(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 June 2017 (29.06.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/111619 A1

(51) International Patent Classification:
G08B 13/00 (2006.01) *G01B 13/00* (2006.01) *G01B 7/14* (2006.01)

(21) International Application Number: PCT/NZ2016/050204

(22) International Filing Date: 22 December 2016 (22.12.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
715489 22 December 2015 (22.12.2015) NZ

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

[Continued on next page]

(54) **Title**: A SENSOR DEVICE

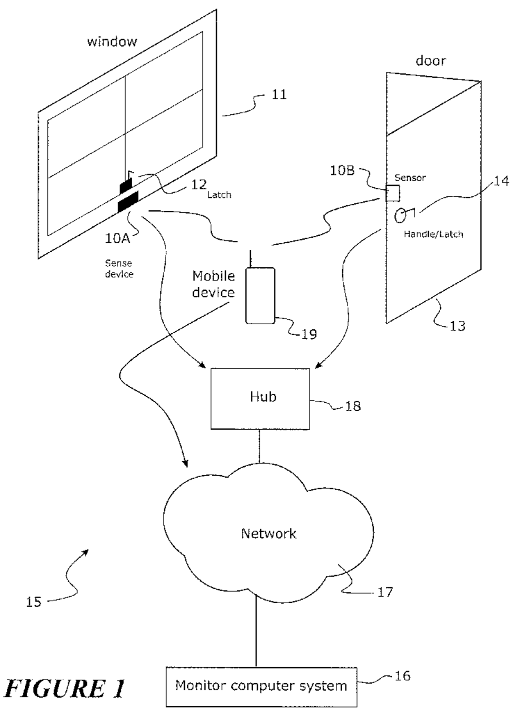


FIGURE 1

(57) **Abstract**: A sensor device for characterising a state of a closure object comprising: an inductor configured to produce an electromagnetic field in use that interacts with a closure device in the vicinity, the closure device disturbing the electromagnetic field based on its state, the disturbed electromagnetic field influencing at least one electrical characteristic of the inductor, and a processor configured to: measure or receive a measure of at least one inductor parameter being or being indicative of the electrical characteristic, and determine the state of the closure object based on the measure of the inductor parameter.

WO 2017/111619 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

A SENSOR DEVICE

TECHNICAL FIELD

A sensor device is described for monitoring the state one of at least one closure object such as a window or door, and the use of such a sensor device in a monitoring system.

BACKGROUND ART

One of the most important aspects to home and/or business security and one that is often overlooked are windows and doors. In general, burglars enter a premise through the doors or windows, and unwanted entry is made even easier if the windows and doors are not securely latched.

There are several types of window alarms on the market. These can be complicated systems that involve infrared motion detectors to monitor the area around the window, and activating when motion is detected, but before the window is opened or broken. However, a disadvantage of such a window or door alarm type system is that it is not only complicated, but does not monitor the status of the locking mechanism even if the window or door is physically closed, but unlocked and hence vulnerable to home invasion.

There is a need for an improved sensor device that overcomes disadvantages of known alarm and sensor devices or at least provides the public with a useful choice.

SUMMARY

It is an object of the invention to provide a sensor device and/or system for monitoring the state of closure objects.

In one aspect the present invention may comprise a sensor device for characterising a state of a closure object comprising: an inductor configured to produce an electromagnetic field in use that interacts with a closure object in the vicinity, the closure object disturbing the electromagnetic field based on its state, the disturbed electromagnetic field influencing at least one electrical characteristic of the inductor, and a processor configured to: measure or receive a measure of at least one inductor parameter being or being indicative of the electrical characteristic, and determine the state of the closure object based on the measure of the inductor parameter.

Optionally the processor determines the state of the closure device based on the measure of the inductor parameter and further on at least one reference corresponding to one or more possible states of the closure object.

Optionally the measure of the inductor parameter comprises a plurality of values of the inductor parameter over time, wherein the processor determines the state of the closure object based on the plurality of values.

Optionally the state is an event of the closure device.

Optionally determining the event comprises detecting the event, for example whether the event is occurring or has occurred.

Optionally determining the event further comprises classifying the event.

Optionally the event is detected by identifying a change in the plurality of values.

Optionally the event is classified by a change in the plurality of values, and optionally by reference to an existing static state of the closure object.

Optionally the processor is further configured to determine a static state of the closure object from the determined event.

Optionally the determining the state comprises the processor: detecting an event by identifying a change in the plurality of values, classifying the event by identifying a change in the plurality of values, and based on the classified event, and optionally an existing static state of the closure object, determining the static state of the closure object.

Optionally determining the state comprises identifying a change in the plurality of values between a first portion of the plurality of values and a second portion of the plurality of values.

Optionally identifying a change in the plurality of values comprises determining a first metric of the first portion and a second metric for the second portion of the plurality of values, and determining the relationship between the first and second metrics; or alternatively determining a first metric of the first portion and the second portion of the plurality of values and determining the relationship between the first metric and a reference, such as statistical measure.

Optionally determining the relationship between the first and second metrics comprises determining how the first and second metrics differ with respect to a statistical measure, such as a standard deviation.

Optionally determining the relationship comprises determining whether first metric for the first portion of data differs from the second portion of data by more than a number of standard deviations.

Optionally the number of standard deviations is a reference.

Optionally a metric for the first or second portion of data; or for both the first and second portions of data is:

- the gradient,
- the range,
- the mean, and/or
- standard deviation.

Optionally the state of the closure object is:

- a static state, for example open, closed, locked, unlocked or the like, and/or
- an event, such as:
    - a transition event (a change/transition in static state), for example opening, closing, locking, unlocking, moving, and/or
    - a miscellaneous and/or external event (null event), for example disturbance of the closure object such as knocking, bumping presence of movable body, traffic, wind, ground movement or the like.

Optionally the closure object is:

- is a latch device, such as a bolt, lock, latch, hook, padlock, bar, clamp or other object that secures a covering object, and/or
- covering object, such as a window, door, panel, lid or other object that closes off an aperture.

Optionally the electrical characteristic is one or more of:

- Inductance
- Inductor resonant frequency

- Parallel resistance

Optionally the sensor device further comprises a transmitter coupled to the processor for transmitting the state determination.

Optionally the state determination is transmitted to a:

- Hub
- Mobile device
- Server
- Monitoring system

In another aspect the present invention may comprise a sensor system for characterising a state of a closure object comprising: an inductor configured to produce an electromagnetic field in use that interacts with a closure object in the vicinity, the closure object disturbing the electromagnetic field based on its state, the disturbed electromagnetic field influencing at least one electrical characteristic of the inductor, a processor configured to: measure or receive a measure of at least one inductor parameter being or being indicative of the electrical characteristic, and determine the state of the closure object based on the measure of the inductor parameter, and a transmitter for transmitting signals, wherein the inductor and transmitter are disposed in a package for positioning near a closure object to determine its state, and the processor is in the package or external thereto.

In another aspect the present invention may comprise monitoring system comprising one or more sensor devices according to any described herein and a monitoring computer system in communication with the one or more sensor devices.

In another aspect the present invention may comprise a sensor device comprising: a sensor for sensing the conductance of at least one object in a first state and at least one further state; and an inductor element for producing an electromagnetic field configured to measure the conductance of the at least one object in the electromagnetic field via parallel resistance of the inductor element sensed by the sensor; wherein, the sensor device is configured to detect changes between the first state and the at least one further state of the object and send a notification by way of a wireless communication network to a user communication device.

Optionally the sensor senses the object which includes any one of a window, door, latch, locking mechanism or the like in the first open or unlocked state.

Optionally the sensor senses the object which includes any one of a window, door, latch, locking mechanism or the like in the second closed or locked state.

Optionally the sensor senses engagement or disengagement of the locking mechanism in the first and second states respectively.

Optionally the inductor element is an air core inductor.

Optionally the air core inductor is either a wire wound coil or manufactured from tracks on a printed circuit board (PCB).

Optionally the air core inductor coil is a single layer coil to minimise crossing magnetic field interference and increase sensing distance between objects in an electromagnetic field.

Optionally the parallel resistance of the air inductor coil is affected by permeability of the material object entering the electromagnetic field thereby allowing a set of defined parallel resistances to determine whether the object is in a first or second state.

Optionally the excitation frequency of the coil is configured to minimise noise interference and power consumption.

Optionally a frequency applied to the air inductor coil circuitry allows measurement of relative frequency changes of the material object entering the electromagnetic field to be compared with a set of predetermined reference frequencies thereby allowing the sensor to determine whether the object is in the first or second state.

Optionally a combination of parallel resistance and frequency measurement parameters of the sensor device allows for increased sensitivity and detection of less conductive objects entering the magnetic field.

Optionally the sensor device detects less conductive objects manufactured out of wood, plastic materials and the like.

Optionally the inductor element detects movement and orientation of the objects in the magnetic field.

Optionally the sensor includes an integrated body of unitary construction to minimise the area of the sensor during installation.

Optionally the sensor is retrofitted to allow integration into existing window, door and like applications.

Optionally the sensor device includes an inductance-to-digital converter (LDC).

Optionally the inductance-to-digital converter (LDC) is selected from any one of the following Texas Instruments™: LDC1000, LDC1041, LDC1051, LDC1101, LDC1312, LDC1314, LDC1612 or LDC1614.

Optionally the LDC provides control of a 1 kHz to 10 MHz clock signal sent to the inductor element, such that changes in frequency of sensing environment results in measured changes in conductance of objects and parallel resistance of the inductor element sensed by the sensor.

Optionally the LDC includes a serial interface for communication with a microcontroller (MCU) to allow for measurements to be read and in-built IC registers to be controlled.

Optionally the LDC provides regulation of oscillator amplitude in a closed loop system configuration while measuring energy dissipated in a circuit thereby allowing for parallel resistance of the circuit to be measured.

Optionally the LDC is replaced with Analog to Digital (ADC) Converter / Digital to Analog Converter (DAC) and oscillator circuitry.

Optionally the MCU is configured to enter an energy saving stand by mode and is activated by information received from communication modules or the LDC.

Optionally the MCU communicates to the communication modules through serial interfaces.

Optionally the MCU and LDC store set thresholds and parameters to correspond with an object in a first and/or second state.

Optionally the MCU conducts signal processing of data during both set-up and operation for exclusion of noise interference.

Optionally the sensor device includes a wireless communication network and/or module that utilises any one of the following frequencies and protocols: 2.4 GHz (Zigbee, Wi-Fi, CC3000, ESP8266, Bluetooth, Bluetooth LE), 900 MHz (Z-wave, Zigbee) or 415MHz.

Optionally the wireless communication module communicates with a smartphone and/or smart-hub for configuration and use.

In another aspect the present invention may comprise a sensor system for monitoring the status of an object in a first and second state comprising: a sensor for sensing the conductance of at least one object in a first state and the at least one further state, the sensor including an inductor element for producing an electromagnetic field configured to measure the conductance of the at least one object in the electromagnetic field via parallel resistance of the inductor element sensed by the sensor; an inductance-to-digital converter (LDC) for control of frequency signals sent to the inductor element, such that changes in frequency of sensing environment result in measured changes in conductance of the object and parallel resistance of the inductor element sensed by the sensor; a microcontroller (MCU) in communication with the LDC to allow for receiving of the parallel resistance and frequency measurements sensed by the sensor; and a wireless communication module to receive signals from the sensor via a user communicaton device; wherein, the sensor device is configured to detect changes between the first state and the second state of the object and send a notification by way of the wireless communication network to the user communication device.

In another aspect the present invention may comprise a method of configuring a sensor system for monitoring the status of a door or window in a first state and at least one further state comprising the steps of: H. establishing a wireless communication network between a user communication device and the sensor system; I. an application of the user communication device acknowledging the established wireless communication network between the user communication device and the sensor system; J. the application initiating a calibration process that directs a user to close the door or the window and mount the sensor system proximate to the door or window; K. the application confirming the sensor system is mounted in a location that is within sensing range of the door or window and the sensor notifying the user via the application that the door or window is in the first closed or locked state; L. the application initiating a further calibration process that directs the user to open the door of the window and the sensor notifying the user via the application that the door or window is in the further open or unlocked state; M. the application reinitiating steps D and E depending on feedback of results during the calibration process; and N. the application confirming completion of the calibration process, wherein the sensor system monitors and detects changes between the first state and the second state of the door or window and sends a notification by way of the wireless communication network to the user communication device.

Optionally the wireless connection between the user communication device and the sensor system is established via a direct Bluetooth connection or a central hub.

Advantages of the above include a sensor device that not only notifies a user whether an object such as a door or window is in first (locked) and second (unlocked) state, but allows transition states to be sensed. For example, the ability to track in real time whether a locking mechanism is engaged or not irrespective of whether the door or window is physically open.

In embodiments the sensor device includes an integrated body of unitary construction compared with prior art magnetic relay type devices that are two piece (magnet and relay). This construction minimises the area of the sensor during installation, hence a smaller footprint than magnetic relays and thereby allowing for wider applications. The sensor is able to be retrofitted to allow integration into existing window, door and the like applications. The sensor has a simple installation and optional calibration process without the requirement for additional components or custom installation.

In embodiments, a combination of parallel resistance and frequency measurement parameters of the sensor device allows for increased sensitivity and detection of less conductive objects entering the magnetic field compared with other sensor systems that can only sense ferrite materials. The sensor utilises established communications hardware and protocols to communicate with existing home automation systems.

For the purposes of this specification, the term 'about' or 'approximately' and grammatical variations thereof mean a quantity, level, degree, value, number, frequency, percentage, dimension, size, amount, weight or length that varies by as much as 30, 25, 20, 15, 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1% to a reference quantity, level, degree, value, number, frequency, percentage, dimension, size, amount, weight or length.

The term 'substantially' or grammatical variations thereof refers to at least about 50%, for example 75%, 85%, 95% or 98%.

The term 'comprise' and grammatical variations thereof shall have an inclusive meaning - i.e. that it will be taken to mean an inclusion of not only the listed components it directly references, but also other non-specified components or elements.

The term 'conductance' or grammatical variations thereof refers to an ability to conduct or transmit electricity through an object or body material. The degree to which is quantified by the term conductance.

The term 'inductor' or grammatical variations thereof refers to a two terminal electrical component that resists the change in electrical current passing through it.

The term 'parallel resistance' or grammatical variations thereof refers to the resistance in parallel to an inductor, a theoretical value that cannot easily be directly measured, but may be inferred from the sensor coil and how it is connected in a circuit. During operation of an inductance-to-digital converter (LDC), mathematical relationships can be derived from the power in vs. power out of the coil and knowing the coils parameter such as inductance value and driving frequency, the parallel resistance can be calculated.

The term 'state' or grammatical variations thereof refers to the particular position or condition of an object in an electromagnetic field.

BRIEF DESCRIPTION OF THE DRAWINGS

Further aspects of the sensor device will become apparent from the following description that is given by way of example only and with reference to the accompanying drawings in which:

Figure 1 is a block diagram of a security system with sensor devices for determining the state of a closure object.

Figures 1A and 1B show examples of attachment of a sensor device to a closure object in more detail.

Figures 2 and 3 are a block diagram of one example of a sensor device.

Figure 4 is a flow diagram showing how a sensor device determines the state of a closure object.

Figures 5 and 6 show a graph of a times series of data indicating events of a closure object.

Figure 7 shows a buffer with data points from the time series.

DETAILED DESCRIPTION

General embodiment of sensor device and monitoring system

Figures 1, 1A, 1B shows examples of a sensor device 10A, 10B (more generally 10) according to embodiments described herein that can be fitted (preferably retrofitted) to a closure object to determine the state of the object. Figure 1 shows, as an example, a first sensor device 10A fitted (preferably retrofitted) to a window 11 near a latch 12 on the window, and a second sensor device 10B fitted (preferably retrofitted) on a door 13 near the door handle 14. The closure object monitored by the first sensor device 10A is the window 11 and/or the latch 12 (depending on which is being monitored). The first sensor device 10A can determine the state of the window 11 and/or latch 12, such as static states opened, closed, locked, unlocked etc. or a transition of between static states. Likewise, the closure object monitored by the second sensor device 10B is the door 13 and/or door handle 14 (depending on which is being monitored). The second sensor device 10B can determine the state of the door/door handle, such as static states opened, closed, locked, unlocked etc. or a transition between static states. More generally, the sensor devices 10 can form part of an overall monitoring/security system 15. A number of sensor devices 10 (of which only two are shown in Figure 1) can be placed in the vicinity of/proximate various closure objects (more generally shown in Figure 4 and labelled 27) around a premises to be monitored. Each sensor device 10 can determine then transmit the state determination of the respective closure object to a suitable destination, such as a hub 18, mobile device 19, for further transmission over a network 17 to a server/monitoring computer system 16 or the like, all of which form part of the monitoring/security system 15. Two non-limiting examples of how a sensor device might be placed are shown in Figures 1A, 1B.

More generally, but without limitation, the closure object 27 could be:

- a latch device, such as a bolt, lock, latch, hook, padlock, bar, clamp or other object that secures a covering object, and/or
- a covering object, such as a window, door, panel, hatch, lid or other object that closes off an aperture.

Also, more generally, but without limitation, the state of the closure object could be:

- a static state, for example open, closed, locked, unlocked or the like, and/or
- an event, such as:
  i. transition event (a change/transition in static state), for example opening, closing, locking, unlocking, moving, and/or
  ii. an miscellaneous and/or external event (null event), for example disturbance of the closure object, such as knocking, bumping presence of movable body, traffic, wind, ground movement or the like.

Reference to an event could mean an event currently occurring, or one that has occurred.

The state (static or event) of each closure object 27 can be monitored by the corresponding sensor device 10 and system 15, and appropriate action taken if any state is inappropriate. For example, if one or more windows 11 or doors 13 are left open or unlocked, that can be detected, the owner notified and they can rectify that. If one or more windows or doors are detected as originally closed/locked, but then are detected as transitioning to open/unlocked that could suggest a security breach. Again, the owner or security services alerted, and action taken.

An example of a sensor device 10 is shown in more detail with reference to Figure 2. It comprises a sensor coil (inductor) 20 (which forms an LC tank with an inherent parallel resistance and capacitance, as well as inductance), the output of which is coupled to a processor 21. The processor can comprise an LDC (inductance to digital converter) 22 and microprocessor/microcontroller (MCU and used interchangeably without limitation) 23 – either separate components or integrated. The processor alternatively might just comprise a microprocessor configured to do the measurement. The output of the processor 21 is coupled to a transmitter 24. The transmitter can transmit the state of a closure objected determined by the sensor device 10 to a suitable device in the security system 15, such as the hub 18 (or router), server/monitoring system 16, mobile device 19 or the like which forms part of or connects to the security system 15. A power source 25 is provided to power the sensor device 10, preferably a battery although other sources are possible such as mains power, solar power, or wireless (inductive or capacitive) power transfer.

The device can also have or work with an attachment means. For example, referring to Figure 1B, the device could be attached to a closure object 27 using a bracket 29. The bracket allows the sensor device 10 to easily slide on and off the closure object 27 to make it easier to charge and replace etc. The bracket could attached to the closure object 27 using an adhesive strip or the like. During set up, the device/bracket set up as one piece. Once attached to the closure object 27, the sensor device 10 can be slid off the bracket 29.

In general terms, the sensor device 10 works as follows. The sensor device is secured near/proximate/in the vicinity of the closure object 27 being monitored, such that the electromagnetic field 26 of the inductor interacts with (that is, influenced/disturbed by) the closure object – shown generally as 27 in Figure 2. For example, the inductor might be placed near the metallic latch 12 of a window stay to detect the state of the latch 12, or near the wooden/metallic window frame 11 to detect the position (and therefore open/closed state). As another example, the sensor device 10 might be placed near the handle/lock/latch 14 of a door, or near the door edge 13 and door frame to detect the respective states. The microprocessor 23 is configured to operate the inductor 20 to create the electromagnetic field 26, which may include various electrical characteristics, comprising (but not limited to) frequency and strength. The inductor itself 20 will also have various electrical characteristics comprising (but not limited to) inductance, resonant frequency, parallel resistance and the like. That electromagnetic field 26 emanates towards and interacts with the closure object 27. The closure object disturbs/influences the nature of the electromagnetic field and its electrical characteristics. This in turn results in/induces particular electrical characteristics of the inductor 20. The closure object that is being monitored/sensed does not necessarily have to be a metal object. Wooden or plastic objects or the like can also be sensed as all materials will affect the electromagnetic field and its electrical characteristics to some extent.

The processor 21 can measure or receive a measure one or more of the electrical characteristics of the inductor 20, or measure or receive a measure one or more parameters indicative of the electrical characteristics. Each electrical characteristic being measured or the parameter indicative of such an electrical characteristic can be termed an "inductor parameter". The inductor parameter may have dimensions, or may be a dimensionless parameter indicative of an electrical characteristic. One or more inductor parameters could be measured for an inductor 20, and multiple measurements of each parameter could be made to provide a plurality of values for each inductor parameter. The measured inductor parameter is then used by the processor 21 to determine a state of the closure object 27 being monitored by the sensor device 10. The processor 21 can use the inductor parameter alone to determine the state of the closure object 27, or optionally it can be used in combination with other information, such as a reference, including other parameters and/or metrics (such as statistical measures). For example, the reference might be a value or a set of values relating to a parameter that assists in making a decision about the state of the closure object 27 in view of the measured inductor parameter. The inductor parameter values themselves might also be processed into a metric, which is used for determination.

In one example, the processor 21 comprises an LDC 20 and a microprocessor 21 as shown. The LDC is coupled to the inductor and receives output from the inductor indicative of the parallel resistance and/or resonant frequency of the inductor. This output is digitally converted and is passed to the microprocessor 21, which can further process the inductor parameter values and use them to determine the state of the closure object 27 or compare those processed values to a reference value or values. Various other options are possible. Once the state of the closure object 27 is determined by the processor 21, output of the determination is passed to the transmitter 24 and data indicating the determination is transmitted to other devices as previously described.

Embodiments of the sensor device 10 described herein use an inductor 20 to interact with the closure object 27. Alternative elements with electrical characteristics that can be affected by closure object could be used instead. For example, such elements may include, but not be limited, to capacitive sensors, hall effect, resistance, and pressure, etc. It is envisaged that any sensor may be used where there is an output of an electronic signal that can be influenced by interaction with the closure object. The processor and determination could in alternative embodiments be made remote to the sensor device 10 – for example the inductor parameter values are transmitted off the device, and a determination made in a server or other computing device, in the same manner as to be described herein.

Figures 1 and 2 show just one example of a sensor device, and should not be consider limiting. Other configurations using an inductor, or electrical element for that matter as described above, could be used.

One example of a sensor device and its operation

One non limiting example embodiment of a sensor device 10 and its operation will be described with reference to the Figures 1 to 7.

In this embodiment, a sensor device 10 such as previously described in relation to Figures 2 and 3, will be described in relation to use in a monitoring system 15 such as shown in Figure 1. Referring to the method flow diagram of Figure 4, an overview of the operation will be described. The processor 21 operates the sensor device to determine a state in the following manner. The inductor 20 is driven to create an electromagnetic field 26, which interacts with the closure object 27, step 40. A time series of inductor parameter values are measured and received by the processor (raw data collection), step 41. An event is then determined, step 44. To do this, first the processor the detects if there is an event by looking for (preferably statistical notable/significant) changes in the inductor parameter values, such as an increase or decrease, step 42 – preferably by using metrics which assist with accuracy of detection by reducing susceptibility to noise, anomalies and the like. The processor then classifies the detected event, again by looking at (preferably statistically notable/significant) changes in the inductor parameter values – again preferably by using metrics which assist with accuracy of classification by reducing susceptibility to noise, anomalies and the like, step 43. This can determine if there is a transition event, step 46, and if so, what type (e.g. opening, closing, locking, unlocking) or whether it is a null event, step 45. To assist, the existing state of the closure object 27 might be used. The event can then be transmitted as the output state, step 48, or alternatively (and preferably), the current static state determined from the event and existing static state, and the current static state transmitted as the output state, step 48. Detection characteristics can then be updated to improve further detection, step 47.

Preferably, but optionally, prior to use (e.g. during installation), a calibration is undertaken wherein the sensor device is installed in the correct position and then the closure object is put in its various states (e.g. open/closed or locked/unlocked), step 39. In the same manner as described above, the processor 21 records/stores these states as a reference, and also uses it to record/store an initial state that the closure object 25 is in, which can be used to improve state determination later on. The sensor device 10 optionally could be periodically or regularly recalibrated also to improve accuracy to state determination. In one example, a calibration is carried to compare the difference in averages to a nominal difference in values for a controlled "lock event" of a door. In such as case, the calibration sequence is as follows:

1. Door is locked.
2. Average value from LDC while locked is recorded.
3. Door is unlocked
4. Average value from LDC while unlocked is recorded.
5. Difference in averages is recorded as the calibrated difference.

The initial calibration might not be perfect, so subsequent lock events that have similar differences have their differences averaged with the previous differences, and the new value is used as the calibrated difference. This allows for more accurate decisions to be made over a long period.

The embodiment will now be described in further detail with respect to a particular example. The microprocessor 22 is configured to control the inductor 20 (preferably a non-linear square planar coil, although that is not essential) to emanate or output an electromagnetic field 26 (at a frequency/field strength), step 40, which interacts with the closure object 27. Based on the orientation, position (including proximity), movement and/or other physical, movement and geometric aspects of the closure object 27, the electromagnetic field 26 is influenced or disturbed, resulting in particular electrical characteristics of the inductor 20.

For example, the electrical characteristic could be parallel resistance. The parallel resistance at any point in time can be indicative of the physical status of the closure object 27. The processor 21 can collect data over on the parallel resistance from the inductor 20, step 41. To do this, the LDC 22 of the processor 21 receives/measures the parallel resistance of the inductor 20 and generates and provides an inductor parameter output which is representative of/indicative of the parallel resistance. The LDC 22 can measure/receive multiple instances of the parallel resistance over time, each forming a data point that together can be output as a time series of data points (plurality of values). Each data point is a value that is a particular instance of the inductor parameter that represents the electrical characteristic, in this case parallel resistance.

In an alternative, resonant frequency can be used as the electrical characteristic of the inductor. The electromagnetic field 26 disturbance is observed as a change in inductance of the inductor 20 which can be measured as a shift in the resonant frequency of the inductor. The LDC 22 can measure the resonant frequency at multiple instants over time, for each instance, find the ratio between the resonant frequency and a reference frequency, and output a value based on the ratio of frequencies. The ratio for each time instant are output to form the time series of data points (plurality of values). The coil frequency could be approximately 2.5MHz, and the reference frequency 10MHz. The values from the LDC 22 are unitless in this case, but changes in the values produced by the LDC 22 correspond to physical, movement and geometric aspects of the closure object 27 in the electromagnetic field. The values typically increase when metals are placed near the sensor, and drop when water-containing objects are placed near (e.g. water bottle, human hand). The values also drop when a person touches metals close to the sensor (i.e. puts their hand on the lock mechanism.

The remainder of the example will refer to use of a resonant frequency (or parameter derived therefrom) as the electrical characteristic/inductor parameter. But it will be appreciated that the example could work with other electrical characteristics also.

The processor 21 is then configured to use the time series of data to determine the state, step 44, of the closure object 27. In this embodiment determining the state, step 44, of the closure object corresponds to determining an event relating to the closure object. That determination is further comprised of detecting an event occurring (or having occurred), step 42; and then classifying the event 43; that is, determining the nature of type of the event. Closure object event classification, step 43, is where the detected event, step 42, is analysed further to determine if it was transition event (such as the act of opening, closing, locking, unlocking) or something else (null event) that is not relevant to the state of the closure object (e.g. an external disturbance such as bumping, traffic etc.). Event determination also keeps track of the closure object static state (open, closed, locked, unlocked etc.) so the erroneous state changes do not cause issues in the long term. For example, a door that is locked cannot then be locked again, it can only be unlocked.

If the event is confirmed to be a closure object transition event, the detection characteristics are updated to account for long term changes in the closure object and sensor device. These changes are outside sources of interference such as temperature, which affect the raw data that is received from the sensor device 10, and as such can be accounted for. If the event is not a transition event, but rather classified as an irrelevant event, it is deemed a null event (rejection). For example, a spike in the raw data time series due to someone knocking on the door. These events result in changes of the running metrics that are calculated for the time series of data, but are removed, as otherwise they can result in events not being correctly detected, resulting in the loss of correct state detection. This is due to values of the standard deviation, range, and mean of the time series data now including the erroneous event, increasing the thresholds triggering the event detection algorithm, resulting in smaller changes in the data not being detected as easily. By excluding the null event, the system has an overall quicker reaction time.

One example of detecting an event and then classifying the event will now be described in further detail.

To detect and register that an event is occurring (or has occurred), step 42, the microprocessor 23 is configured to receive the time series of data points (raw data points) from the LDC 22. Metrics (like gradient, and also such as, but not restricted to statistical measures, like mean, range and/or standard deviation) of the time series data are obtained and used by the processor 21 to determine the state of the closure object 27 to which the device is paired. The microprocessor monitors the data coming from the LDC and uses the statistical measures to determine whether or not the recent data contains an event. In general terms, this might be a sharp change in the stream of LDC inductor parameter values, or a significant change in the average of the recent values compared to old values, or some other change.

One non-limiting example will now be described, with reference to Figures 5 and 6, which show time series of data 50 of an inductor parameter indicative of an electrical characteristic (in this case resonant frequency) and can be analysed to detect the state of the closure object. In particular, Figure 5 shows a large series of lock 51 and unlock 52 events 53 of a latch closure object, such as a lock 14 of a door 13. The high points 51 in the graph generally correspond to when the door 13 is locked, and the low points 52 on the graph generally correspond to the when the door is unlocked. The transition between the two states is a transition event 53 – an upward change in the data indicates a locking transition event 53A, and a downward change indicating unlocking transition event 53B.

The metrics described below can be utilised to detect these transition events. At around data point 500 the general average of the data 50 shifts upward. This is likely due to mechanical movement in the device itself (an irrelevant null event), and is not a characteristic of the movement/transition of the locking mechanism itself. This type of movement is accounted for/discounted using the metrics described below. Figure 6 shows a portion of the Figure 5 data in more detail, where noise 60 is apparent. To detect transition events 53, noise 60 is compensated for. In this example, this is achieved by using statistical measure metrics of an average and standard deviation of data values. These values are then used to determine a significant event (being a transition event 53). The values on the x-axis are the number of data points, so the value of 280 would be the 280th data point collected.

So in this example, initially the lock 14 is in an unlocked position at point A, with the set metrics for the unlocked state (i.e. standard deviation, range, mean, current gradient). At around the 290th data point the lock state changes (see Figure 6) – a transition event 53 being a lock event L 53A. This is shown by the large increase in data value 50, which results in a large change of gradient G (a data metric) in the data, the data value and/or the gradient of the event 53A exceeding a set multiple of the standard deviation (a statistical measure metric) for a reference set of data values and/or gradients. At around data point 350 the opposite happens, the value of the data significantly drops, resulting in it once again exceeding the set number of standard deviations for such data, the gradient G also being very large and exceeding a set number of standard deviations for gradients. This is a transition event 53 being an unlock event U 53B. It can also be seen that the data value drops below the value it settles at for an unlocked state around the 360th data point. This lower section and resulting settling is due to the interaction of the movement of the deadbolt, as well as the movement of the locking mechanism itself, and the person interacting with the locking mechanism (e.g. touching the lock to lock the door).

Time series data 50 shown in Figures 5 and 6 is obtained by the microprocessor 23 from the LDC 22 at e.g. 100 millisecond intervals, although other sampling rates are possible. This time series of data is stored in a buffer/register 70, such as shown in Figure 7. As an example that is 40 data points long (D1 to D40), although the buffer could be any suitable length. This buffer is nominally split into two portions, a leading buffer/window 71 that contains (e.g. 10) data points of lead portion data D1 to D10, and a tailing buffer/window 72 that contains (e.g. 30) data points of end portion data D11 to D40. When a data point is obtained from the LDC 22, it is placed into the start of the leading buffer 71, and all the data points are incremented by 1, and the last data point in the tailing buffer is removed. Figure 7 shows the buffer at an instance in time, which could correspond, for 72 example, to the window shown in Figure 5 and 6.

Each time a new data point Dx is placed in the buffer 70, the microprocessor 23 calculates a suitable metric or metrics that characterise(s) each buffer portion 71, 72 and can be used to detect an event of the closure object 27. As one example, the microprocessor 23 calculates the mean and standard deviation of the data points in the: a) leading buffer 71 (lead portion data), and/or b) tailing buffer 71 (end portion data). Then the gradient between the two buffers is calculated – that is, using a suitable metric representative of the data in each buffer (such as a mean) the gradient is found between the metric for the leading buffer and the metric of the tailing buffer (e.g. by subtracting one from the other and dividing by the number of data points between them). In addition or alternatively, the range of the leading buffer 71 and the tailing buffer 72 could also be calculated. From this information, the microprocessor 23 can determine if there is/has been an event, such as the closure object state changing (such as a lock opening/closing).

To detect if an event has occurred or is occurring, step 41, the microprocessor determines:

a) if the gradient of the lead data portion to end data portion representative metric exceeds a certain number of standard deviations (e.g. 5); and/ or

b) the range of the lead data portion exceeds the range of the end data portion by more than a certain number of standard deviations (e.g. 5), and/or

c) the mean of the lead data portion exceeds the mean of the end data portion by more than a certain number of standard deviations (e.g. 5).

One option uses a multiple of 5 standard deviations, although other multiples are possible. If one or both or all three of those conditions are satisfied, an event (of a type yet to be classified) is detected. Just one of the metrics could be used, but by using more of the metrics, the accuracy of the determination of the state has more confidence. At this stage, all that is known is that something has changed, whether it is open/closing, locking/unlocking, or some irrelevant external disturbance is unknown.

If this occurs, a number of metrics are recorded and stored for a short time, usually until the event has finished, as events can occur over a varying number of samples. Preferably, those metrics are the mean of the tailing buffer (end data portion), the range of the tailing buffer, and the gradient.

Other metrics and means of detecting an event could be envisaged and used instead or as well as those above. More generally, the microprocessor can be configured to detect an event 53 based on any suitable changes in the time series of data 50 indicative of an event. The above is only one example. For example, other metrics that could be used are:

- standard deviation at a resting state,
- range of data in the last 1 second
- range of data in the last 4 seconds
- mean of the data 4 seconds before an event
- mean of the data 4 seconds after an event
- first differential (gradient) of data with spike/shelf exclusion for drift

By measuring changes in these metrics, the specific values of the metrics, and the order in which these occur, events can be characterized. For example, a large change in the recent data range, followed by an increase in the resting mean, suggests that the lock was moved from the unlocked state to the locked state. By subtracting the overall gradient from the time sequence, the processor can compensate for any drift of the sensor during an event.

It should be noted that the event 53 being detected could be one of interest, such as the change in state (transition event) of the closure object, or alternatively an event which is to be disregarded, such as some irrelevant external disturbance (such as someone touching the lock or door handle). At this point, it is about detecting the event occurring 53, not necessarily classifying the type of event.

Next, the microprocessor implements a classification process that determines the nature/type of the detected event, step 42. The event could be a null event, namely one that is irrelevant and should be disregarded; or alternatively a closure object transition event which needs to be acted upon. To do this, the microprocessor calculates one or more metrics specific to the event that is occurring so that it can be determined if the event is a change in the closure state (e.g. lock state, door/window state open/closed) or an event that is something else that should be ignored, e.g. such as a person bumping a window or door. It also uses the existing determined state (namely the state that was previously determined prior to the event occurring and which has previously been stored). At the very beginning, this existing determine state is the state determined during calibration.

For example, referring to the data series in Figures 5 and 6, the state of the lock determined by comparing the mean of the lead buffer/lead portion data 71 to the stored mean of the tailing buffer/end portion data 72. If the lead portion data 71 mean is larger than the stored mean of the tailing portion data 72 (preferably, by more than a certain number of standard deviations), then it is classified that the door has been locked 53B (that is, a locking transition event is classified). Alternatively, if the leading buffer/lead portion data 71 mean is less than (preferably, by more than a certain number of standard deviations) the stored tailing buffer/end portion data 72 mean, then it is classified that the door is unlocked (that is, an unlocking transition event is classified). (This can also be expressed as the microprocessor analyses the time series data around the event by comparing the average of the time series data after the event to the average of the time series data before the event, and classifies the event based on the difference in the averages.)

This set of criteria may be reversed depending on the lock mechanism. Sometimes the mean value when locked will be lower than when unlocked. If none of the criteria are satisfied, then the event is classified as a null event that should be ignored. That is, it is assumed that it is not a locking/unlocking transition event, but rather some sort of other disturbance.

Preferably, the existing stored determined state is also used to validate whether the classified transition event is indeed a transition event. For example, if the existing door state is locked, it cannot be triggered to change into a locked state again. Therefore, if a locked transition event is determined, this must clearly be an error. This would be some other type of null event that may need to be ignored. Likewise, if the existing door state is unlocked, it cannot be unlocked again. Therefore if an unlocked transition event is determined, this must also clearly be an error and rather be classified as a null event.

In one example, preferably the metrics that are used to determine the transition event are:

- *Epsilon*, which is two time the standard deviation of the tailing buffer 72 recorded during calibration,
- *Delta*, which is the mean of the leading buffer (lead portion data) minus the mean of the tailing buffer (end portion data) that was stored earlier, and
- a threshold, which is either the stored range of the tailing buffer/end portion data if the delta found during calibrating the device is zero (usually meaning that calibration has yet to be completed), or the value of the following equation:
    - *(delta_c * 7) / 10 - epsilon*.

    where delta_c is the delta value found during calibration.

If it is determined that the event is a change in static state (transition event) of the closure object (e.g. opening/closing, locking/unlocking), next the microprocessor determines which the resultant static state. This is determined by taking the existing static state, and inferring the new current static state based on the transition event. For example, if the existing static state is unlocked, and a locking transition event is determined, then the new current static state must be locked. Likewise, if the existing static state is locked, and a unlocking transition event is determined, then the new current static state must be unlocked.

As will be apparent to one skilled in the art, the above criteria and processing can be applied to other closure objects and events also, such as open/close static states and transition events.

Once the event has been confirmed to be a change in lock state (transition event), preferably the delta value used for future event processing is updated, step 47, if it is larger than two times the delta used in a previous lock state change, to allow for changes in time in the sensing environment (i.e. temperature changes). The equation to calculate the new delta is as follows: new_delta = (absolute (delta_c * 5) + absolute(delta)) / 6. This improves accuracy of determination in the future.

In this example, a null event can be determined based on the derivative of the time-series data, and comparing the peak first derivative values of a null event to that of a lock event. A null event could be as simple as a person putting their hand on the door handle, which increases the capacitance of the lock, and thus changes the values that come from the LDC. These events can be rejected based on the derivative of the time-series data, and comparing the peak first derivative values of a null event to that of a lock event.
The detection characteristics and then updated, step 47.

If a transition event is detected, then the state determination is transmitted from the sensor device as previously described, step 48. This preferably is an indication of the static state of the closure object, but it could also additionally be the transition event.

The processes above and the metrics used have been determined to work well in general cases for various types of closures based on testing and analysis of closure object transition events numerous times. The present inventors have determined the metrics that improve accuracy. There are other alternatives for determining an event using the time data series and metrics, in addition to those above. The examples above are illustrative only, and should not be consider limiting. Also, while metrics (including statistical measures) are used, these are not essential, and are simply desirable to improve accuracy. In general terms, the processor could use any suitable means to determine an event by looking at changes in a time series of data. Furthermore, the approach may not necessarily need to detect the event, and then classify the event separately. Rather, it is envisaged that a processor could be configured to simply determine the nature of the event (transition event – e.g. opening/closing, or alternatively a null event) without detecting the event as a separate step. However, using metrics and proceeding as above can improve accuracy and/or confidence of the state determination.

It will be appreciated that the sensor device as described is suitable for installation without particular expertise and without the requirement for sophisticated configuration and/or sophisticated calibration or bespoke design for a particular closure object. Rather, the sensor device can be installed by an inexperienced person, going through a simple calibration process of putting the closure object into its various states. The processor configuration which analyses and processes the time series data can determine states for a range of different closure devices and so is flexible enough to do that without the need for specific configurations.

Alternative embodiments of a sensor device and its operation

A range of variations will now be described.

In another aspect there is provided a sensor device comprising: a sensor for sensing the conductance of at least one object in a first state and at least one further state; and an inductor element for producing an electromagnetic field configured to measure the conductance of the at least one object in the electromagnetic field via parallel resistance of the inductor element sensed by the sensor; wherein, the sensor device is configured to detect changes between the first state and the at least one further state of the object and send a notification by way of a wireless communication network to a user communication device.

The sensor may sense the object which includes any one of a window, door, latch, locking mechanism or the like in the first open or unlocked state and at least one further closed or locked state.

It should be appreciated by those skilled in the art that multiple states may be sensed in real time, wherein the sensor may sense engagement or disengagement of the locking mechanism in the first and further states respectively. Other multiple sensing states may include sensing of a key engaging with the lock mechanism, tampering with the lock mechanism or the lock mechanism being in a partially unlocked state.

Furthermore, the sensor is not limited to the above and may sense other types of closure objects and/or have additional applications other than for windows and doors. For example, the sensor and corresponding calibration set up may be applied to many types of sensor systems, that may include, but not be limited to capacitive sensors, hall effect, resistance, and pressure, etc. It is envisaged that any sensor may be used where there is an output of an electronic signal. Furthermore, utilising the calibration setup and interfacing it to the aforementioned sensor types may provide the ability to remotely monitor a sensing system through a connected device. In this way, such sensor applying a calibration sequence, may learn from the environment and correspond with user set states. A further example may be a calibration sensor placed on a gate way, measuring in real time a non-conductive body as it passes through the sensor i.e. counting animal walking through a gateway or at a drinking trough.

The sensor device may include a wireless communication network and/or module that utilises any one of the following frequencies and protocols: 2.4 GHz (Zigbee, Wi-Fi, CC3000, ESP8266, Bluetooth, Bluetooth LE), 900 MHz (Z-wave, Zigbee) or 415MHz.

Preferably, the protocol for the calibration step of the sensor device may be Bluetooth LE. An advantage of this protocol is that it may allow the sensor device to directly communicate with a user's smart communication device during set up. Following this calibration step, the sensor device may communicate primarily using Zigbee or Z-Wave as these protocols have greater range than that of Bluetooth, and the Hub platforms commonly utilised for communicating with other home security devices. Also, due to the implementation of the Zigbee and Z-Wave protocols these may allow communications to be passed through other security devices in the home, if the sensor device is out of range of the Hub.

The sensor device may include an inductor element, preferably an air core inductor. However, other types of coils can be conceivably used with this invention such as an iron core inductor which consists of iron core with copper winding placed around it in a spiral fashion. An advantage of an air core inductor is that this type of inductor has a low profile compared with an iron core inductor.

In one embodiment, the air core inductor may either be a wire wound coil or manufactured from tracks on a printed circuit board (PCB). An advantage of a wire wound coil is that a wider range of wire diameters can be used during manufacture, this allowing for a greater range of inductances to be utilised. However, an advantage of a PCB coil is the simpler manufacture process and integration into the sensor system.

In further embodiments, the air core inductor coil may be a single layer coil to minimise crossing magnetic field interference and increase sensing distance between objects in an electromagnetic field. However, this should not be seen as a limitation on the embodiments envisaged for this invention as a multilayer coil could conceivably be used with this invention. An advantage of a multilayer coil compared with that of a single layer coil is that a multilayer may have a higher inductance value over that of a single layer coil, while still maintaining the same foot print area with a minimal increase in physical height.

The parallel resistance of the air inductor coil may be affected by permeability of the material object entering the electromagnetic field. In this way a set of defined parallel resistances may be used to determine whether the object is in a first or further state. Without being bound by theory, the oscillation frequency of the inductor may be coupled to the conductive object that is passed within its range. This in turn induces eddy currents in the object, thereby pulling power away from the inductor. This changes the electrical characteristics of the inductor, and therefore the parallel resistance of the inductor changes depending on the permeability of the object entering the electromagnetic field.

The coil of the sensor device may utilise an excitation frequency of 5 kHz to 5 MHz depending on the LDC chip and may be configured to minimise noise interference and power consumption. In this way, higher frequencies may allow for more precise measurements to be made, but also increase the power consumption. Conversely, lower frequencies have lower power consumption, but have less precise measurements resulting in more interference in the system being measured.

Furthermore, the excitation frequency of 5 kHz to 5 MHz via a LDC1000 Chip applied to the air inductor coil circuitry may allow measurement of relative frequency changes of the material object entering the electromagnetic field to be compared with a set of predetermined reference frequencies thereby allowing the sensor to determine whether the object is in the first or further state. More preferably, the frequencies may be between the range of 1 MHz to 5 MHz, as the inventors' have found that this frequency range may provide more accurate measurements of the parallel resistance and have less interference.

In a preferred embodiment, a combination of parallel resistance and frequency measurement parameters of the sensor device may allow for increased sensitivity and detection of less conductive objects entering the magnetic field. Without being bound by theory this may work by cross referencing the parallel resistance measurements and frequency measurements against one another, allowing for noise rejection to be more easily accomplished as changes in the parallel resistance may also result in changes in the frequency, and vice versa. If this does not occur then this may indicate some interference in one of the measurements, resulting in a change of state not being detected. In this way, the sensor device may detect less conductive objects such as those manufactured out of wood, plastic materials and the like.

The inductor element may detect movement and orientation of the objects in the magnetic field. All objects are charged (or conduct) to some degree, when they pass into the coils electromagnetic field. The particles in the object are charges that may present a unique signature to the coil in the form of eddy currents that form in the object. In metallic objects and other highly conductive objects these eddy currents form based on a number of factors such as the type of material, its conductivity and its density. The factors involved in detection of movement and orientation relate to the size and shape of the object as well as it intrinsic uniformity. The shape and the size of the object may affect the amount of eddy currents that are formed on the surface of the object. The intrinsic uniformity of the object internally also affects the eddy currents that a produced by the object although this may be more difficult to measure using the intrinsic internal uniformity. Also, with metals in general they have a direction of charge in them from the manufacturing process that makes the determination of their orientation much easier as the received signal from the coil increases and fades in different parts of the object.

The sensor device may include an integrated body of unitary construction to minimise the area of the sensor during installation. In this way, the sensor may be easily retrofitted to allow integration into existing window, door and the like applications.

The sensor device may include an inductance-to-digital converter (LDC). An LDC may be an integrated circuit and its functionality may be to reduce the size and cost of a set of discrete components that make up a circuit, as well as increasing the performance of some discrete circuits. It should be understood by those skilled in the art that discrete circuit/components may refer to a set of electronic components such as resistors, transistors, capacitors, or the like that make up an electrical circuit.

In preferred embodiments, the inductance-to-digital converter (LDC) may be selected from any one of the following Texas Instruments™: LDC1000, LDC1041, LDC1051, LDC1101, LDC1312, LDC1314, LDC1612 or LDC1614. However, this should not be seen as a limitation on the embodiments envisaged for this invention. Other proprietary LDCs and/or modified LDCs may be utilised that provide the desired functionality.

The LDC may provide control of a 1 kHz to 10 MHz clock signal sent to the inductor element, such that changes in frequency of sensing environment may result in measured changes in conductance of objects and parallel resistance of the inductor element sensed by the sensor. In this way, interference from other electronic devices also may interfere with the measurements made using the inductance-to-digital converter. To overcome this potential problem, the frequency at which the inductor element is driven at may be changed to reduce this interference.

The LDC may include a serial interface for communication with a microcontroller (MCU) to allow for measurements to be read and in-built LDC registers to be controlled. It should be understood by those skilled in the art, LDC registers may refer to the set of data holding places on the LDC. These registers allow for data to be written into the LDC which in turn affects the way in which the LDC operates. Data can also be read out of these registers such that measured values may be retrieved from the LDC.

The LDC may provide regulation of oscillator amplitude in a closed loop system configuration while measuring energy dissipated in a circuit thereby allowing for parallel resistance of the circuit to be measured. In this way, the LDC may regulate the input amplitude of the oscillation of the inductor in a closed loop configuration such that the input amplitude remains constant. The energy the inductor dissipates may then monitored. From monitoring the power in vs power out of the inductor, the parallel resistance can be measured.

In another embodiment, the LDC may be replaced with Analog to Digital (ADC) Converter / Digital to Analog Converter (DAC) and oscillator circuitry. This may be achieved by exciting a coil using a simple oscillating signal, and then measuring the signal in the coil using an ADC, in combination with an MCU as it will require some computational power. Another method may be to effectively create a discrete version of an LDC1000 series of chips. This may comprise an oscillator to drive the inductor, simple circuitry to measure power in and power out and then sending these values to a MCU that may then convert these measured values into parallel resistance values.

The MCU may be configured to enter an energy saving stand by mode and is activated by information received from communication modules or the LDC. In this way, the battery power of the device is conserved.

The MCU may communicate to the communication modules through serial interfaces. An advantage of this configuration is that it may provide a high speed reliable communication, while not requiring a large number of connections between the MCU and communication module.

The MCU and LDC may store set thresholds and parameters to correspond with an object in a first and/or further state. The thresholds may vary depending on multiple factors, hence the preference for calibration of the sensor device.

In this way, the MCU may conduct signal processing of data during both set-up and operation for exclusion of noise interference.

The sensor device may include a wireless communication module that communicates with a smartphone and/or smart-hub for configuration and use. In this way, the sensor device may 20 communicate with the smart-hub such that the smart-hub may know the state of the door / window or the like that the sensor may be mounted on. The smart-hub may allow the user to set security features for the user's whole premises. It is also envisaged that the smart-hub may also link all the other smart security devices in the user's home together.

In another aspect there is provided a sensor system for monitoring the status of a closure object in a first state and at least one further state comprising:

- a sensor for sensing the conductance of at least one object in the first state and the at least one further state, the sensor including an inductor element for producing an electromagnetic field configured to measure the conductance of the at least one object in the electromagnetic field via parallel resistance of the inductor element sensed by the sensor;
- an inductance-to-digital converter (LDC) for control of frequency signals sent to the inductor element, such that changes in frequency of sensing environment result in measured changes in conductance of the object and parallel resistance of the inductor element sensed by the sensor;
- a microcontroller (MCU) in communication with the LDC to allow for receiving of the parallel resistance and frequency measurements sensed by the sensor; and
- a wireless communication module to receive signals from the sensor via a user communication device;

wherein,
the sensor device is configured to detect changes between the first state and the at least one further state of the object and send a notification by way of the wireless communication network to the user communication device.

In another aspect there is provided a method of configuring a sensor system for monitoring the status of a door or window in a first state and at least one further state comprising the steps of:

A. establishing a wireless communication network between a user communication device and the sensor system;

B. an application of the user communication device acknowledging the established wireless communication network between the user communication device and the sensor system;

C. the application initiating a calibration process that directs a user to close the door or the window and mount the sensor system proximate to the door or window;

D. the application confirming the sensor system is mounted in a location that is within sensing range of the door or window and the sensor notifying the user via the application that the door or window is in the first closed or locked state;

E. the application initiating a further calibration process that directs the user to open the door of the window and the sensor notifying the user via the application that the door or window is in the further open or unlocked state;

F. the application reinitiating steps D and E depending on feedback of results during the calibration process; and

G. the application confirming completion of the calibration process, wherein the sensor system monitors and detects changes between the first state and the further state of the door or window and sends a notification by way of the wireless communication network to the user communication device.

The wireless connection between the user communication device and the sensor system may be established via a direct Bluetooth connection or a central hub.

Advantages of the above include:

- A sensor device that not only notifies a user whether an object such as a door or window is in first (locked) and second (unlocked) state, but allows multiple states to be sensed in addition;
- The ability to track in real time whether a locking mechanism is engaged or not irrespective whether the door or window is physically open;
- The sensor device includes an integrated body of unitary construction that minimises the area of the sensor during installation, hence a smaller footprint than magnetic relays and thereby allowing for wider applications;
- The sensor is able to be retrofitted without tools to allow integration into existing window, door and the like applications;
- The sensor has a simple installation and calibration process without the requirement for additional components or custom installation;
- The use of a combination of parallel resistance and frequency measurement parameters of the sensor device allows for increased sensitivity and detection of less conductive objects entering the magnetic field;
- The sensor utilises established communications hardware and protocols to communicate with existing home automation systems; and

- An optimised frequency range configured to minimise noise interference and power consumption.

The embodiments described above may also be said broadly to consist in the parts, elements and features referred to or indicated in the specification of the application, individually or collectively, and any or all combinations of any two or more said parts, elements or features.

Further, where specific integers are mentioned herein which have known equivalents in the art to which the embodiments relate, such known equivalents are deemed to be incorporated herein as of individually set forth.

WORKING EXAMPLES

The above described device, method and uses thereof are now described by reference to specific examples.

EXAMPLE 1

With reference to Figure 2, the block diagram shows a sensor, LDC and MCU modules comprising the sensor device in electronic communication with two external modules, namely a Wireless comms and hub that link the sensor device and the user's smart device together. The lines between each of the modules represent the connection between the corresponding modules. The simple straight lines between the sensor coil and the LDC, consist of only two wires. The lines between the LDC and MCU, as well as the MCU and Wireless Comms module represent multiple wires between these modules. The symbols between the Wireless Comms and Hub, Hub and Smart device, represent wireless protocols between these modules.

Modules and Componentry

Sensor Coil: Consists of an air core coil that is the sensor element.

Inductance-to-digital converter (LDC): An LDC1000 chip manufactured by Texas Instruments, which drives the sensor coil with an oscillating signal, and in turn measures the parallel resistance, and frequency changes in the sensor coil. The LDC connects to the Micro controller (MCU) using a Serial Peripheral Interface (SPI).

MCU: The MCU module is a micro controller that provides the central processing of the sensor data and monitors when states in the system have changed and relays this to the user by controlling the wireless comms module.

Wireless Comms: The Wireless comms module utilises a number of different communication protocols such as Bluetooth LE and Zigbee to communicate with the Hub. The Wireless comms connects to the MCU using a variety of different interfaces depending on the type of communication device used. As shown, the sensor device utilises Bluetooth LE and a SPI interface, while the Zigbee interface utilises a modified Universal Synchronous/Asynchronous Receiver Transmitter (USART) interface.

Hub: The hub is an enabling device such as a Samsung Smart-things hub or Google Nest device, which connects to the internet and allows the user to receive updates about their state of the door or window the sensor device is mounted thereon.

Smart Device: The smart device allows the user via an application to check on the current state of the doors or windows the sensor device is mounted thereon on at any time from their smart device. The smart device also enables the calibration of the sensor device during set up and installation.

With reference to Figure 3, the block diagram shows a simplified wiring layout of the sensor device. Firstly, the sensor coil is connected to the LDC chip *via* two wires. The LDC device provides an oscillating signal to the sensor coil, and in turn measures the parallel resistance and frequency of the sensor coil. The LDC chip has two voltage sources and two grounds, the 5V (volts) source is used to run the LDC chip's power circuitry, whereas the 3.3V signal provides the reference for the signals that the LDC will use to communicate with the MCU. There are two grounds for the LDC chip. The DGND is a digital ground which is used for the digital signals coming from the MCU, whereas the AGND, is an analogue ground that is used for the analogue circuitry contained in the LDC chip. The LDC also has 6 digital signals connected between itself and the MCU. These are the 4 SPI (Serial Peripheral Interface) lines, SCLK: the serial clock, SDO: the serial data out of the MCU and into the LDC, SDI: the serial data in from the LDC to MCU, and the CSB: Chip select bus. The other two signals include the TCLK: which, provides the frequency for the sensor coil to be oscillated at, and the INTB: which is an interruption signal from the LDC to MCU, which is used to wake the MCU from sleep mode when a threshold is met by the parallel resistance measured by the LDC.

The Comms module connects to the MCU *via* a set of wires having a voltage source of 3.3V, and a digital ground DGND.

The MCU has a 3.3V power source along with two ground sources, AGND, DGND.

The battery depicted in the Figure 2 is a lithium ion battery, but could be substituted with other types of batteries such as AA, 9V or even coin cell battery depending on application.
The power converter takes the battery voltage and converts it to both 3.3V and 5V such that for minimal power consumption.

Operation of Sensor Device

The sensor device is configured to operate as follows:

Firstly, the MCU sends initial data to fill the register on the LDC1000 chip over the SPI interface. The LDC device is then setup for initial calibration. At this point, the MCU begins transmitting the frequency that the coil should be driven at to the LDC chip using the TCLK line. During calibration the thresholds for the device are set, such that the states of open, closed, locked, unlocked and interim states thereof are distinctly determined. Also during this calibration process – see description further below, the frequency of the driving signal over the TCLK line can be modified to reduce any interference the device may be receiving. Once calibration is completed, the MCU has the ability to run in a low power mode during most of its operation, waking up only when triggered by state changes in the system.

These state changes are received from the sensing coil through the LDC chip utilising the interrupt (INTB) line, or changes in battery level prompting the user to change the battery. The sensor device is also woken up by signals from the wireless communications indicating that the user or smart-hub system wants to check the current state of the system.

EXAMPLE 2

The sensor system is first calibrated with a hub/smart phone as follows:

A wireless Comms network is established between the smart device and the sensor system. An application of the smart device acknowledges the established wireless Comms network between the smart device and the sensor system.

The application initiates the calibration process that directs a user to close the door or the window and physically mount the sensor system proximate to the door or window in known fashion.

The application confirms that the sensor system is mounted in a location that is within sensing range of the door or window and the sensor notifies the user *via* the application that the door or window is in the first closed or locked state.

The application initiates a further calibration process that directs the user to open the door of the window and the sensor notifies the user *via* the application that the door or window is in the further open or unlocked state.

The application reinitiates the above process depending on feedback of results during the calibration process. The application confirms completion of the calibration process, wherein the sensor system monitors and detects changes between the first state and the further state of the door or window and sends a notification by way of the wireless Comms network to the user's smart device.

Aspects of the present invention have been described by way of example only and it should be appreciated that modifications and additions may be made thereto without departing from the scope of the claims herein.

CLAIMS:

1. A sensor device for characterising a state of a closure object comprising:

an inductor configured to produce an electromagnetic field in use that interacts with a closure object in the vicinity, the closure object disturbing the electromagnetic field based on its state, the disturbed electromagnetic field influencing at least one electrical characteristic of the inductor, and

a processor configured to:

measure or receive a measure of at least one inductor parameter being or being indicative of the electrical characteristic, and

determine the state of the closure object based on the measure of the inductor parameter.

2. A sensor according to claim 1 wherein the processor determines the state of the closure device based on the measure of the inductor parameter and further on at least one reference corresponding to one or more possible states of the closure object.

3. A sensor device according to claim 1 or 2 wherein the measure of the inductor parameter comprises a plurality of values of the inductor parameter over time, wherein the processor determines the state of the closure object based on the plurality of values.

4. A sensor device according to any preceding claim wherein the state is an event of the closure device.

5. A sensor device according to claim 4 wherein determining the event comprises detecting the event, for example whether the event is occurring or has occurred.

6. A sensor device according to claim 5 wherein determining the event further comprises classifying the event.

7. A sensor device according to any one of claims 5 to 6 wherein the event is detected by identifying a change in the plurality of values.

8. A sensor device according to any one of claims 6 to 7 wherein the event is classified by a change in the plurality of values, and optionally by reference to an existing static state of the closure object.

9. A sensor device according to claim 9 the processor further configured to determine a static state of the closure object from the determined event.

10. A sensor device according to claims 3 wherein the determining the state comprises the processor:

detecting an event by identifying a change in the plurality of values,

classifying the event by identifying a change in the plurality of values,

and based on the classified event, and optionally an existing static state of the closure object, determining the static state of the closure object.

11. A sensor device according to any one of claims 3 to 10 wherein determining the state comprises identifying a change in the plurality of values between a first portion of the plurality of values and a second portion of the plurality of values.

12. A sensor device according to claim 11 wherein identifying a change in the plurality of values comprises determining a first metric of the first portion and a second metric for the second portion of the plurality of values, and determining the relationship between the first and second metrics; or alternatively determining a first metric of the first portion and the second portion of the plurality of values and determining the relationship between the first metric and a reference, such as statistical measure.

13. A sensor device according claim 12 wherein determining the relationship between the first and second metrics comprises determining how the first and second metrics differ with respect to a statistical measure, such as a standard deviation.

14. A sensor device according to claim 13 wherein determining the relationship comprises determining whether first metric for the first portion of data differs from the second portion of data by more than a number of standard deviations.

15. A sensor device according to claim 15 wherein the number of standard deviations is a reference.

16. A sensor device according to any one of claims 12 to 15 wherein a metric for the first or second portion of data; or for both the first and second portions of data is:

- the gradient,
- the range,
- the mean, and/or
- standard deviation.

17. A sensor according to any preceding claim wherein the state of the closure object is:

- a static state, for example open, closed, locked, unlocked or the like, and/or
- an event, such as:
    - a transition event (a change/transition in static state), for example opening, closing, locking, unlocking, moving, and/or
    - a miscellaneous and/or external event (null event), for example disturbance of the closure object such as knocking, bumping presence of movable body, traffic, wind, ground movement or the like.

18. A sensor device according to any preceding claim wherein the closure object is:
    - is a latch device, such as a bolt, lock, latch, hook, padlock, bar, clamp or other object that secures a covering object, and/or
    - covering object, such as a window, door, panel, lid or other object that closes off an aperture.

19. A sensor device according to any preceding claims wherein the electrical characteristic is one or more of:
    - Inductance
    - Inductor resonant frequency
    - Parallel resistance

20. A sensor device according to any preceding claim further comprising a transmitter coupled to the processor for transmitting the state determination.

21. A sensor device according to claim 20 wherein the state determination is transmitted to a:
- Hub
- Mobile device
- Server
- Monitoring system

22. A sensor system for characterising a state of a closure object comprising:

an inductor configured to produce an electromagnetic field in use that interacts with a closure object in the vicinity, the closure object disturbing the electromagnetic field based on its state, the disturbed electromagnetic field influencing at least one electrical characteristic of the inductor,

a processor configured to:

measure or receive a measure of at least one inductor parameter being or being indicative of the electrical characteristic, and

determine the state of the closure object based on the measure of the inductor parameter,

and

a transmitter for transmitting signals,

wherein the inductor and transmitter are disposed in a package for positioning near a closure object to determine its state, and the processor is in the package or external thereto.

23. A monitoring system comprising one or more sensor devices according to any one of claims 1 to 22, and a monitoring computer system in communication with the one or more sensor devices.

24. A sensor device comprising:

- a sensor for sensing the conductance of at least one object in a first state and at least one further state; and
- an inductor element for producing an electromagnetic field configured to measure the conductance of the at least one object in the electromagnetic field via parallel resistance of the inductor element sensed by the sensor;

wherein,

the sensor device is configured to detect changes between the first state and the at least one further state of the object and send a notification by way of a wireless communication network to a user communication device.

25. The sensor device as claimed in claim 24, wherein the sensor device detects less conductive objects manufactured out of wood, plastic materials and the like.

26. The sensor device as claimed in claim 24 or 25, wherein the inductor element detects movement and orientation of the objects in the magnetic field.

27. The sensor device as claimed in any one of claims 24 to 26, wherein the sensor is retrofitted to allow integration into existing window, door and like applications.

28. A sensor system for monitoring the status of an object in a first and second state comprising:

- a sensor for sensing the conductance of at least one object in a first state and the at least one further state, the sensor including an inductor element for producing an electromagnetic field configured to measure the conductance of the at least one object in the electromagnetic field via parallel resistance of the inductor element sensed by the sensor;
- an inductance-to-digital converter (LDC) for control of frequency signals sent to the inductor element, such that changes in frequency of sensing environment result in measured changes in conductance of the object and parallel resistance of the inductor element sensed by the sensor;
- a microcontroller (MCU) in communication with the LDC to allow for receiving of the parallel resistance and frequency measurements sensed by the sensor; and
- a wireless communication module to receive signals from the sensor via a user communication device;

wherein,

the sensor device is configured to detect changes between the first state and the second state of the object and send a notification by way of the wireless communication network to the user communication device.

29. A method of configuring a sensor system for monitoring the status of a door or window in a first state and at least one further state comprising the steps of:

- H. establishing a wireless communication network between a user communication device and the sensor system;
- an application of the user communication device acknowledging the established wireless communication network between the user communication device and the sensor system;
- J. the application initiating a calibration process that directs a user to close the door or the window and mount the sensor system proximate to the door or window;
- K. the application confirming the sensor system is mounted in a location that is within sensing range of the door or window and the sensor notifying the user via the application that the door or window is in the first closed or locked state;
- L. the application initiating a further calibration process that directs the user to open the door of the window and the sensor notifying the user via

the application that the door or window is in the further open or unlocked state;

- M. the application reinitiating steps D and E depending on feedback of results during the calibration process; and
- N. the application confirming completion of the calibration process, wherein the sensor system monitors and detects changes between the first state and the second state of the door or window and sends a notification by way of the wireless communication network to the user communication device.

30. The method as claimed in claim 29, wherein the wireless connection between the user communication device and the sensor system is established via a direct Bluetooth connection or a central hub.

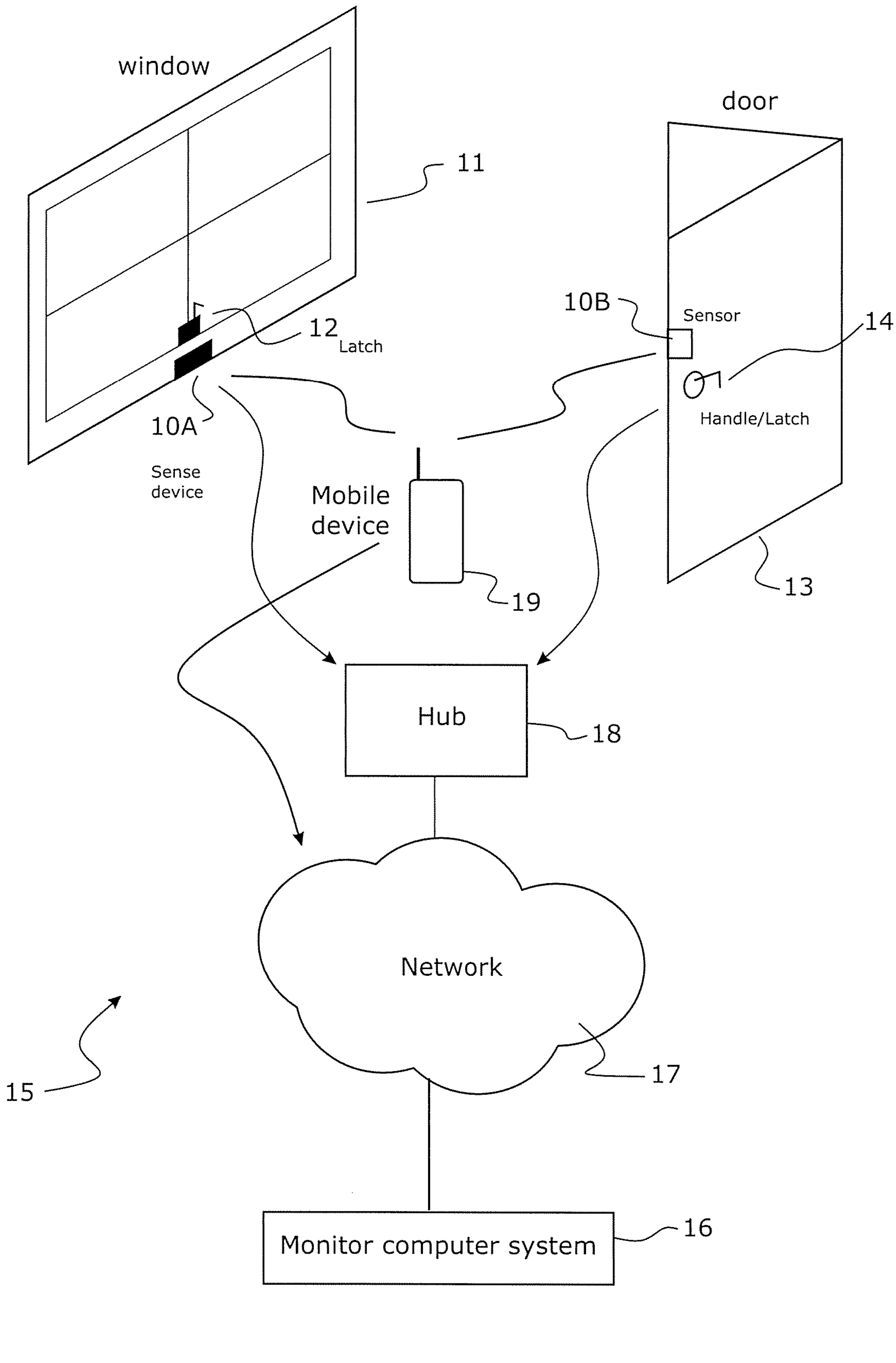

window
11
door
10B
Sensor
14
12
Latch
Handle/Latch
10A
Sense device
Mobile device
19
13
Hub
18
Network
17
15
Monitor computer system
16

FIGURE 1

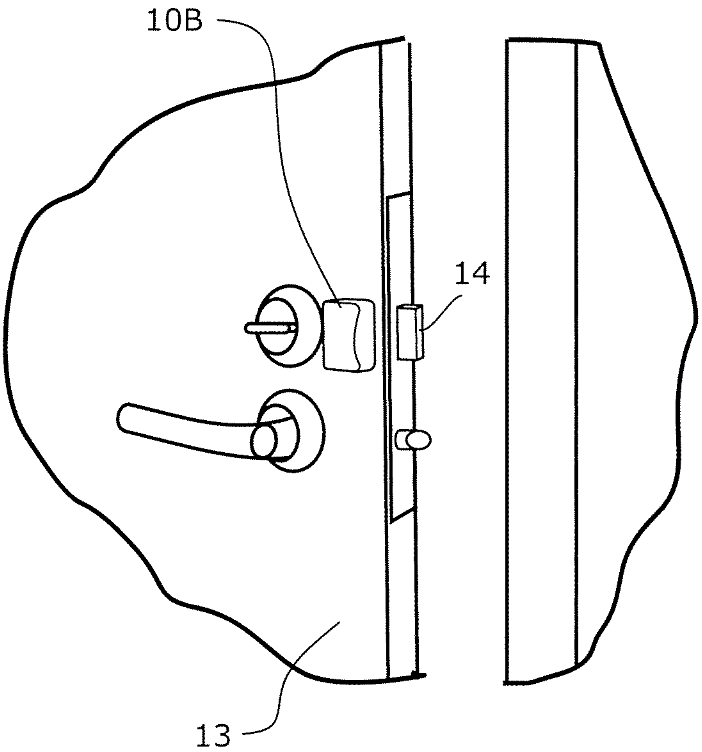


FIGURE 1A

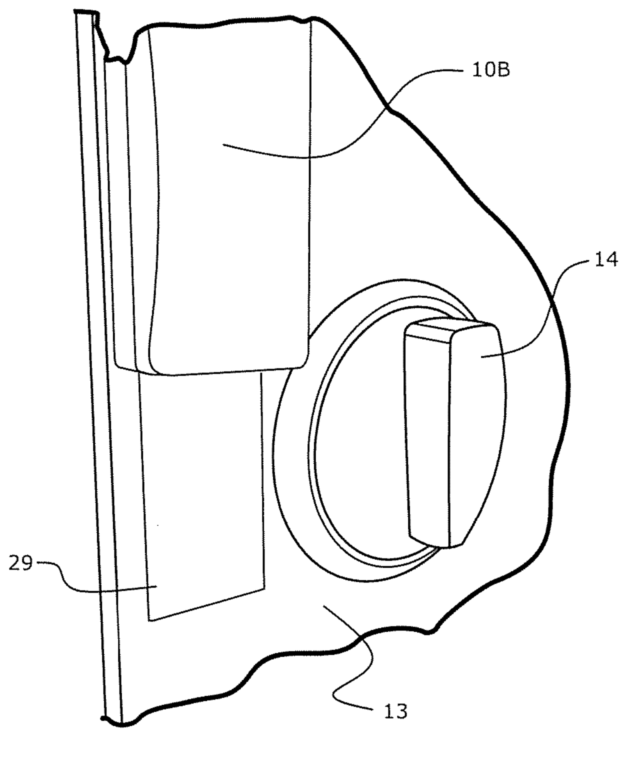
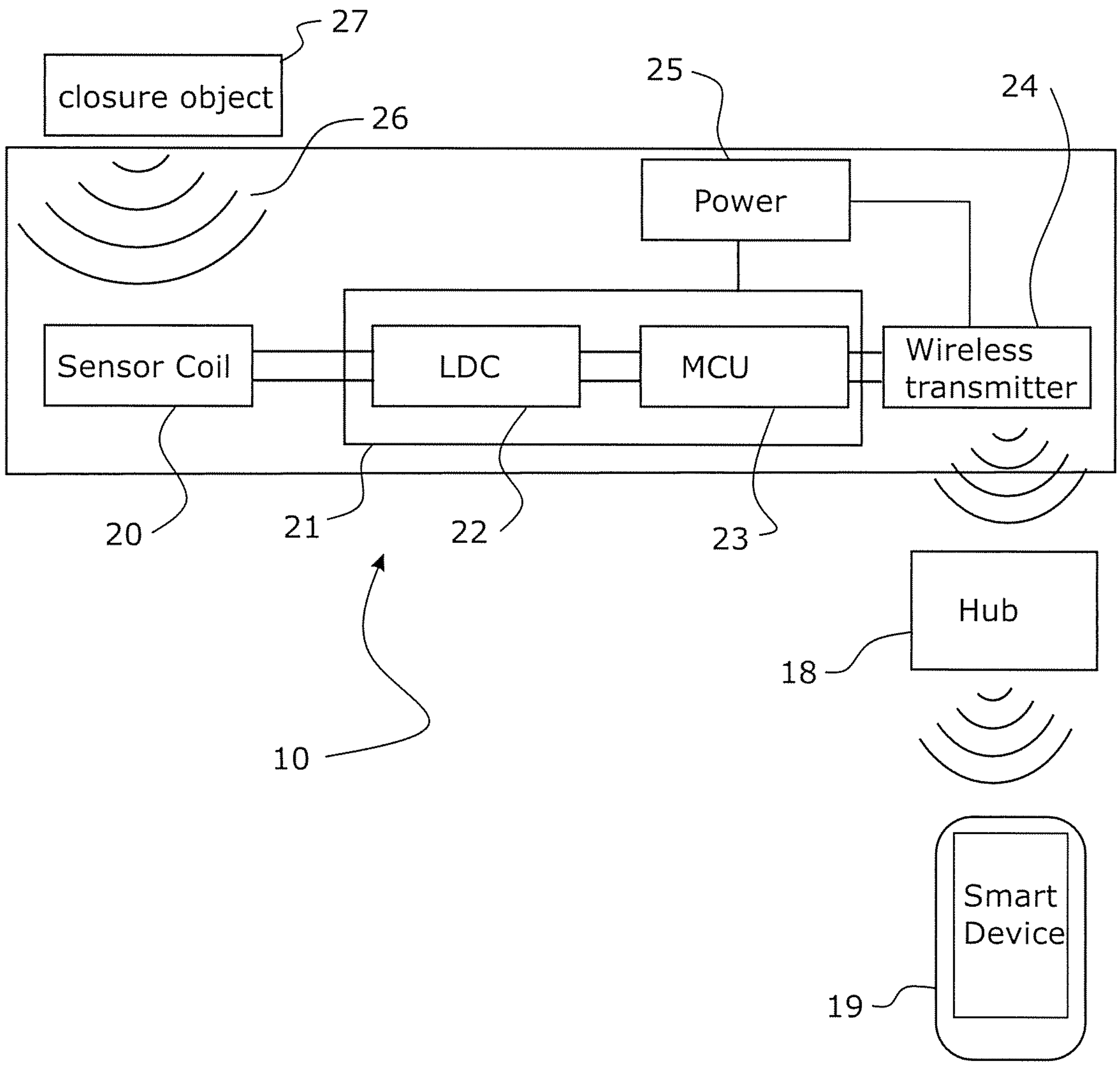


FIGURE 1B



27
closure object
25
24
26
Power
Sensor Coil
LDC
MCU
Wireless transmitter
20
21
22
23
Hub
18
10
Smart Device
19

FIGURE 2

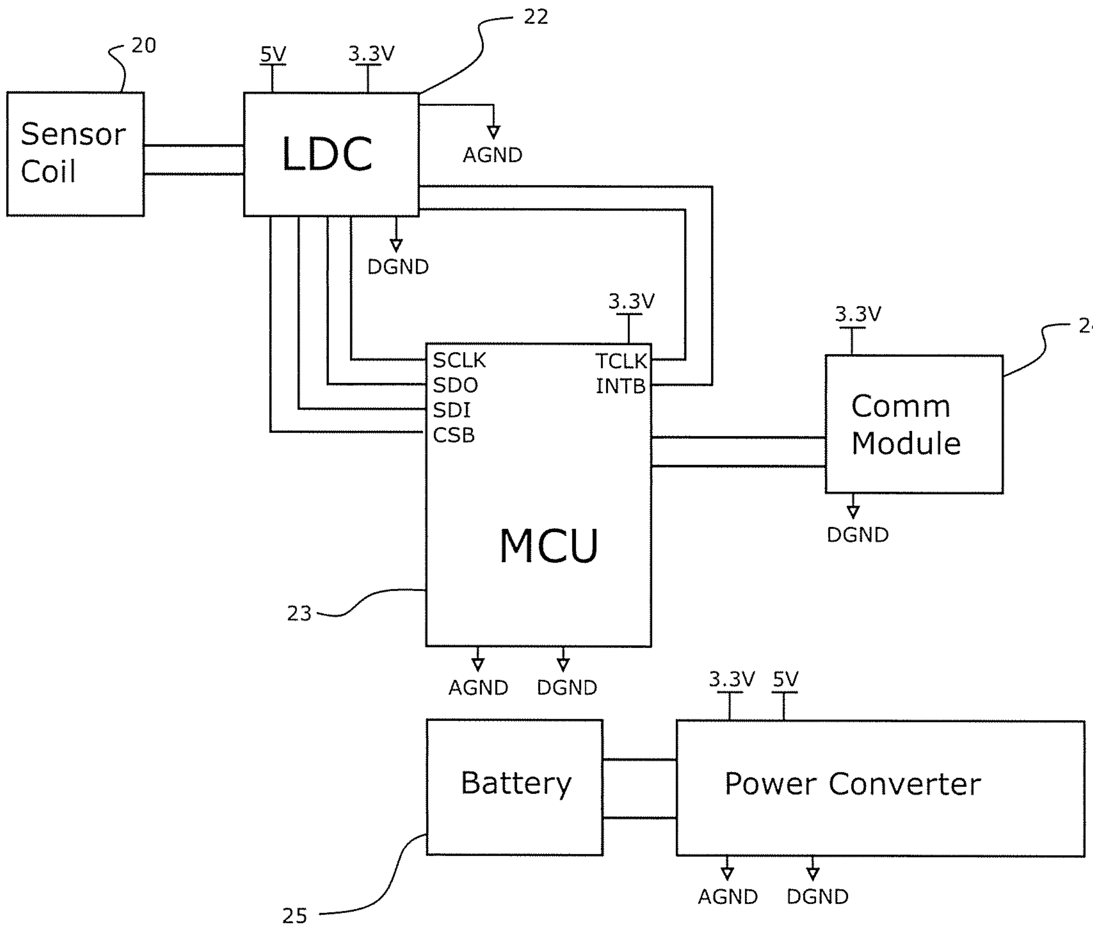

20
Sensor Coil
22
5V
3.3V
LDC
AGND
DGND
3.3V
SCLK
SDO
SDI
CSB
TCLK
INTB
MCU
23
3.3V
24
Comm Module
DGND
AGND
DGND
3.3V
5V
Battery
Power Converter
25
AGND
DGND

FIGURE 3

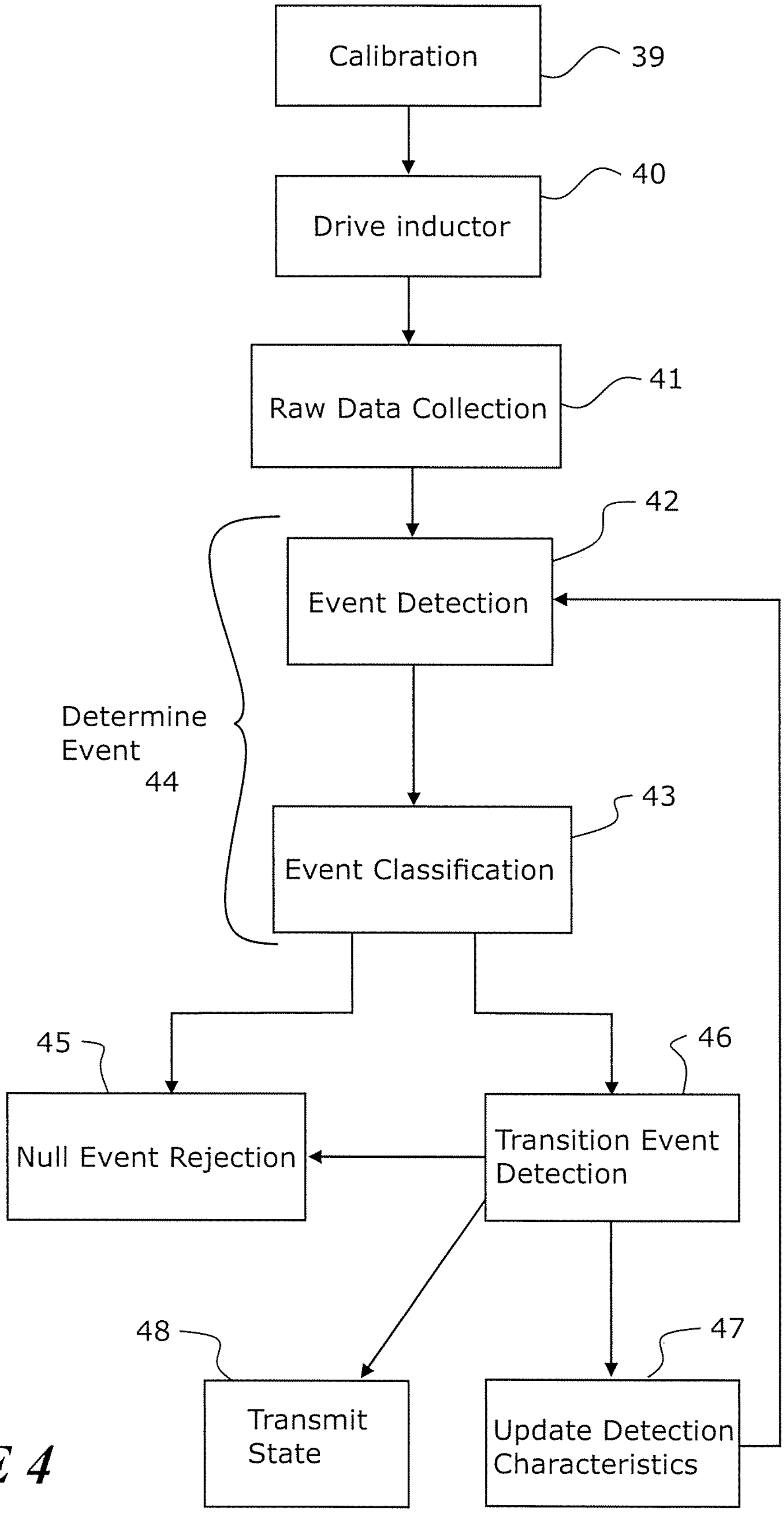

Calibration
39
Drive inductor
40
Raw Data Collection
41
42
Event Detection
Determine Event 44
43
Event Classification
45
Null Event Rejection
46
Transition Event Detection
48
47
Transmit State
Update Detection Characteristics

FIGURE 4

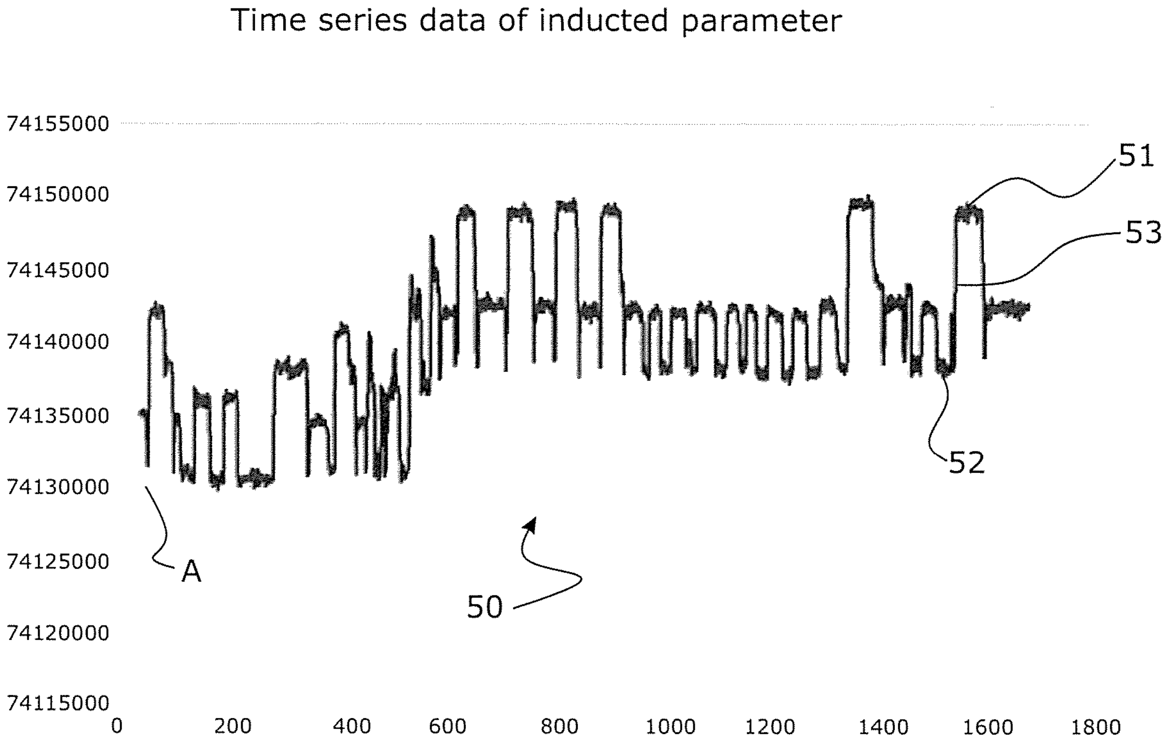


FIGURE 5

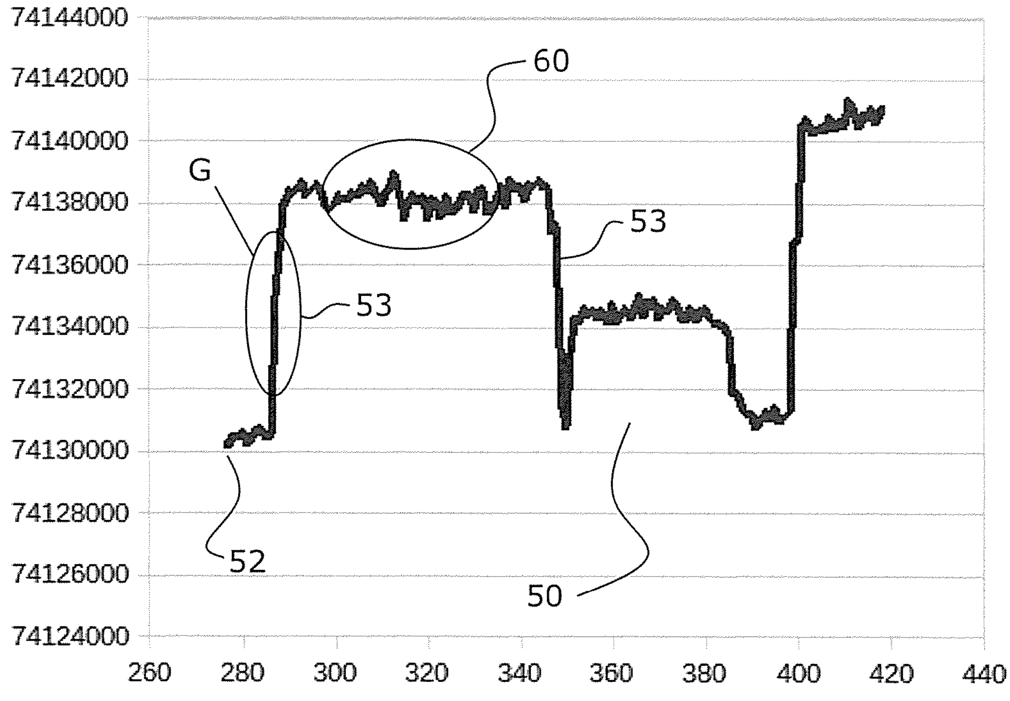


FIGURE 6

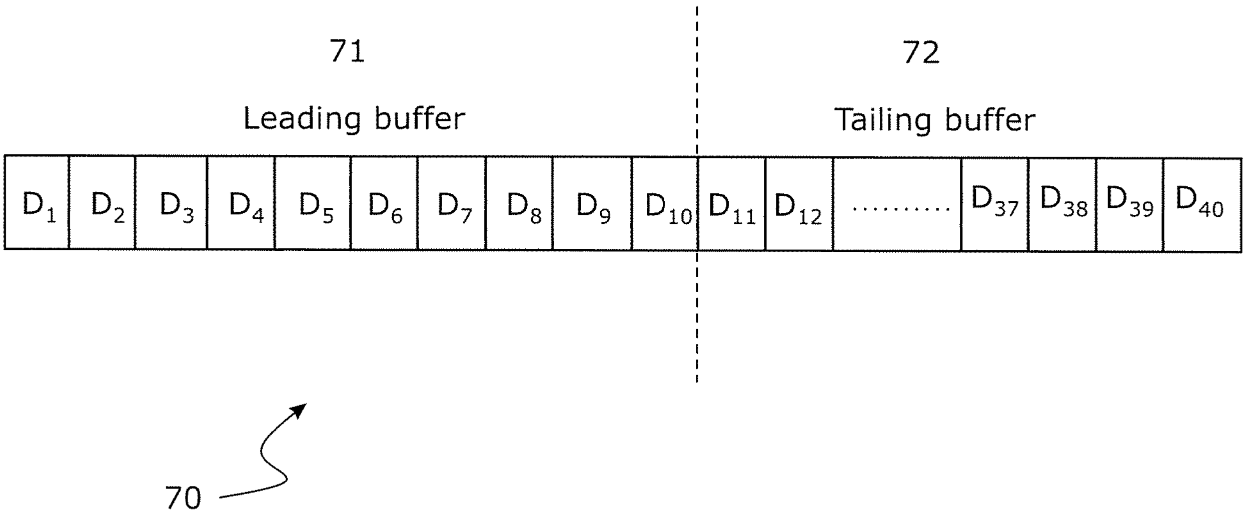

71
Leading buffer
72
Tailing buffer
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
....
D37
D38
D39
D40
70

FIGURE 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ2016/050204

A. CLASSIFICATION OF SUBJECT MATTER

G08B 13/00 (2006.01) G01B 7/14 (2006.01) G01B 13/00 (2006.01)

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)

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 practicable, search terms used)

Internal databases provided by IP Australia, AUSPAT and Espacenet search for applicant and inventor names; WPIAP, EPODOC database search with keywords [closure object sensing inductor, classifier, statistics] and similar terms. TXTE database search with keywords [closure object sensing inductor, classifier, processor] and similar terms. Google Scholar/Patents search with keywords [(door | window) position detector inductor, burglar alarm, classifier, neural network, statistics] and similar terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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
28 April 2017	27 April 2017

Name and mailing address of the ISA/AU	Authorised officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustralia.gov.au	Marthinus Van Der Westhuizen AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. 0262832283

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:

   because they relate to subject matter not required to be searched by this Authority, namely:

   the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including

2. ☐ Claims Nos.:

   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos:

   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

   1-23

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 5712621 A (ANDERSEN) 27 January 1998	
X	Title, abstract; claim 1; fig.1, 7, 8, 8A; col.1 ln.1-15; col.5 ln.28-53; col.7 ln.49-65	1, 2, 4-6, 9, 17-23
Y	whole of document	3, 7, 8 and 10-16
	US 2014/0062466 A1 (THIBAULT et al.) 06 March 2014	
X	Title, abstract; fig.8A, 13; par.0028, 0049-0050, 0054, 0058	1, 2, 4-6, 9, 17-23
Y	whole of document	3, 7, 8 and 10-16
	US 5519784 A (VERMEULEN et al.) 21 May 1996	
Y	Title, abstract; fig.3a, 6; equations in col.6; col.3 ln.12-16, col6 ln.4-11	3, 7, 8 and 10-16
	US 2423649 A (HORVITCH) 08 July 1947	
A	Whole of document	1-23

Supplemental Box

Continuation of: **Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1, 22 and 23 (together with the claims that append to them) are directed to a sensor device or system using an inductive element for detecting changes in the vicinity of an object, a processor for determining the state of the closure object based on the electrical parameter changes detected by the sensor. The feature of the processor determining the sensors electrical parameter changes is specific to this group of claims.
- Claims 24 and 28 (together with the claims that append to them) are directed to a sensor device or system for detecting changes in the vicinity of an object based on changes in electrical parameters and wirelessly communicate with a user communication device. The feature of the wireless communication of the changed electrical parameters is specific to this device.
- Claim 29 (together with the claims that depend on it) is directed to a method of configuring a sensor to communicate the status of a door or window with a user communication device and an application program to calibrate and configure the sensor. The feature of the user application program for wirelessly communicating an calibrating a sensor with the communication device is specific to this group of claims

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. The only feature common to all of the claimed inventions and which provides a technical relationship among them is a sensor device for detecting the state of an object such as a window or a door.

However this feature does not make a contribution over the prior art because it is disclosed in:

US 2423649 A (HORVITCH) 8 July 1947 as an example from many similar citations.

Therefore in the light of this document this common feature cannot be a special technical feature. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a posteriori*.

As the search and examination for the additional inventions will each require more than negligible additional search and examination effort over that for the first invention and each other, two additional search fees are warranted. Where appended claims introduce features of one of the claimed inventions and yet are additionally appended to claims directed to any other of the claimed inventions, such claims will only be searched and reported on to the extent that additional search fees have been paid for all such claimed inventions.

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		**Patent Family Member/s**	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
US 5712621 A	27 January 1998	US 5712621 A	27 Jan 1998
US 2014/0062466 A1	06 March 2014	US 2014062466 A1	06 Mar 2014
US 5519784 A	21 May 1996	US 5519784 A	21 May 1996
		AU 5150193 A	26 Apr 1994
		BR 9307213 A	30 Mar 1999
		CA 2146451 A1	14 Apr 1994
		EP 0664012 A1	26 Jul 1995
		EP 0664012 B1	14 May 1997
		WO 9408258 A1	14 Apr 1994
		ZA 9307447 B	25 Mar 1994
US 2423649 A	08 July 1947	US 2423649 A	08 Jul 1947

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.