SP14
CORRECT SENSED VALUE IN FIRST STATE WITH SENSED VALUE IN SECOND STATE
SP15
SP16
HAS PREDETERMINED PERIOD OF TIME ELAPSED?
NO
YES

FIG. 6

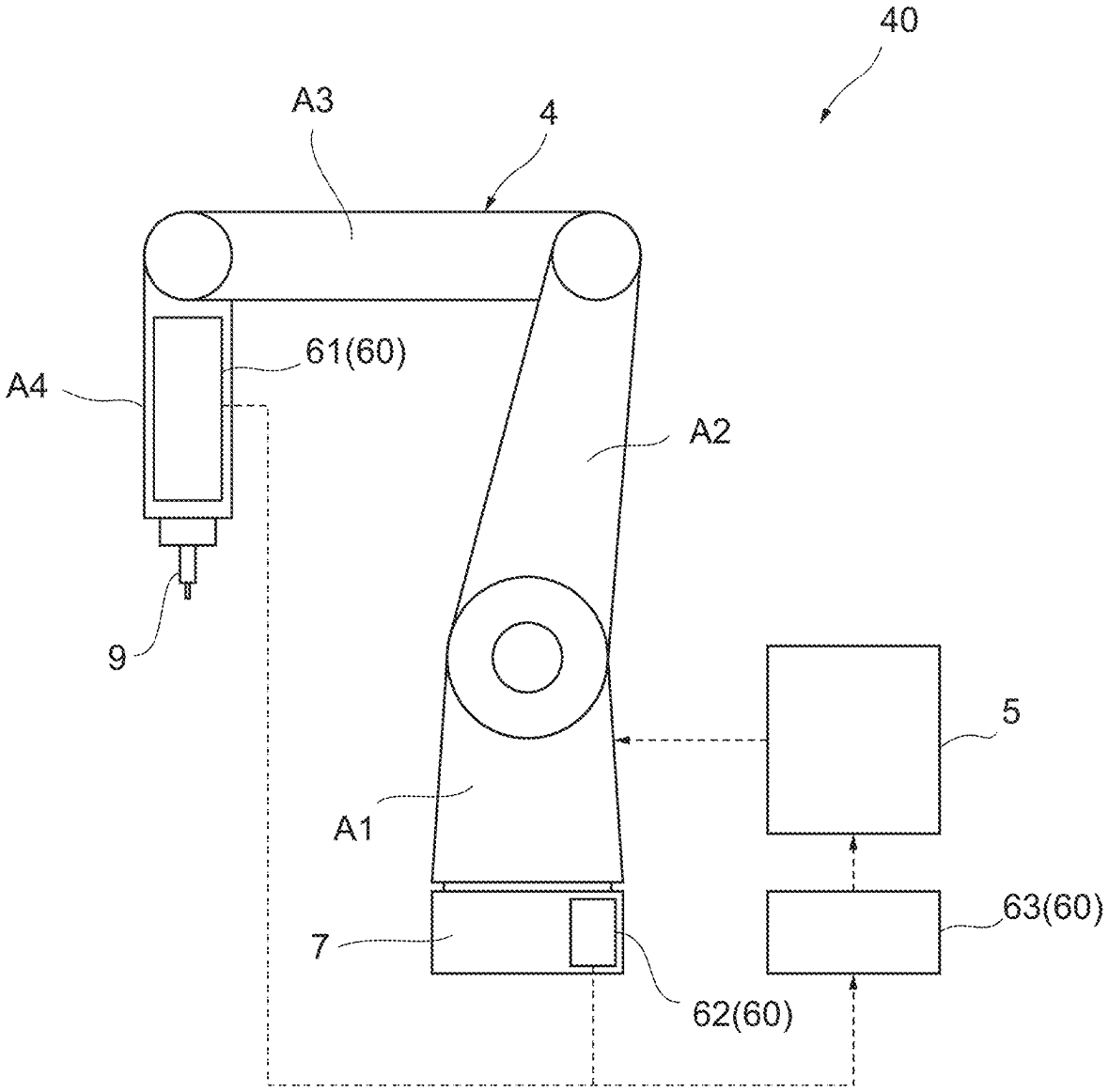


FIG. 7

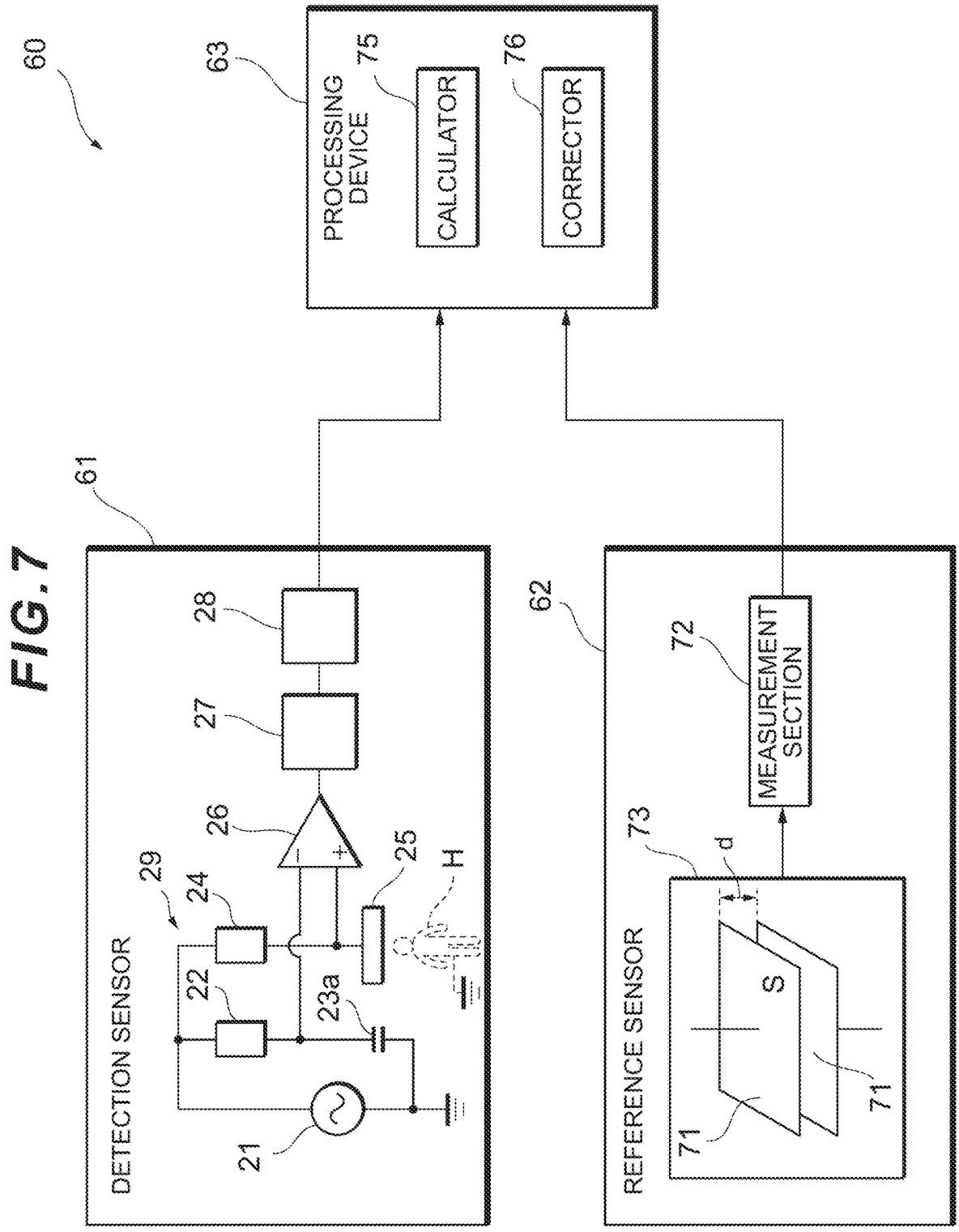
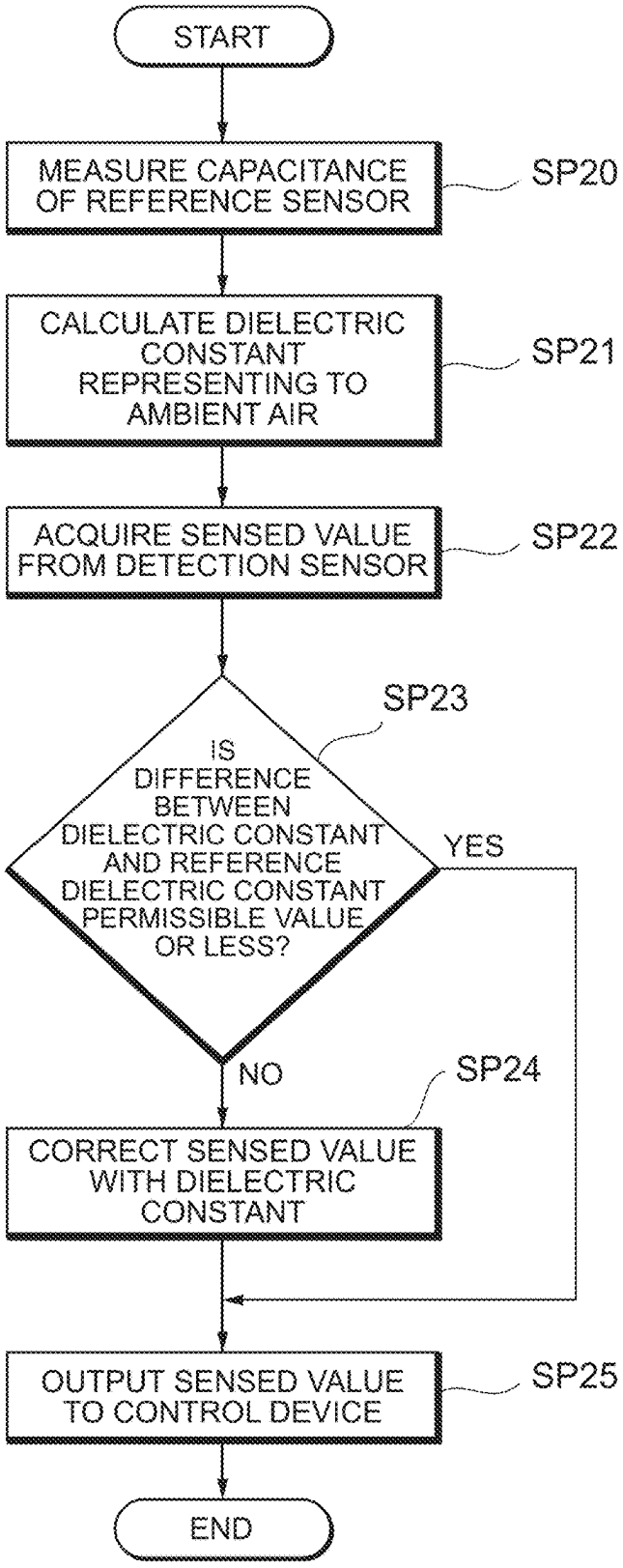

60
63
PROCESSING DEVICE
75
CALCULATOR
76
CORRECTOR
61
DETECTION SENSOR
28
27
26
25
H
29
24
22
23a
21
62
72
MEASUREMENT SECTION
73
d
REFERENCE SENSOR
S
71
71

FIG. 8


START
MEASURE CAPACITANCE OF REFERENCE SENSOR
SP20
CALCULATE DIELECTRIC CONSTANT REPRESENTING TO AMBIENT AIR
SP21
ACQUIRE SENSED VALUE FROM DETECTION SENSOR
SP22
SP23
IS DIFFERENCE BETWEEN DIELECTRIC CONSTANT AND REFERENCE DIELECTRIC CONSTANT PERMISSIBLE VALUE OR LESS?
YES
NO
SP24
CORRECT SENSED VALUE WITH DIELECTRIC CONSTANT
OUTPUT SENSED VALUE TO CONTROL DEVICE
SP25
END

CAPACITANCE SENSOR AND ROBOT SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2024-018350 filed on Feb. 9, 2024, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to a capacitance sensor and a robot system.

BACKGROUND ART

[0003] There are occasions where a human worker and a robot collaborate with each other to perform an operation on a workpiece. The robot used in such occasions is called a collaborative robot. Since the collaborative robot shares the same work space with a human worker, the human worker safety needs to be ensured. For this purpose, a capacitance sensor that is capable of detecting the presence of a proximate object is sometimes mounted on the collaborative robot.

[0004] the capacitance sensor is notorious in being prone to a sensing drift caused by ambient temperature and humidity changes. When a sensing drift occurs, it is possible that the detection accuracy is compromised. Especially when a sensing range, within which the capacitance sensor is required to operate for detection, is set long, the influence of the drift becomes non-negligible.

[0005] For example, Patent Literature 1 teaches a capacitance sensor that uses a detection electrode and a reference electrode to correct, using a signal from the reference electrode, fluctuations of a signal of the detection electrode caused by changes in the ambient state including an ambient temperature and an ambient humidity.

CITATION LIST

Patent Literature

[0006] Patent Literature 1: JP 2006-145413 A

SUMMARY OF INVENTION

[0007] However, the capacitance sensor taught in Patent Literature 1 has a problem in that a special arrangement is necessary to be set up to prevent an object from being detected by the reference electrode, whose purpose for correction of a sensing signal. The special arrangement required to be set up for Patent Literature 1 includes setting up a preventive circumstance that provides a sufficiently large space or a shield or the like around the reference electrode.

[0008] In view of the above-mentioned problems, the present invention is contemplated to provide a capacitance sensor and a robot system that are capable of correcting a sensing drift in the object detection signal, caused by changes in the ambient state, with a simplified configuration.

[0009] To solve the above-mentioned issue, a capacitance sensor according to the present invention includes a detection sensor that includes a detection electrode and is configured to output a sensed value representing a capacitance created between the detection electrode and an object. The capacitance sensor also includes a reference electrode provided to face the detection electrode and coupled to a reference potential via a switch. The sensor also includes a processing device that controls opening/closing of the switch to transition between a first state in which the reference electrode is opened and a second state in which the reference electrode is coupled to the reference potential.

[0010] The processing device of the capacitance sensor corrects the sensed value measured in the first state with the sensed value measured in the second state.

[0011] The sensed value measured in the first state is a value representing a capacitance created between the detection electrode and the object via the opened reference electrode, and the sensor value measured in the second state is a value representing a capacitance created between the detection electrode and the reference electrode coupled to the reference potential.

[0012] In another aspect of the present invention, a capacitance sensor includes a detection sensor that includes a detection electrode and is configured to output a sensed value representing a capacitance created between the detection electrode and an object. the capacitance sensor includes a reference sensor provided at a position that is different from a position of the detection electrode and including electrodes paired via ambient air. The capacitance sensor further includes a processing device that calculates a dielectric constant of the ambient air based on an output from the reference sensor and that corrects the sensed value with the dielectric constant.

[0013] The detection electrode in the detection sensor and the reference sensor are provided to different members.

[0014] The detection sensor is provided in plural, the reference sensor is provided with respect to the plural detection sensors, and the processing device uses the dielectric constant calculated from an output from the reference sensor to correct the sensed value measured by each of the plural detection sensors.

[0015] In another aspect of the present invention, a robot system includes a base, a plurality of arms provided to the base and the capacitance sensor described in the previous paragraphs. The detection electrode and the reference electrode are provided in any of the plurality of arms.

[0016] In another aspect of the present invention the robot system includes a base, a plurality of arms provided to the base and the capacitance sensor described in the previous paragraphs. The detection electrode in the detection sensor is provided in any of the plurality of arms, and the reference sensor is provided in the base.

[0017] The capacitance sensor and the robot system according to the present invention make it possible to correct a sensing drift in the object detection signal, caused by changes in the ambient state, with a simplified configuration.

BRIEF DESCRIPTION OF DRAWINGS

[0018] FIG. **1** is a schematic view illustrating an example of an overall configuration of a robot system equipped with a capacitance sensor according to a first embodiment of the present invention.

[0019] FIG. **2** is a block diagram illustrating an exemplary configuration of the capacitance sensor illustrated in FIG. **1**.

[0020] FIG. **3** is a conceptual view illustrating a first state in which the capacitance sensor illustrated in FIG. **1** operates.

[0021] FIG. **4** is a conceptual view illustrating a second state in which the capacitance sensor illustrated in FIG. **1** operates.

[0022] FIG. **5** is a flowchart showing an exemplary flow of processing steps executed by the processing device illustrated in FIG. **1**.

[0023] FIG. **6** is a schematic view illustrating an exemplary configuration of a robot system equipped with a capacitance sensor according to a second embodiment.

[0024] FIG. **7** is a block diagram illustrating an exemplary configuration of the capacitance sensor illustrated in FIG. **6**.

[0025] FIG. **8** is a flowchart showing describing an exemplary flow of processing steps executed by the processing device illustrated in FIG. **6**.

DESCRIPTION OF EMBODIMENTS

[0026] Embodiments of the present invention will be described below with reference to the accompanying drawings. Note that in each drawing, an identical constituent element is denoted using an identical reference number wherever possible for facilitating understanding, and an overlapping description is omitted when appropriate.

First Embodiment

[0027] First, a first embodiment is described.

<Overall Configuration>

[0028] FIG. **1** is a schematic view illustrating an exemplary configuration of a robot system **2** equipped with a sensor **6** that is a capacitance sensor according to the first embodiment of the present invention. The sensor **6**, i.e., a capacitance sensor, may be a proximity sensor or a displacement sensor. That is, the sensor **6** may be a sensor that detects a proximity or a sensor that detects a displacement. In the present embodiment, a description will be given using a proximity sensor as an example of the sensor **6**. Note that the sensor **6** outputs a signal that changes according to a distance to a proximate object and is referred to as a "sensed value".

[0029] The robot system **2** is, for example, an industrial robot that performs processing such as processing and conveying a workpiece. Alternatively, the robot system **2** may, for example, be a collaborative robot that shares the same work space with a human worker while performing an operation.

[0030] As illustrated in FIG. **1**, the robot system **2** mainly includes a robot **4**, a control device **5**, and the sensor **6**.

[0031] The robot **4** is a multijoint robot and includes a plurality of arms and a plurality of joints. Specifically, the robot **4** includes a base **7**, a first arm A**1**, a second arm A**2**, a third arm A**3**, and a fourth arm A**4**. Note that the number of arms to be mounted on the robot is not limited thereto. The base **7** is a base for the robot **4** and is provided on an installation surface on which the robot **4** is disposed. The base **7** is fixed to a floor surface and supports the entire robot **4**. The first arm A**1**, the second arm A**2**, the third arm A**3**, and the fourth arm A**4** are a plurality of arms mounted on the base **7**. The first arm A**1** is connected to the base **7** via a pivot axis. Additionally, the first arm A**1** is configured to pivot about the pivot axis with respect to the base **7** by means of a motor, which is not illustrated. The second arm A**2** is connected to the first arm A**1** via a pivot axis and configured to pivot about the pivot axis by means of the motor, which is not illustrated. The third arm A**3** is connected to the second arm A**2** via a pivot axis and configured to pivot about the pivot axis by means of the motor, which is not illustrated. The fourth arm A**4** is connected to the third arm A**3** via a pivot axis and configured to pivot about the pivot axis by means of the motor, which is not illustrated. A distal end of the fourth arm A**4** is provided with a tool **9**. By operating each joint, the robot **4** performs prescribed operations and operates the tool **9** to perform a prescribed process on a workpiece.

[0032] The control device **5** is an information processing device that controls operations of the robot **4**. The control device **5** includes, for example, a central processing unit (CPU), a memory, a communication device, and a storage device, and executes certain programs to implement various kinds of functions. The control device **5** directs operations of each arm of the robot **4** and the tool **9** to control the robot **4** to execute prescribed operations. The prescribed operations executed by the robot **4** under the control of the control device **5** include, for example, an operation of gripping a workpiece with the tool **9** and an operation of conveying the workpiece from a position to a different position.

[0033] Additionally, the control device **5** uses a sensed value output from the sensor **6**, to be described later in detail, to place the operation of the robot **4** on hold. Specifically, if the sensor **6** is a proximity sensor, the control device **5** compares the sensed value with a threshold value, and determines whether or not an object, such as a human worker, is present within a close proximity to the robot **4**. Upon a determination that the sensed value indicates that an object is present within a close proximity to the robot **4**, the control device **5** places the operation of the robot **4** on hold. For example, when the sensed value increases as the object approaches, the control device **5** determines that the object is present in a close proximity if the sensed value becomes the threshold value or more. For example, when the sensed value decreases as the object approaches, the control device **5** determines that the object is in a close proximity if the sensed value becomes a threshold value or less. For example, if it is found that a human worker who is working with the robot **4** has come in a close proximity to the robot **4**, the robot **4**'s operation is placed on hold even in the middle of performing a prescribed operation. Note that if the sensor **6** is the displacement sensor, the control device **5** acquires a detection result from the sensor **6** regarding a displacement and performs the process for holding the operation of the robot.

[0034] The sensor **6** is a capacitance sensor that detects an object such as a human worker. The sensor **6** mainly includes a detection sensor **11**, a reference electrode **12**, and a processing device **13**.

[0035] The detection sensor **11** is a capacitance sensor that detects the presence of an object. The detection sensor **11** is provided in the robot **4**. For example, the detection sensor **11** is provided in an arm of the robot **4**. In the present embodiment, a description will be given using the detection sensor **11** that is provided in the fourth arm A**4** for example. Note that the detection sensor **11** may be provided in another part of the robot **4** or provided in each of a plurality of arms, and locations for installation thereof are not restrictive.

[0036] Note that the description has been given using the detection sensor **11** that is provided in the arm in the above-mentioned examples. However, it is sufficient as long as at least a detection electrode **25**, described later in detail,

of the detection sensor **11** is provided in the arm, and other components of the detection sensor **11** may not be provided in the arm.

[0037] The detection sensor **11** detects the presence of an object that comes in a close proximity to the detection sensor **11** within a detection area located in a predetermined direction.

[0038] FIG. **2** is a block diagram illustrating an exemplary configuration of the sensor **6**. The detection sensor **11** includes a selectable waveform generator **21**, a resistor **22**, a capacitor **23***a*, a capacitor **23***b*, a resistor **24**, the detection electrode **25**, an operational amplifier **26**, a lock-in amplifier **27**, and an analog/digital (A/D) converter **28**. The resistor **22**, the capacitor **23***a*, the capacitor **23***b*, the resistor **24**, and the detection electrode **25** constitute a resistor-capacitor (RC) bridge circuit **29**.

[0039] The selectable waveform generator **21** generates a sinusoidal waveform voltage or a rectangular waveform voltage having a predetermined frequency with respect to a ground potential (GND potential) serving as a reference potential, which is input to the RC bridge circuit **29**. One end of the resistor **22** is electrically coupled to the selectable waveform generator **21**, and the other end thereof is electrically coupled to the capacitor **23***a*. One end of the capacitor **23***a* is electrically coupled to the resistor **22**, and the other end thereof is electrically coupled to the reference potential of the selectable waveform generator **21**. The capacitor **23***b* is electrically coupled in parallel to the capacitor **23***a* via a switch **30***a*. One end of the resistor **24** is electrically coupled to the selectable waveform generator **21**, and the other end thereof is electrically coupled to the detection electrode **25**. The resistor **22**, the capacitor **23***a*, the capacitor **23***b*, and the resistor **24** have preset values. For example, the resistors **22** and **24** may have a common resistance value.

[0040] The detection electrode **25** is electrically coupled to the resistor **24**. The detection electrode **25** is, for example, in a flat plate shape and generates an electric field. The area of the generated electric field serves as an area for detection or a detection area, and an object that enters in the detection area is detected. A shield electrode coupled to the reference potential or an active shield electrode charged at the same potential as that of the detection electrode **25** may be provided on the opposite side of the detection area of the detection electrode **25**.

[0041] Specifically, the detection electrode **25** creates a capacitance between the detection electrode **25** and an object. FIG. **2** illustrates a human worker H as an example of the object. It is assumed that the human worker H has the same potential as that of the reference potential. The detection electrode **25** creates a capacitance between the detection electrode **25** and the human worker H, which constitutes part of the RC bridge circuit **29**.

[0042] An inverting input terminal of the operational amplifier **26** is electrically coupled between the resistor **22** and the capacitor **23***a*, and a non-inverting input terminal is electrically coupled between the resistor **24** and the detection electrode **25**. An output terminal is electrically coupled to the lock-in amplifier **27**. The lock-in amplifier **27** uses a signal from the selectable waveform generator **21** as a reference signal for synchronous waveform detection. The operational amplifier **26** performs a differential amplification to amplify a difference of voltages applied to the inverting input terminal and the non-inverting input terminal. The signal differentially amplified is subjected to the synchronous waveform detection at the lock-in amplifier **27** and converted from an analog signal to a digital signal at the A/D converter **28**. The digital signal is output as a sensed value to the processing device **13**, which will be described later in detail. In this manner, the sensed value output from the detection sensor **11** turns into a value corresponding to the capacitance created according to a state (distance) between the detection electrode **25** and the object. Note that the sensed value is not limited in the form of an output from the A/D converter **28**. For example, an output from the lock-in amplifier **27** may be used as the sensed value.

[0043] As long as the output sensed value corresponds to the capacitance created at the detection electrode **25** a specific circuit configuration of the detection sensor **11** is not limited to that illustrated in FIG. **2**.

[0044] The reference electrode **12** is positioned to face the detection electrode **25**. The reference electrode **12** is positioned at a predetermined distance from the detection electrode **25** in a direction of the detection area. Hence, the reference electrode **12** is positioned at a substantially identical location to the detection electrode **25**. The reference electrode **12** is provided in the arm as is the detection electrode **25**. The reference electrode **12** is, for example, in a flat plate shape.

[0045] The reference electrode **12** is coupled to the reference potential via a switch **30***b*. The switch **30***b* is controlled open and close by the processing device **13**, which will be described later in detail. When the switch **30***b* is in an open state, the reference electrode **12** is in an open state. When the switch **30***b* is in a closed state, the reference electrode **12** is placed in connection to the reference potential (grounded state). The open state of the reference electrode **12** is referred to as a "first state", and the state in which the reference electrode **12** is coupled to the reference potential is referred to as a "second state".

[0046] The reference electrode **12** is switched between the first state and the second state. FIG. **3** is a conceptual view illustrating the first state. FIG. **4** is a conceptual view illustrating the second state. As illustrated in FIG. **3**, in the first state, an electric field generated by the detection electrode **25** passes through the reference electrode **12**. A capacitance is created between the detection electrode **25** and the human worker H depends on the distance between the detection electrode **25** and the human worker H. Since the switch **30***b* is in the open state, the reference electrode **12** is in the open state. Hence, the influence of the reference electrode **12** on the electric field generated by the detection electrode **25** is negligible. For this reason, in the first state, the sensed value output from the detection sensor **11** turns into a value corresponding to the capacitance created via the opened reference electrode **12** between the detection electrode **25** and the object such as the human worker H.

[0047] In the second state, since the switch **30***b* is in the closed state, the reference electrode **12** is coupled to the reference potential as illustrated in FIG. **4**. Thus, the electric field generated by the detection electrode **25** does not pass through the reference electrode **12**, and thus a capacitance is created only between the detection electrode **25** and the reference electrode **12**. For this reason, in the second state, the sensed value output from the detection sensor **11** turns into a value corresponding to a capacitance created between the detection electrode **25** and the reference electrode **12** coupled to the reference potential. The reference electrode **12** preferably has a size (area) equal to the size of the

detection electrode **25** or a size (area) larger than the size of the detection electrode **25**. The reference electrode **12** so configured can suppress the electric field generated by the detection electrode **25** from leaking from the reference electrode **12**, and can suppress the influence of the object such as the human worker H.

[0048] In the first state and the second state, air capacitances are created. In the first state and the second state, the air capacitances are created under the equal ambient air conditions. In a parallel-plate capacitor, the ambient air conditions affect its dielectric constant ε and change the capacitance value thereof. Specifically, the dielectric constant ε is affected and changed by a temperature and a humidity (a relative humidity or an absolute humidity). The dielectric constant ε tends to be affected especially by the absolute humidity. The change in the dielectric constant ε becomes a cause for a sending drift of the sensed value. To address this, by switching the reference electrode **12** to the second state, it becomes possible to obtain the sensed value under the same ambient air conditions as in the first state in which the influence of the object such as the human worker H is suppressed. That is, the sensed value measured in the second state represents a value indicating a drift component of the sensed value dependent on the ambient air conditions.

[0049] Returning to FIG. **2**, the processing device **13** includes an information processing device that controls operations in the first state and the second state. The processing device **13** includes, for example, a CPU, a memory, a communication device, and a storage device, and executes prestored programs to implement various kinds of functions.

[0050] The processing device **13** includes a switcher **35** and a corrector **36**. The switcher **35** and the corrector **36** are illustrated in FIG. **2** as functional blocks included in the processing device **13**.

[0051] The switcher **35** performs switching between the first state and the second state of the reference electrode **12**. The switcher **35** opens and closes the switch **30***b* to perform the switching. Specifically, the switcher **35** brings the switch **30***b* into the open state to place the reference electrode **12** into the first state. Additionally, the switcher **35** places the switch **30***b* into the closed state to bring the reference electrode **12** into the second state.

[0052] Furthermore, the switcher **35** opens and closes the switch **30***a* according to the switching control. Specifically, by placing the reference electrode **12** into the first state, the switcher **35** brings the switch **30***a* into the open state. By placing the reference electrode **12** into the second state, the switcher **35** brings the switch **30***a* into the closed state. That is, in the second state, the capacitor **23***a* and the capacitor **23***b* are electrically coupled to each other in parallel to exhibit a combined capacitance. This is because the value of a capacitance created in the detection electrode **25** in the second state is larger than that created in the first state.

[0053] The switcher **35**, for example, repeats switching between the first state and the second state at a predetermined control interval. It is preferable that each period of time for the first state is set longer than a respective period of time for the second state. A switching timing performed by the switcher **35** is not limited to the above-mentioned timing. For example, the switcher **35** may place the reference electrode **12** in the first state while the robot **4** is in operation and may place the reference electrode **12** in the second state while the robot **4** is not in operation.

[0054] The corrector **36** corrects a sensed value measured in the first state using the sensed value measured in the second state. The corrector **36** calculates a difference between the sensed value measured in the first state and the sensed value measured in the second state.

[0055] Specifically, the corrector **36** subtracts the sensed value measured in the second state from the sensed value measured in the first state. That is, the corrector **36** suppresses a drift component of the sensed value measured in the first state that changes according to the ambient air conditions. For example, the corrector **36** subtracts the sensed value most recently measured in the second state from the sensed value measured in the first state to thereby suppress the drift component. The sensed value measured in the second state for subtraction may be a single sensed value measured in the second state, or may be an average value of a plurality of sensed values measured in the second state.

[0056] The correction process performed in this manner can suppress the influence of the volatile ambient air conditions (drift component), such as a temperature and a humidity. Since the respective sensed values measured in the first state and the second state are output from the identical circuit as illustrated in FIG. **2**, it is also possible to suppress the influence of a temperature drift caused within the circuit itself. Since the detection electrode **25** is used commonly in the first state and the second state, it is possible to further suppress the influence of a change caused by the states of the electrode. The states of the electrode include, for example, dirt and condensation on the surface of the detection electrode **25**.

[0057] The corrector **36** corrects the sensed value measured in the first state, and outputs the corrected sensed value to the control device **5**.

[0058] In the above embodiment, the description has been given in which the correction operation is performed by obtaining of the difference between the sensed value measured in the first state and the sensed value measured in the second state. However, as long as the sensed value measured in the first state is corrected, using the sensor value measured in the second state, to suppress the drift component caused by the ambient air conditions, a correction method is not limited to the above-described method. For example, a correction method may be performed in which the sensed value measured in the second state is multiplied by a constant ratio and subtracted from the sensed value measured in the first state.

<Flow of Processing>

[0059] FIG. **5** is a flowchart showing an exemplary flow of correction processing steps according to the present embodiment. Each of the following processing steps is executed, for example, when the operation of the robot **4** is initiated. The order or contents of the following steps can be changed when appropriate.

(Step SP**10**)

[0060] The switcher **35** places the switch **30***b* in the closed state to bring the reference electrode **12** into the second state. The process then proceeds to processing in step SP**11**.

(Step SP**11**)

[0061] The corrector **36** acquires the sensed value measured in the second state. The process then proceeds to the processing step in step SP**12**.

(Step SP**12**)

[0062] The switcher **35** determines whether or not a predetermined period of time has elapsed since the switch **30***b* is placed in the closed state. In response to a determination that the predetermined period of time has not elapsed, the process returns to step SP**11**, and the step is executed again. In response to a determination that the predetermined period of time has elapsed, the process then proceeds to step SP**13**.

(Step SP**13**)

[0063] The switcher **35** places the switch **30***b* in the open state to bring the reference electrode **12** into the first state. The process then proceeds to step SP**14**.

(Step SP**14**)

[0064] The corrector **36** acquires the sensed value measured in the first state. The process then proceeds to step SP**15**.

(Step SP**15**)

[0065] The corrector **36** corrects the sensed value measured in the first state with the sensed value measured in the second state and outputs the corrected sensed value measured in the first state to the control device **5**. Specifically, the corrector **36** subtracts the sensed value measured in the second state from the sensed value measured in the first state. For example, the corrector **36** subtracts the sensed value measured in the second state, which is acquired in step SP**11**, which is executed immediately before the execution of step SP**15**, from the sensed value measured in the first state.

(Step SP**16**)

[0066] The switcher **35** determines whether or not a predetermined period of time has elapsed since the switching of the switch **30***b* into the open state. In response to a determination that the predetermined period of time has not elapsed, the process returns to step SP**14**, and the step is executed again. In response to a determination that the predetermined period of time has elapsed, the process returns to step SP**10**, and the step is executed again.

[0067] In this manner, the sensed value regarding the object detection is corrected. The control device **5** receives the sensed value, determines, for example, a proximate presence of the object, and uses the determination to control the robot **4**.

<Actions and Effects>

[0068] As described above, in the present embodiment, the reference electrode **12** is provided to face the detection electrode **25**, and switching is performed between the first state in which the reference electrode **12** is opened and the second state in which the reference electrode **12** is coupled to the reference potential. With this configuration, it is possible to obtain the sensed value representing an object and the sensed value representing the drift component that changes according to the ambient air conditions. As a result, it is possible to correct the sensed value representing the object. since the reference electrode **12** for correction is provided to face the detection electrode **25**, the need for, for example, a special arrangement is eliminated, such as installing a shield to prevent the object from being detected, and thus the configuration for correction can be simplified. That is, it is possible to correct the result of object detection that may a change depending on the ambient air conditions, and it is also possible to simplify the configuration for correction.

[0069] It becomes possible to correct the sensed value measured in the first state with the sensed value measured in the second state to thereby suppress the drift component of the sensed value measured in the first state.

[0070] Although the reference electrode **12** is provided to face the detection electrode **25**, it is possible to obtain the sensed value representing to an object near the detection electrode **25** when the reference electrode **12** is opened. In the second state, it is possible to obtain the sensor value representing the drift component.

[0071] Furthermore, by providing the detection electrode **25** in the arm of the robot **4**, it becomes possible to detect an object with respect to the arm.

Second Embodiment

[0072] A second embodiment will be described below.

[0073] In the second embodiment, a description will be given in which a sensed value is corrected using a reference sensor **62**. Descriptions of constituents in the second embodiment similar to those described in the first embodiment are omitted. The second embodiment may be combined with the first embodiment.

<Overall Configuration>

[0074] FIG. **6** is a schematic view illustrating an exemplary configuration of a robot system **40** equipped with a sensor **60** as a capacitance sensor according to the present embodiment. The sensor **60** functions as a capacitance sensor and may include a proximity sensor or a displacement sensor. That is, the sensor **60** may be a sensor that detects a proximity or a sensor that detects a displacement. In the present embodiment, a description will be given using the sensor **60** that includes a proximity sensor for example.

[0075] The robot system **40** is an industrial robot, and is, for example, a collaborative robot, similar to the robot system **2**.

[0076] As illustrated in FIG. **6**, the robot system **40** mainly includes the robot **4**, the control device **5**, and the sensor **60**.

[0077] The sensor **60** is a capacitance sensor that detects an object such as a human worker with respect to the robot **4**. The sensor **60** mainly includes a detection sensor **61**, a reference sensor **62**, and a processing device **63**.

[0078] The detection sensor **61** is a capacitance sensor that detects, similar to the detection sensor **11**, an object presents in a detection area in a predetermined direction. The detection sensor **61** is provided in an arm of the robot **4** (for example, the fourth arm A**4**). The detection sensor **61** may be provided in another part of the robot **4** or provided in each of a plurality of arms. It is sufficient as long as at least the detection electrode **25** of the detection sensor **61** is provided in the arm, similar to the detection sensor **11**. The detection electrode **25** will be described later in detail.

[0079] FIG. **7** is a block diagram illustrating an exemplary configuration of the sensor **60**. The detection sensor **61** includes the selectable waveform generator **21**, the resistor **22**, the capacitor **23***a*, the resistor **24**, the detection electrode **25**, the operational amplifier **26**, the lock-in amplifier **27**, and the A/D converter **28**, similar to the detection sensor **11**. The

detection electrode **25** forms part of the RC bridge circuit **29**. As long as the sensed value corresponding to the capacitance created by the detection electrode **25** is output, the specific circuit configuration of the detection sensor **61** is not limited to that illustrated in FIG. **7**.

[0080] The detection electrode **25** creates a capacitance between the detection electrode **25** and an object such as the human worker H. The sensed value output from the detection sensor **61** turns into a value corresponding to the value of the capacitance created between the detection electrode **25** and the object. The sensed value is output to the processing device **63**.

[0081] Returning to FIG. **6**, the reference sensor **62** and the detection sensor **61** are positioned at different locations from each other. Specifically, the detection sensor **61** (or the detection electrode **25** more accurately) and the reference sensor **62** are provided to different members. In the present embodiment, the detection sensor **61** is provided in the fourth arm A**4**, and the reference sensor **62** is provided in the base **7**. For example, the detection sensor **61** is provided in a movable member, and the reference sensor **62** is provided in a fixed (immovable) member. An installation position of the reference sensor **62** is not restrictive.

[0082] The reference sensor **62** is preferably positioned not to interfere with the function of the detection sensor **61**. That is, the reference sensor **62** is positioned separate from the detection sensor **61** by a predetermined distance or more. Specifically, while the robot **4** is operating, there are chances that the detection sensor **61** (the detection electrode **25** in particular) and the reference sensor **62** come close to each other. The reference sensor **62** is provided at a sufficient distance from the detection sensor **61** so that it is separated from the detection sensor **61** by at least the predetermined distance or more even when the detection sensor **61** and the reference sensor **62** come closest to each other. In this manner, while the robot **4** is operating, at least the predetermined distance between the detection sensor **61** and the reference sensor **62** (measured, for example, linearly) is secured. The predetermined distance is set more than or equal to the range in which the influence of an electric field generated by one of the detection sensor **61** and the reference sensor **62** with respect to the other is permissible. By positioning the detection sensor **61** and the reference sensor **62** separate from each other by the predetermined distance or more, an accidental contact between the detection sensor **61** and the reference sensor **62** can be prevented. The detection sensor **61** and the reference sensor **62** may be positioned to interfere with each other if an appropriate positioning restrictions or the like are imposed.

[0083] As illustrated in FIG. **7**, the reference sensor **62** includes a pair of electrodes **71** and a measurement section **72**.

[0084] Two electrodes **71** are provided in pair and form a capacitor **73** in a parallel plate shape. There is air between the electrodes **71** in communication with the air (ambient air surrounding the robot **4**). It is more preferable that the air between the electrodes **71** is under the ambient air conditions equal (or close) to the ambient air conditions of the air surrounding the detection sensor **61**. An electrode area S of each electrode **71** and a distance d between the electrodes are set in advance at fixed values (design values).

[0085] For example, the electrodes **71** may be configured with a specification (for example, an electrode area) that is identical to the specification for the detection electrode **25** of the detection sensor **61** or may be configured to have an area that is smaller than that of the detection electrode **25** of the detection sensor **61**. For example, by configuring the electrodes **71** of the reference sensor **62** to have the electrode area smaller than that of the detection electrode **25** of the detection sensor **61**, it becomes possible to downsize the entire sensor **60**.

[0086] The measurement section **72** measures a capacitance Cs in the capacitor **73** formed of the electrodes **71**. For example, the measurement section **72** flows a known current Is in the electrodes **71** and measures a time Tc until the voltage between the electrodes **71** reaches a reference voltage Vc. The measurement section **72** then calculates an accumulated charge Qc from the current Is and the time Tc and divides the calculated charge Qc by the reference voltage Vc to obtain the capacitance Cs. That is, the measurement section **72** calculates the capacitance Cs based on a relationship of $Cs=(Is\times Tc)/Vc$. As long as the capacitance Cs created by the electrodes **71** is calculated, a calculation method is not limited to the above-mentioned method. Information regarding the calculated capacitance Cs is output to the processing device **63**, which will be described below.

[0087] The processing device **63** is an information processing device that corrects detection result information from the detection sensor **61** using reference information from the reference sensor **62**. The detection result information represents the sensed value and the reference information represents the dielectric constant ε. The processing device **63** includes, for example, a CPU, a memory, a communication device, and a storage device, and executes stored programs to implement various kinds of functions.

[0088] The processing device **63** includes a calculator **75** and a corrector **76**. The calculator **75** and the corrector **76** are illustrated in FIG. **7** as functional blocks included in the processing device **63**.

[0089] The calculator **75** calculates the dielectric constant ε from the capacitance Cs in the reference sensor **62**. Specifically, the calculator **75** acquires the capacitance Cs calculated by the measurement section **72**. The calculator **75** then calculates the dielectric constant ε based on the capacitance Cs and preset specification information regarding the reference sensor **62**. The specification information regarding the reference sensor **62** includes the electrode area S of the electrodes **71** and the distance between electrodes d. The calculator **75** multiplies a ratio of the distance between electrodes d to the electrode area S (d/S) by the capacitance Cs to calculate the dielectric constant ε. That is, the calculator **75** calculates the dielectric constant ε from $\varepsilon=Cs\times(d/S)$. A method of calculating the dielectric constant ε is not limited to the above-mentioned method.

[0090] The dielectric constant ε fluctuates according to the ambient air conditions including a temperature and a humidity. By calculating the dielectric constant ε based on the reference sensor **62** having a known configuration, it becomes possible to obtain the dielectric constant ε corresponding to the ambient air surrounding the robot **4**. The calculator **75** outputs the calculated dielectric constant ε to the corrector **76**.

[0091] The corrector **76** corrects the sensed value measured by the detection sensor **61** based on the dielectric constant ε calculated by the calculator **75**. Specifically, taking the dielectric constant ε calculated under reference ambient air conditions as a reference dielectric constant ε**0**,

the corrector **76** corrects the sensed value based on a difference between the dielectric constant ε and the reference dielectric constant ε**0**. For example, the difference between the dielectric constant ε and the reference dielectric constant ε**0**, and a correction value for the sensed value are correlated with each other as correction data in a form of table data or in a form a relational equation. The corrector **76** then performs an addition, a subtraction or other arithmetic operations on the sensed value using the correction value derived in relation to a difference value calculated as explained above. Alternatively, a preset conversion equation may be prepared in advance that converts the sensed value into the corrected sensed value according to the difference between the dielectric constant ε and the reference dielectric constant ε**0**, and the corrector **76** may use the conversion equation to perform the correction.

[0092] By performing the correction in this manner, it becomes possible to obtain the sensed value in which the influence of the ambient air conditions, such as a temperature and a humidity, is suppressed. The sensor value is output to the control device **5**.

[0093] FIG. **6** illustrates an example in which the detection sensor **61** is provided in the fourth arm A**4**, but the detection sensors **61** may be provided at a respective plurality of positions including the fourth arm A**4**, the third arm A**3**, and the like. That is, one reference sensor **62** may be provided with respect to the plurality of detection sensors **61**. In such a configuration, the processing device **63** uses the dielectric constant ε calculated from the sensed value from the reference sensor **62** to correct respective sensed values measured from the plurality of detection sensors **61**. Alternatively, a plurality of reference sensors **62** may be provided with respect to one detection sensor **61**.

<Flow of Processing>

[0094] FIG. **8** is a flowchart describing an exemplary flow of correction processing steps according to the present embodiment. Each processing step in the following steps is, for example, repeatedly executed at a predetermined control interval. The order or contents of the following steps can be changed when appropriate.

(Step SP**20**)

[0095] The measurement section **72** measures the capacitance Cs of the reference sensor **62**. The process then proceeds to step SP**21**.

(Step SP**21**)

[0096] The calculator **75** calculates the dielectric constant ε representing the ambient air of the robot **4** based on the capacitance Cs. Specifically, the calculator **75** uses the capacitance Cs, and known information on the electrode area S and the distance between electrodes d to calculate the dielectric constant ε from ε=Cs×(d/S). The process then proceeds to step SP**22**.

(Step SP**22**)

[0097] The corrector **76** acquires the sensed value measured by the detection sensor **61**. The process then proceeds to step SP**23**.

(Step SP**23**)

[0098] The corrector **76** determines whether or not the difference between the dielectric constant ε and the reference dielectric constant ε**0** is a permissible value or less. In response to a determination that the difference between the dielectric constant ε and the reference dielectric constant ε**0** is equal to or less than the permissible value, the process proceeds to step SP**25**. In response to a determination that the difference between the dielectric constant ε and the reference dielectric constant ε**0** is not equal to or less than the permissible value, the process proceeds to step SP**24**.

(Step SP**24**)

[0099] The corrector **76** corrects the sensed value with the dielectric constant ε. The process then proceeds to step SP**25**.

(Step SP**25**)

[0100] The corrector **76** outputs the sensed value to the control device **5**. In response to a determination that the difference between the dielectric constant ε and the reference dielectric constant ε**0** is equal to or less than the permissible value, the sensed value is output uncorrected, and in response to a determination that the difference between the dielectric constant ε and the reference dielectric constant ε**0** is not equal to or less than the permissible value, a corrected sensed value is output.

[0101] In this manner, the sensed value of object detection is corrected. The control device **5** receives the sensed value, determines, for example, a proximity of the object, and uses the determination to control of the robot **4**.

Advantageous Effects

[0102] As described above, in the present embodiment, the sensor **60** functioning as a capacitance sensor uses the reference sensor **62** including the electrodes **71** paired to have the ambient air between them to correct the sensed value from the detection sensor **61**. Hence, although there is a possibility that the sensed value may drift depending on the ambient air conditions, it is possible to correct the drifted sensed value according to the air characteristics of the ambient air conditions. Since the object detection is performed based on the sensed value, it becomes possible to increase the accuracy of object detection. Furthermore, since the reference sensor **62** includes the capacitor **73** including the paired electrodes **71**, the need is eliminated for special arrangements for installing a shield or the like to prevent the object from being detected and thus the configuration for correction can be simplified. That is, it is possible to correct an object detection result even with changes in the ambient air conditions, and it is also possible to simplify the configuration for correction. Although the ambient air conditions such as a temperature and a humidity can be directly measured, the measurement accuracy tends to be low. However, the above-mentioned correction method makes it possible to perform correction with high accuracy without directly measuring the temperature and the humidity.

[0103] By providing the detection electrode **25** in the detection sensor **61** and the reference sensor **62** as separate members (components), the interference between the detection sensor **61** and the reference sensor **62** can be suppressed.

[0104] Additionally, it is possible to use one reference sensor **62** to correct respective sensed values measured by the plurality of detection sensors **61**. This eliminates the need for providing the reference sensors **62**, respectively, for the detection sensors **61**, resulting in downsizing the sensor **60**.

[0105] If a configuration is taken in which the detection sensor **61** is provided in the arm, and the reference sensor **62** is provided in the base **7**, the interference between the detection sensor **61** and the reference sensor **62** can be suppressed. Further, a problem can be avoided in that if the reference sensor **62** is provided in the arm, a region in which the object cannot be detected may be created.

Modifications

[0106] The present invention is not limited to the above-mentioned embodiments. That is, the above-described embodiments even modified with a design change considered routine by one of ordinary skill in the art still fall within the scope of the present invention as long as the modified embodiments practice the features of the present invention. Additionally, the features of the above-described embodiments and the features of the following modifications may be combined as long as combinations are technically feasible, and those combinations still fall within the scope of the present invention as long as the combinations practice the features of the present invention.

[0107] For example, in the first and second embodiments, the description has been given in which the sensor **6** or the sensor **60** is provided as a capacitance sensor in the robot **4** for example. However, the capacitance sensor may be positioned in any device other than the robot **4**.

[0108] In the first and second embodiments, the description has been given in which the control device **5**, and the processing device **13** or the processing device **63** have separate functions. However, part or all of functions of the processing device **13** or the processing device **63** may be provided in the control device **5**, or part of functions of the control device **5** may be included in the processing device **13** or the processing device **63**. For example, the description has been given in which the control device **5** has the function of determining whether or not the object is present in a close proximity to the robot **4** based on the sensed value. However, the function may be included in the processing device **13** or the processing device **63**.

[0109] In the first and second embodiments, the detection sensor **11** and the detection sensor **61** have been described using specific configuration. However, the detection sensor **11** and the detection sensor **61** are not limited to the specific configurations as long as the specific configurations include the detection electrode **25**, and a value representing the capacitance between the detection electrode **25** and the object is output as the sensed value. For example, the detection sensor **11** and the detection sensor **61** may be configured in a form that adopts an oscillation frequency that changes according to a capacitance created between the detection electrode **25** and the object. Even with the configuration, it is possible to correct the sensed value.

[0110] In the first embodiment, the corrector **36** subtracts the sensed value measured in the second state, which is acquired in step SP**11** immediately before step SP**15**, from the sensed value in the first state. However, a method of correcting the sensed value in the first state is not limited thereto. For example, the corrector **36** may subtract an average value of a plurality of sensor values measured during the second state, which are acquired during a predetermined period of time in step SP**12**, from the sensed value measured in the first state.

[0111] In the second embodiment, the description has been given in which the reference sensor **62** is provided in the base **7** of the robot **4** for example. However, an installation position of the reference sensor **62** is not limited thereto. For example, the reference sensor **62** may be provided at a position distant from the robot **4** in a space surrounding the robot **4**. there is no restriction on the number of installed reference sensors **62**. For example, a plurality of reference sensors **62** may be provided, respectively, for a plurality of detection sensors **11**.

[0112] In the second embodiment, the description has been given in which the dielectric constant ε is calculated from one reference sensor **62** and used to correct the sensed value for example. However, the dielectric constant ε may be calculated based on a plurality of reference sensors **62**. For example, a plurality of reference sensors **62** may be provided to surround the robot **4**, and the sensed value may be corrected by calculating the dielectric constant ε using one of the plurality of reference sensors **62** located closest to the robot **4**. That is, the reference sensor **62** for calculating the dielectric constant ε may be selected according to the operation of the robot **4**. Additionally, a plurality of reference sensors **62** may be provided, and the sensed value may be corrected with an average value of the dielectric constants ε calculated respectively from measurement results of the plurality of reference sensors **62**. That is, the correction is performed using the plurality of dielectric constants ε obtained from measurement results of the plurality of reference sensors **62**.

[0113] In the second embodiment, the description has been given in which the dielectric constant ε is calculated, and the sensed value is corrected for example. However, but a timing of calculating the dielectric constant ε and a timing for correction may not be simultaneous. For example, at the time of performing the correction, the dielectric constant ε previously calculated (recently calculated) may be used. In the second embodiment, the correction may be performed based on a difference or the like between an output from the reference sensor **62** and an output from the detection sensor **11**, like as performed in the first embodiment.

[0114] In the second embodiment, the description has been given in which the reference sensor **62** is fixed in a fixture such as the base for example. However, a mover that moves the position of the reference sensor **62** may be provided. That is, the mover may move the position of the reference sensor **62** according to the operation of the robot **4** to prevent the reference sensor **62** from interfering with the detection sensor **11** mounted on the arm.

[0115] In the second embodiment, the processing device **63** may control turning ON/OFF of the reference sensor **62**. Specifically, the processing device **63** may turn ON/OFF the reference sensor **62** according to the operation of the robot **4**. For example, when the detection sensor **11** comes close to the reference sensor **62** as a result of the operation of the robot **4**, the processing device **63** places the operation of the reference sensor **62** on hold. This prevents the calculation of the dielectric constant ε from including the influence on the reference sensor **62** by an electric field generated by the detection sensor **11**.

[0116] In the first and second embodiments, the description has been given in which the sensor **6** and the sensor **60** use a self-capacitance detection method for example, However, the sensor **6** and the sensor **60** may use a mutual capacitance method. For example, the first embodiment may adopt the detection electrodes **25** for the detection sensor **11** that are formed with two electrodes (a pair of electrodes), and the reference electrode **12** is provided to face the pair of electrodes. The second embodiment may adopt for example the detection electrodes **25** for the detection sensor **61** that are formed with two electrodes (a pair of electrodes). In both cases, an object is detected according to the mutual capacitance method that uses the pair of electrodes that form the detection electrodes **25**.

[0117] In the first and second embodiments, the description has been given in which each of the processing device **13** and the processing device **63** is an information processing device including the CPU or the like. However, at least part of (or all of) the functions may be implemented in a logic circuit. In this configuration, there are no restrictions on a specific configuration of each of the processing device **13** and the processing device **63**.

What is claimed is:

1. A capacitance sensor comprising:

a detection sensor including a detection electrode and configured to output a sensed value representing a capacitance created between the detection electrode and an object;

a reference electrode provided to face the detection electrode and coupled to a reference potential via a switch; and

a processing device configured to open and close the switch to transition between a first state in which the reference electrode is opened and a second state in which the reference electrode is coupled to the reference potential.

2. The capacitance sensor according to claim **1**, wherein the processing device is configured to correct the sensed value measured in the first state with the sensed value measured in the second state.

3. The capacitance sensor according to claim **1**, wherein

the sensed value measured in the first state is a value representing a capacitance created between the detection electrode and the object via the opened reference electrode, and

the sensed value measured in the second state is a value representing a capacitance created between the detection electrode and the reference electrode coupled to the reference potential.

4. A capacitance sensor comprising:

a detection sensor including a detection electrode and configured to output a sensed value representing a capacitance created between the detection electrode and an object;

a reference sensor provided at a position that is different from a position of the detection electrode and including electrodes paired via ambient air; and

a processing device configured to calculate a dielectric constant of the ambient air based on an output from the reference sensor and to correct the sensed value with the calculated dielectric constant.

5. The capacitance sensor according to claim **4**, wherein the detection electrode of the detection sensor and the reference sensor are provided to separate members.

6. The capacitance sensor according to claim **4**, wherein

the detection sensor is provided in plural,

the reference sensor is provided with respect to the plural detection sensors, and

the processing device is configured to use the dielectric constant calculated from an output from the reference sensor to correct the sensed value measured from each of the plural detection sensors.

7. A robot system comprising:

a base;

a plurality of arms provided to the base; and

the capacitance sensor according to claim **1**,

wherein the detection electrode and the reference electrode are provided in any of the plurality of arms.

8. A robot system comprising:

a base;

a plurality of arms provided to the base; and

the capacitance sensor according to claim **4**, wherein

the detection electrode in the detection sensor is provided in any of the plurality of arms, and

the reference sensor is provided in the base.

* * * * *