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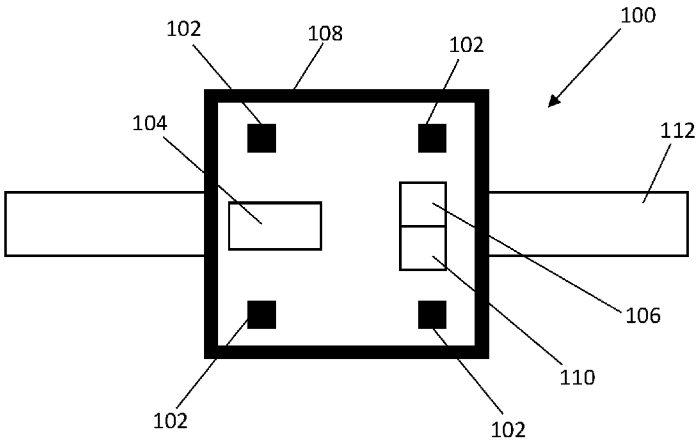

Figure 2

(57) **Abstract:** Disclosed is a wearable body (100) comprising (i) one or more electrodes (102) positioned at a location at which a non- contact gesture, performed by a wearer when wearing the wearable body, is detectable by the sensor device, (ii) an excitation source (104) for supplying an excitation signal to the one or more electrodes, (ill) a processor (106) for using the excitation signal to detect changes in capacitance of the one or more electrodes in response to the one or more electrodes building a respective electric field with an object performing the non-contact gesture, and processing the detected changes using a machine learning algorithm to identify the non-contact gesture.

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WEARABLE BODY COMPRISING CAPACITIVE SENSOR

Technical Field

The present invention relates, in general terms, to wearable bodies that employ capacitive sensory systems. Embodiments of the invention may be used in, but are not limited to, the sensing and recognition of hand movements/gestures.

Background

The rise of increasingly portable mobile devices (e.g. smart phones, smart watches, smart glasses, smart shoes, smart gloves, and smart pendants) has warranted more seamless human-device interaction requirements. In addition, as devices further miniaturize, the on-board power capacity is reduced. This therefore necessitates the use of sensors and electronics that consume as little power as possible.

These mobile devices are extremely portable and provide avenues to improve quality of life, such as continuously tracking a user's vital signal regardless of his/her activities and the ease of communication with other individuals through the mobile devices. However, the interaction signal integrity must be maintained regardless of the activities.

Current human-machine interaction implementations make use of physical touches on a touch screen. Resistive based touch digitizers are not a good implementation as there is a high possibility that foreign objects will randomly activate the screen. The most popular form of such implementation currently uses capacitance from physical touch. However, that implementation has further problems such as the inability to operate normally if the signal is not registered properly. Examples of situations in which a signal may not properly register include, but are not limited, use in water environments, and in winter environments particularly where thick gloves are needed. Signal distortions and reading errors depend on wet/dry conditions, conductive/non-conductive object touches and so on.

To mitigate these issues, proximity based interfaces have been proposed, that intend to avoid the requirement of touch. Several solutions have been proposed and studied such as the use of infrared imaging, visible imaging, and mm wave based radar. However, these solutions are either unsuitable for device miniaturisation, or power consumption requirements are too high to be suitable for on-board battery power supply.

It would be desirable to overcome or ameliorate at least one of the above-described problems, or at least to provide a useful alternative.

Summary

Disclosed herein are capacitive proximity sensing devices. Capacitive based proximity sensing appears to provide a more promising solution for avoiding or mitigating the abovementioned situational issues. For example, being generally passive in nature, there is zero (or near zero) off-state power (i.e. power usage when not sensing), thus reducing the power requirements. Some embodiments disclosed herein are coupled with or include machine learning algorithms. These provide the potential to be able to classify the kinds of gestures the wearer is executing, and refining the classification algorithm, thus providing a new and effective way of enabling human-device interaction.

"Capacitance sensing" is a technique for measuring distances of nearby conductive objects by measuring the capacitance between the sensor and the object and using a transmitter electrode and a receiver electrode. The magnitude of the receiving signal is proportional to the frequency and voltage of the transmitted signal, as well as to the capacitance between the two electrodes. Three different modes of capacitive proximity sensing are illustrated in Figure 1 namely, a transmit mode, a shunt mode, and a loading mode. In all cases, the modification of the electric field lines causes a detectable capacitance change and hence enables the "sensing" sensing function (e.g. using capacitance change to identify an event being sensed).

In this regard, disclosed herein is a wearable body comprising:

one or more electrodes positioned at a location at which a gesture, performed by a wearer when wearing the wearable body, is detectable;

an excitation source for supplying an excitation signal to the one or more electrodes;

a processor for:

using the excitation signal to detect changes in capacitance of the one or more electrodes in response to the one or more electrodes building a respective electric field with an object performing the gesture (the **detected changes**); and

processing the detected changes using a machine learning algorithm to identify the gesture.

The excitation signal (e.g. current or voltage) may be continuously supplied. The excitation signal may instead be supplied at regular intervals.

The wearable body may further comprise a plurality of capacitive sensors incorporated into the wearable body, each capacitive sensor comprising a plurality of electrodes. The capacitive sensors may be spaced around the wearable body.

The processor may be configured to:

sample the excitation signal to determine a capacitance of each electrode of the one or more electrodes; and

identify the gesture based on a relationship of a capacitance of a first said electrode relative to a capacitance of a second said electrode.

The processor may be configured to:

sample the excitation signal for each capacitive sensor to determine a capacitance of each capacitive sensor; and identify the gesture based on a relationship of a capacitance of a first of said capacitive sensors relative to a capacitance of a second of said capacitive sensors.

The processor may be configured to identify the gesture based on a spatial distribution of capacitance of the electrodes or the capacitive sensors. The processor be configured to identify the gesture based on a temporal change of capacitance of the electrodes or the capacitive sensors.

The processor may comprise a gesture recognition module for receiving:

a plurality of samples of the excitation signal; and

at least one weight input for weighting at least one said sample to influence an effect of the at least one sample on determination of the gesture, and wherein the gesture recognition module is configured to identify the gesture based on the plurality of samples and the at least one weight. The processor may be configured to update the at least one weight based on samples for which gestures have previously been determined.

The wearable body may further comprise a memory for storing at least one of (i) the samples of the excitation signal and (ii) the at least one weight.

The one or more electrodes may comprise a plurality of electrodes. The electrodes may be interdigitated to form a sensing area. The electrodes may be rectangularly interdigitated or circularly interdigitated. The electrodes may be disposed in a meandering arrangement. The one or more electrodes may be uniformly distributed across an area.

Each electrode of the one or more electrodes may comprise a silver-coated nanostructure.

The wearable body may further comprise a shielding layer positioned to be disposed between the one or more electrodes and the user, when the wearable body is being worn.

The wearable body may comprise one of, or at least one of, a glove, smartphone, watch, shoe, jewellery or glasses.

Advantageously, using the excitation signal to determine capacitance indirectly measures a change in displacement current in an electric field built by the respective electrode. Changes in displacement current occur when a gesture is being performed in the electric field by a grounded object or body – e.g. a user's hand. Moreover, displacement current change is proportional to the proximity of the grounded object or body to the electrode. Thus, each electrode, and e.g. its self-capacitance, can be used to determine a proximity of an object.

Embodiments herein provide high speed detection (e.g. gesture detection) while maintaining low power consumption. This is particularly the case when the solutions proposed herein are compared with existing methods – vision, radar wave, infrared.

Embodiments herein provide low cost, low complexity interdigitated electrode, capacitive sensors. The proposed system or wearable body uses extremely low cost interdigitated capacitor sensors that can be large scale manufactured with ease.

Embodiments herein provide conformal, mechanically robust sensors that use nanostructure infused silver conductors. The sensors can be manufactured on any kind of surface (e.g. plastic, glass, flat, non-flat, rigid, flexible). The infusion of nanostructures within the silver conductor ink allows the sensor to be more robust on flexible substrate.

Embodiments herein provide devices in which spatial and temporal data can be detected or inferred using a machine learning (ML) algorithm. Using a data set obtained using an array of uniformly distributed sensors, the implementation of ML algorithms disclosed herein is able to obtain spatial and temporal information, eventually identifying the gestures a user is performing to interact with the device, as well as to reject unwanted interference from the surroundings.

Brief description of the drawings

Embodiments of the present invention will now be described, by way of non-limiting example, with reference to the drawings in which:

Figure 1 is an Illustration of the different modes of capacitance proximity sensing namely, a transmit mode, a shunt mode, and a loading mode;

Figure 2 is a schematic illustration of a wearable body in accordance with present embodiments;

Figure 3 provides a) a photo image of a fabricated interdigitated electrode (IDE) sensor array, b) a testing setup for capacitance vs human finger spatial distance measurement, and c) an implementation of a shielding layer with a sensor;

Figure 4 is an illustration of a sensor implementation on a) a smartphone, b) a smart watch, c) a smart glasses, d) smart gloves, e) smart shoes, and f) a pendant;

Figure 5 illustrates a) capacitance as a function of sweep frequency, and b) capacitance as a function of human finger distance with different environmental conditions indicated in legend;

Figure 6 shows capacitance change of the sensors, with different situations indicated in the legend;

Figure 7 illustrates front, top, and side views of a watch, and how sensors are distributed in order to obtain datasets to be fed into machine learning algorithm to identify gestures and to reject unwanted interferences; and

Figure 8 illustrates various types of capacitance sensor design embodiments.

Detailed description

In the present disclosure, proximity capacitance sensors are proposed along with devices (wearable bodies) employing those sensors. In general, in the applications disclosed herein an array of capacitive proximity sensors is used for the control of portable mobile devices with displays. In embodiments, the sensor has or can be used in a "loading model" where self-capacitance of each electrode in an interdigitated electrode array is affected by the proximity of a large grounding body. The present sensor can be fabricated on various surfaces (e.g. non-flat, flexible, rigid) using a nanostructure infused silver conductor or silver-coated nanostructure to enhance mechanical robustness. Techniques disclosed herein can be used to print on various substrates (e.g. glass, plastics, wood).

The capacitive sensor can be uniformly placed across/around a mobile device (e.g. wearable body such as a smart phone, smart watch, smart glasses, smart shoes, smart glove, and a smart pendant), and interfaced with a sensing interface and processing unit of the device. In some embodiments, during operation, excitation signals are injected into all of the sensors or electrodes of each sensor and the capacitance values are read out at equal time intervals. In other embodiments, capacitance values are read out at different intervals, such as sequentially. Coupled with ML algorithms, the data set obtained can be used to obtain spatial and temporal information, eventually identifying the gestures a user is performing to interact with the device, as well as the ability to reject unwanted interference from surroundings.

Using the excitation signal to determine capacitance indirectly measures a change in the displacement current in an electric field built by the respective electrode. A system is therefore attached to the capacitive sensor to supply power to at least one of the electrodes of the capacitive sensor, to build the electric field. Changes in displacement current occur when a gesture is being performed in the electric field by a grounded object or body – e.g. a user's hand.

Moreover, displacement current change is proportional to the proximity of the grounded object or body to the electrode. Thus, each electrode (e.g. its self-capacitance) can be used to determine a proximity of an object. As a result, the capacitive sensors disclosed herein can be used in sensing and gesture recognition, by being located on a wearable object positionable on the body so that gesture movements result in a change in displacement current between an object performing a gesture (e.g. a hand) and at least one electrode of the plurality of electrodes forming the capacitive sensor.

By exploiting this electrical mechanism, proximity sensing can be achieved, that is not limited by the kind of object (conductor/non-conductor) that interacts with the device or sensor. In addition, being passive in nature, there is zero off-state power, thus reducing power requirement. The described technology finds opportunities in areas where non-contact is required such as proximity gesture sensing for human-machine interaction as described herein.

Sensors described herein can be used in various modes as illustrated in Figure 1. The circuit 114 shown in Figure 1a comprises a source 116 presently in the form of a 30 to 100 kHz oscillator or battery. The source 116 supplies power to the circuit 114. The circuit 114 as a transmitting electrode 118 that transmits current 120 in the direction of a receiving electrode 122 that receives current 124. Between the transmitting electrode 118 and the receiving electrode 122, an open circuit capacitance C_o 126 exists. That capacitance is the capacitance between electrodes 118, 122 when there is no object affecting the magnetic field therebetween. As shown in the circuit 114, a grounded body 128 is interfering with the magnetic field between electrodes 118, 122. As a result, a capacitance C_t 130 is set up between transmitting electrode 118 and body 128. Similarly, a capacitance C_r 132 is set up between the body 128 and electrode 122. In proximity of the body 128 to one or both electrodes 118, 122 affects the capacitance read from one or both of those electrodes. Thus the proximity of the body 128 can be inferred from the capacitance reading. To achieve this, a detector 134 receives current 124 and also receives an input from the oscillator 116. These two inputs are synchronised, the detector 134 being in the present embodiment a synchronous detector, to determine the effect of the presence of the body 128 on the magnetic field between electrodes 118 and 122. To facilitate accurate detection, the current 124 may pass through a trans-impedance amplifier 136. Similarly, the signal from oscillator 116 may pass through a phase shifter 138. The synchronous detector 134 outputs the signal – e.g. to an analogue-to-digital converter 140 – for gesture recognition.

Figure 1c illustrates the use of circuit 114 in a device in "shunt mode". In this mode, the grounding capacitance C_g of the body 128 is greater than the transmitting capacitance 130. Part of the electromagnetic field 142 established between electrodes 118, 122 is grounded through the body 128. Therefore, current 124 is less than current 120. The amount of current that is absorbed, depends on the amount of the electromagnetic field 142 that is inhibited by body 128 and thus the location of the body 128 relative to that field 142. Therefore, location information about the body 128 can be inferred by reading current 124. In embodiments providing detection in a shunt mode, at least two electrodes are required so that detection of a body in the electromagnetic field established between those electrodes can be detected.

Figure 1b illustrates the use of a circuit in a device in a "transmitting mode". In the transmitted mode, a transmitting electrode 144 is attached to a body 146. When transmitting, and electromagnetic field 148 is established between transmitting electrode 144 and receiving electrodes 150. The strength of the electromagnetic field 148 is detected at receiving electrode 150 depends on the proximity of body 146, and thus of electrode 144, to electrode 150. Again, proximity information of body 146 to electrode 150 can therefore be obtained by reading the output of electrode 150 – e.g. the current received at, or generated out, electrode 150. In a transmitting mode, again at least two electrodes are required so that the distance between electrodes can be detected.

Figure 1d illustrates the use of a circuit in a device in a "loading mode". In the loading mode, and transmitting electrode 154 transmitting current 156. An object 152 interferes with the field generated by transmitting electrode 154.

The degree of interference, and thus the level of self-capacitance of electrode 154, depends on the proximity of body 152 to electrode 154. Thus, the self-capacitance of electrode 154, and thus the proximity of the body 152 to electrode 154, can be determined by measuring the transmitting current 156. In a loading mode, only one electrode is required since loading mode operates on the basis of self-capacitance.

In each of these embodiments, the electrode or electrodes may be positioned on a flexible substrate, a rigid substrate or, where multiple electrodes are provided, substrates of various materials. Moreover, these embodiments operate off changes in capacitance. Therefore, the material from which each substrate is formed may be, in some circumstances, any material since it is expected that the material may have a uniform impact on capacitance regardless of proximity of an object or of one electrode relative to another.

A device (hereinafter interchangeably referred to as a wearable body) 100 that is shown in Figure 2, employs such a loading mode of capacitive sensing. The body 100 comprises one or more electrodes 102 positioned at a location at which a gesture, performed by a wearer when wearing the wearable body 100, is detectable. The body 100 further includes an excitation source 104 for supplying an excitation signal to the one or more electrodes 102 of which there are presently four, and a processor 106 for using the excitation signal to detect changes in capacitance of the one or more electrodes 102 in response to the one or more electrodes 102 building a respective electric field with an object (e.g. the user's hand) performing the gesture. The processor also processes the detected changes using a machine learning algorithm to identify the gesture being performed by the wearer. The "wearer" will typically be a person and the "gesture" will typically be a movement (e.g. finger or foot movement) performed by the person. For example, when a user's finger comes into proximity of one of electrode 102 it will detectably affect the self-capacitance of that electrode and thus indicate the location of the user's finger relative to device 100. The wearer may instead be another object (e.g. articulated robotic arm or other device) that can perform a movement desired to be detected (the gesture). In some embodiments, the device 100 also includes a shield layer 108 and/or memory 110. The present device 100 is in the form of a smartwatch, having a band 112.

Current smart devices (e.g. smartphones, smartwatches, smart glasses, smart gloves, smart shoes, and smart pendants) use capacitive touch for human-machine interaction. However, they can only recognize well-defined capacitance changes in touch locations for desired interactions. If there are various unintended inputs that distort the capacitance readings, the device will be unable to interpret the readings and thus desired interactions will not be obtained. In situations such as in wet environment or when direct human finger touch is not convenient, desired interaction becomes an issue. This becomes an issue, for example, when attempting to track swimming during which capacitive readings become erratic due to water interference, and when sensing hand gestures of a hand covered with a glove where the capacitive effect of normal human finger interaction is lost.

The same can be applied to industry such as in the food and beverage sector where hygiene is extremely important. In order to reduce risks for consumers, production operators can adopt a non-touch control in the production line.

With the use of a ML algorithm to process a data set obtained via an array of proximity sensors, spatial and temporal information can be obtainable. This allows the identification of intended gestures for interaction, as well as the rejection of unwanted gestures from surroundings. For example, with reference to the device 100, the proximity of a user's finger relative to each of the electrodes 102 may be detected. These proximity measurements can be analysed over time to determine the location of the user's finger anywhere on the surface of the device 100. The processor 106 can therefore probabilistic Lee determine the location of the user's finger on the surface of the device, and infer from that location the user's intention with the gesture the finger is performing. As a consequence, the number of 'buttons' (virtual or physical) or items displayed to the user that can be selected by the user can exceed the number of electrodes 102.

Sensors having functions described herein may be additively printed using an aerosol jet printer in the form of an interdigitated electrode (IDE) capacitor design. The capacitors or sensors can be printed on a variety of substrates (e.g. plastic, glass, flat, non-flat, flexible, rigid materials or fabrics). In testing, in order to enhance the robustness of the sensors, a good conductivity ink (Silver) was chosen and infused with some (5%) carbon nanotubes (CNT). It is to be noted that other nanostructures such as nanowires can also be used. The sensor size can be modified depending on the final size of the product required. As a preliminary test, IDE capacitors of size 2 mm x 2 mm are fabricated on a piece of flexible substrate (kapton) – see Figure 3a. The flexible substrate allows easy integration onto non flat surface.

For proximity testing, one IDE capacitor sensor was connected to a high precision Inductance, Capacitance, Resistance (LCR) meter for capacitance read out over wide range of frequencies from 10 kHz to 1 MHz. The LCR meter generates an excitation signal to create an electric field, of which the electrical quantity – capacitance – is read back to analyze the environment the sensor is placed in. Two kinds of measurements were taken. The first measurements obtained the capacitance as a function of the excitation frequency to find the optimum frequency. The second measurements obtained the capacitance when the distance between the IDE capacitor and a human finger is varied (Figure 3b). In addition, the measurements are taken with/without the use of a shielding layer to control the sensitivity and directional dependence proximity sensing effects (Figure 3c). In use, a shielding layer is positioned so that it is disposed between the electrode(s) and the user during use of the wearable body.

In Figure 3c(i), no shield was used. As a result, the capacitance established between the interdigitated electrodes 300, 302 was unaffected by any shielding layer. However, the electrodes 300, 302 may be exposed to degradation from the surrounding environment. In Figure 3(ii), tape was used to attach a shield over the field between the electrodes 304, 306. The tape, and the shield attached thereto, did not extend past the lateral boundaries of the electrodes 304, 306. Instead, the tape, and the shield attached thereto, was limited to the area between the electrodes 304, 306. In Figure 3(iii), the entire area of electrode 308, 310 was covered by tape and a shield, the tape and shield extending past the lateral boundaries of the electrodes 308, 310. In Figure 3(iv), the same arrangement as that shown in Figure 3(iii) was used, with an additional lateral shield co-planar with the electrodes 312, 314. This embodiment effectively provided a volume enclosing the electrodes 312, 314. Accordingly, the electrodes 312, 314 were prevented from exposure to the environment, and thus to any degradation that would result from that exposure.

Due to the mechanical robustness of the present sensors, arrays of them can be integrated into various kind of devices (e.g. smart phones, smart watches, smart glasses, smart gloves, smart shoes, and smart pendant or other piece of jewellery) as illustrated in Figure 4. The locations of the sensors enable them to be used in various modes of operation – e.g. shunting, transmitting and/or loading. For example, the electrodes in Figure 4(a), 4(c), 4€ and 4(f) may be used in a loading mode. Similarly, the electrodes in Figure 4(b) may, in the case of the electrodes around the watch face 400, be used in a loading mode and, in the case of the electrodes provided on the watchband 402, be used in a shunting mode as described with reference to Figure 7. The electrodes shown in Figure 4(d) may also be used in a loading mode, or in a transmitting mode when the electrodes attached to the fingers 404 of the glove 406 are brought into proximity of those attached to the palm 408.

As shown in Figure 4, the wearable body in each case may comprise one capacity sensor or, a plurality of capacitive sensors, each capacitive sensor comprising a plurality of electrodes (or a single electrode when used in the loading mode). The sensors are spaced around the wearable body in each case where multiple sensors are used. This enables the relative location of different objects to be determined, therefore increasing the number of, for example, gestures that can be detected by the wearable body.

This enables a processor incorporated into the wearable body to sample the excitation signal (or received signal – e.g. received current) to determine the capacitance of each electrode, and to determine a gesture based on a relationship of the capacitance of the first of the electrodes relative to a capacitance of a second of the electrodes. That relationship may be the absolute value of capacitance of the electrodes, or some other relationship between capacitances thereof. In other words, the relative capacitance between electrodes can be used to determine the gesture being performed by the wearable body – e.g. the gesture being performed by a glove on a user's hand.

In some embodiments, combinations of capacitance values can be used to determine gestures. For example, the processor may be configured to determine the gesture being performed based on the spatial distribution of capacitance of the electrodes or the capacitive sensors is determined from the currents received by those sensors. To facilitate accurate gesture detection, the electrodes may be uniformly distributed across an area, or may be located at locations that are critical for gesture detection.

In some embodiments, the processor may also be configured to determine a gesture being performed based on the temporal change of capacitance of the electrodes or the capacitive sensors. For example, the rate of performance of a gesture may change the interpretation of that gesture – e.g. fast or slow closing of a hand into a fist may be interpreted to be different commands.

Figure 5(a) shows the sensitivity of the IDE capacitor as a function of the sweep frequency, with various distances a human finger (1cm, 5cm, 10cm and 15cm) is located from it indicated in the legend. An excitation frequency >100kHz is seen to provide good spatial resolution. The electrodes are interdigitated to form a sensor having a sensing area. In Figure 5(b), the capacitance relationship is shown with respect to the spatial distance of a human finger at an excitation frequency of 100 kHz. Distances up to 16 cm can be resolved and reflected in the capacitance reading. Different environmental conditions are also reflected in this data. For example, with increased interference from moisture the capacitance on the left-hand axis increases. The capacitance similarly increases, albeit to a lesser extent, with the distance of the object from the sensor. Notably, the effect of water was much greater on an acrylic substrate when compared with a glass substrate.

In some embodiments, the excitation signal is continuously supplied. In other embodiments, the excitation signal is supplied at regular intervals. In the latter case, power is conserved although the responsiveness of the wearable body is reduced.

In the next demonstration, the sensor is shown integrated on a human wrist (e.g. smart watch) and the capacitance measurements taken with various situations as an illustration. Figure 6 shows the measured capacitance vs electrode locations with various situations as indicated in the legend. The locations of the placed sensors along the watch strap and watch case corresponds to the labelled photo in Figure 4(b).

In the actual use case, clear indication of capacitance change (100 pF) can be seen and detected, validating its use for proximity sensing. In the above, the detection of a single sensor capacitance change is demonstrated. In the actual implementation, all the sensor capacitances can be detected simultaneously to allow for gesture identification using a machine learning algorithm such as a Quadratic Discriminant Analysis Model – the manner of employing a machine learning algorithm to the detected sensor capacitances (and other quantities as needed) will be known by the skilled person in view of the present disclosure and need not be described in greater detail than that provided herein. The illustrative embodiment of a watch implementation is described below. The processor 106 may therefore include a gesture recognition module that receives a plurality of samples of the excitation signal (from the one or more sensors) and at least one weight input. The weight input is used for weighting at least one of the samples to influence the effect of that sample or samples on the determination of the gesture – i.e. in determining which gesture has been performed. Thus for gesture recognition module is configured to determine the gesture based on the plurality of samples and the weight. To enable the processor to learn, the weight or weights may be updated based on sample for which gestures have previously been determined. Such a process may involve back propagation of gradient error in a known manner into levels of a machine learning or neural network architecture. To achieve this, memory 110 is required to store one or both of the samples of the excitation signal and the weight or weights.

To generate the readings shown in Figure 6, electrodes are placed at specific locations around a watch casing (i.e. face or dial) and across the watch stripe, strap or band (Figure 7). Depending on the location of the electrodes, X-axis, Y-axis and Z-axis information of the location of the hand/finger/other parts of human body can be obtained. X- and Y-axis information is most appropriate for sensors placed around the watch face 700 whereas Z-axis information is most appropriate for sensors placed around the watchband 702. During operation, excitation signals are injected into all the sensors and the capacitance values are read out at equal time intervals. As a hand approaches a specific electrode, change in capacitance is observed. This allows obtention of 1) spatial information (the location of where the hand is at), and 2) temporal information (the time at which the hand is nearest to individual electrode). The given information is used to identify the movement and gesture of the hand/finger/other parts of human body based on the proximity and the time at which the part is near the individual electrodes. This information is leveraged by a smart machine learning algorithm in order to identify complex gestures and movement controls accurately. In addition, through the machine learning algorithm, the system has the ability to reject unwanted interferences from the surroundings, and the potential ability to identify the user interacting with it. One additional advantage to sensory arrangements such as those disclosed is that the number of objects with which the user may interact can exceed the number of electrodes. For example, in some embodiments, a user may only be able to directly interact with individual electrodes, or combinations of electrodes. In these embodiments, the number of interactions is determined from the number of electrodes and combinations thereof. In other embodiments a user may interact with any space detectable by the electrodes. For example, the location of a user's finger can be detected at any location over a continuous distance between two electrodes. Therefore, the number of objects such as physical or virtual buttons, or any other feature, between the two electrodes that can be used to infer desired functions when selected by the user's finger is limited by the resolution of detection of the location of the user's finger. For example, if an elongated rigid substrate had an electrode placed at either end, with the alphabet printed onto the substrate between those electrodes, the user may select any letter in that alphabet on the location of the user's finger and thus of the letter being selected will be detectable by the relative distance of the user's finger to one or both of the electrodes.

Figure 8 shows various electrode configurations. Some of the electrode configurations are more suitable for use in particular modes of operation described above with reference to Figure 1. For example, in Figure 8a a single electrode 800 is shown that is appropriate for use in a loading mode such as that shown in Figure 1d. Figure 8b and 8c shows, respectively, interdigitated electrodes in a rectangular array and a circular array, while Figure 8 d and 8e shows electrodes in a meandering form. These electrodes (i.e. sensors or sensor arrangements) are appropriate for use in a shunting mode.

The preliminary data as shown in the above figures demonstrates the potential of the capacitive proximity sensing method to eventually be used as an interacting interface between a human and a device without the need to perform physical touch. In addition, it is seen that even under wet environment, sensitivity is maintained. Hence, this technology is very suitable to be used as an alternative interacting method for portable/mobile devices. In addition, with the spatial and temporal capacitance data obtained over a large number of sensors placed across or around the portable device, they can be input into machine algorithm to further classify the gesture a person is performing to interact in a controlled way with the portable device, and the ability to reject unwanted interferences from the surroundings.

The use of above mentioned sensor designs is not limited to only the IDE form. The sensor design can include those illustrated in Figure 8 that includes (Figure 8a) plate, (Figure 8b) rectangular interdigitated, (Figure 8c) circular interdigitated, and (Figure 8d and 8e) meandering form.

It will be appreciated that many further modifications and permutations of various aspects of the described embodiments are possible. Accordingly, the described aspects are intended to embrace all such alterations, modifications, and variations that fall within the spirit and scope of the appended statements or claims.

Throughout this specification and the statements or claims which follow, unless the context requires otherwise, the word “comprise”, and variations such as “comprises” and “comprising”, will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

Claims

1. A wearable body comprising:

one or more electrodes positioned at a location at which a gesture, performed by a wearer when wearing the wearable body, is detectable;

an excitation source for supplying an excitation signal to the one or more electrodes;

a processor for:

using the excitation signal to detect changes in capacitance of the one or more electrodes in response to the one or more electrodes building a respective electric field with an object performing the gesture (the **detected changes**); and

processing the detected changes using a machine learning algorithm to identify the gesture.

2. The wearable body of claim 1, wherein the excitation signal is continuously supplied.

3. The wearable body of claim 1, wherein the excitation signal is supplied at regular intervals.

4. The wearable body of any one of claims 1 to 3, the wearable body further comprising a plurality of capacitive sensors incorporated into the wearable body, each capacitive sensor comprising a plurality of electrodes.

5. The wearable body of claim 4, wherein the capacitive sensors are spaced around the wearable body.

6. The wearable body of claim 4 or 5, wherein the processor is configured to:

sample the excitation signal to determine a capacitance of each electrode of the one or more electrodes; and identify the gesture based on a relationship of a capacitance of a first said electrode relative to a capacitance of a second said electrode.

7. The wearable body of claim 4 or 5, wherein the processor is configured to:

sample the excitation signal for each capacitive sensor to determine a capacitance of each capacitive sensor; and

identify the gesture based on a relationship of a capacitance of a first of said capacitive sensors relative to a capacitance of a second of said capacitive sensors.

8. The wearable body device of claim 6 or 7, wherein the processor is configured to identify the gesture based on a spatial distribution of capacitance of the electrodes or the capacitive sensors.

9. The wearable body of any one of claims 6 to 8, wherein the processor is configured to identify the gesture based on a temporal change of capacitance of the electrodes or the capacitive sensors.

10.The wearable body of any one of claims 6 to 9, wherein the processor comprises a gesture recognition module for receiving:

a plurality of samples of the excitation signal; and

at least one weight input for weighting at least one said sample to influence an effect of the at least one sample on determination of the gesture, and wherein the gesture recognition module is configured to identify the gesture based on the plurality of samples and the at least one weight.

11.The wearable body of claim 10, wherein the processor is configured to update the at least one weight based on samples for which gestures have previously been determined.

12.The wearable body of claim 10 or 11, further comprising a memory for storing at least one of (i) the samples of the excitation signal and (ii) the at least one weight.

13.The wearable body of any one of claims 1 to 12, wherein the one or more electrodes comprises a plurality of electrodes.

14.The wearable body of claim 13, wherein the electrodes are interdigitated to form a sensing area.

15.The wearable body of claim 14, wherein the electrodes are rectangularly interdigitated or circularly interdigitated.

16.The wearable body of claim 13, wherein the electrodes are disposed in a meandering arrangement.

17.The wearable body of any one of claims 1 to 16, wherein the one or more electrodes are uniformly distributed across an area.

18.The wearable body of any one of claims 1 to 17, wherein each electrode of the one or more electrodes comprises a silver-coated nanostructure.

19.The wearable body of any one of claims 1 to 18, further comprising a shielding layer positioned to be disposed between the one or more electrodes and the user, when the wearable body is being worn.

20.The wearable body of any one of claims 1 to 19, wherein the wearable body comprises at least one of a glove, smartphone, watch, shoe, jewellery or glasses.

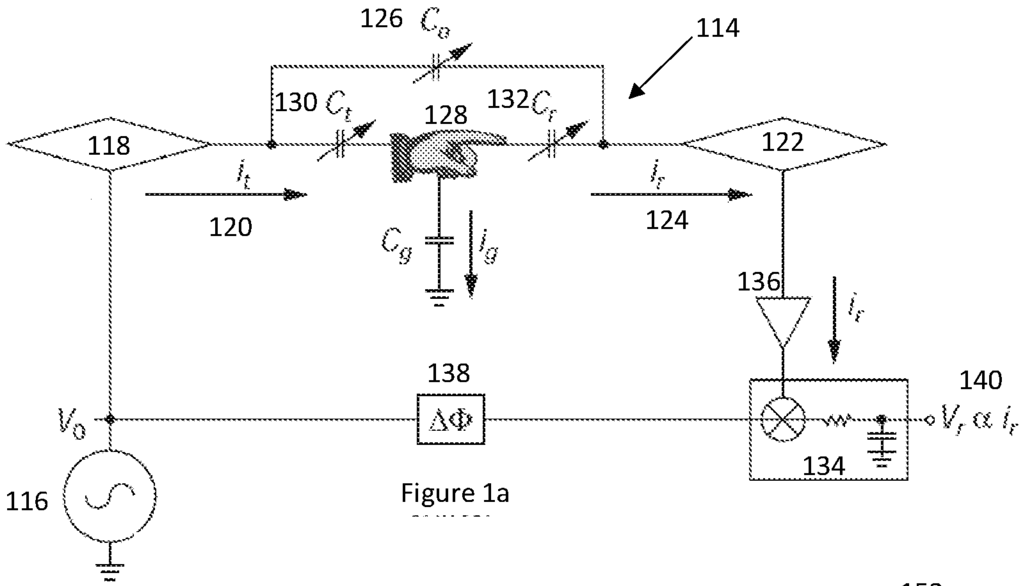
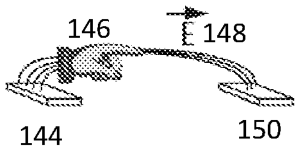
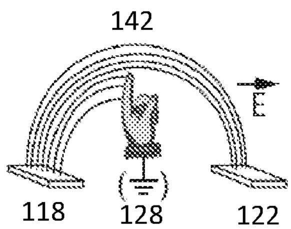


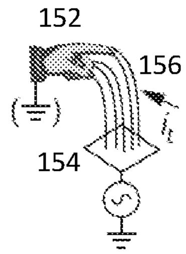
Figure 1a



(C_t>>C_g)
Figure 1b



(C_g>>C_t)
Figure 1c



(measure I_t)
Figure 1d

Figure 1

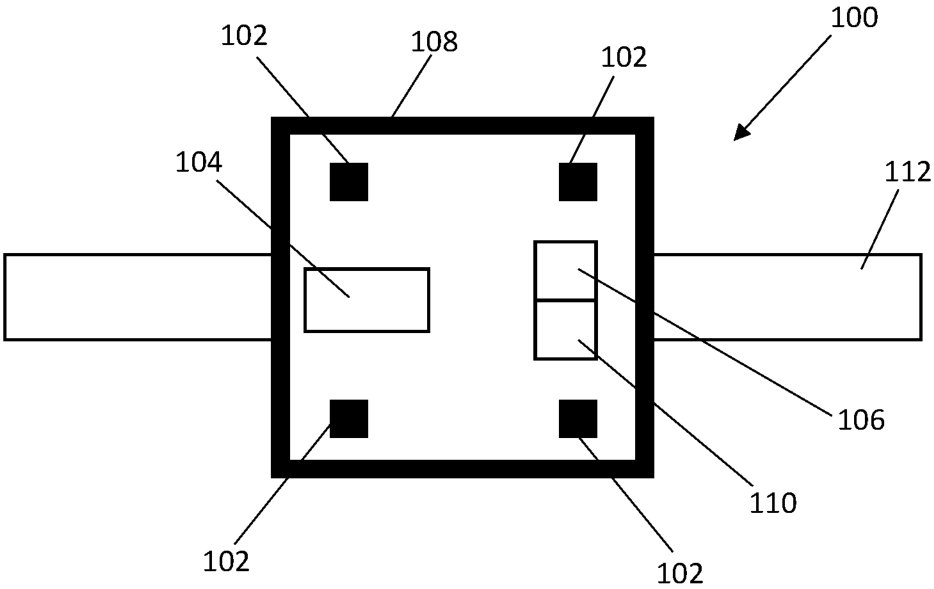


Figure 2

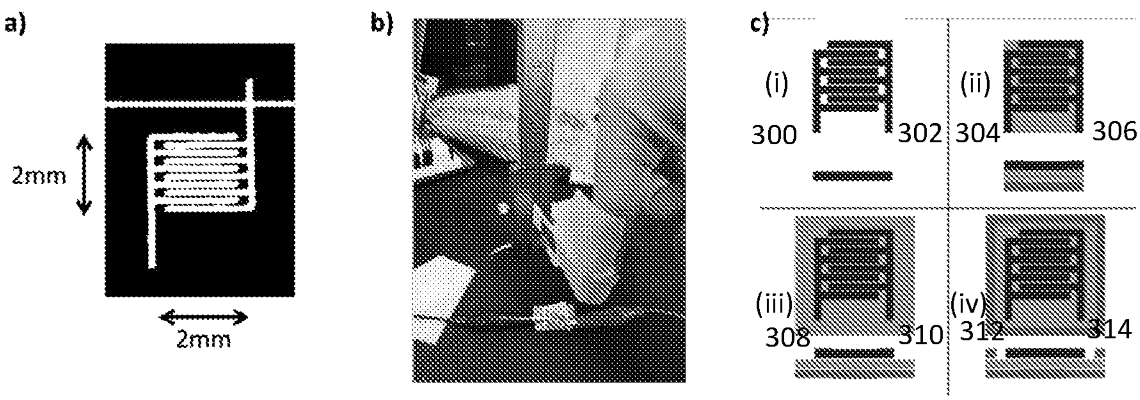


Figure 3

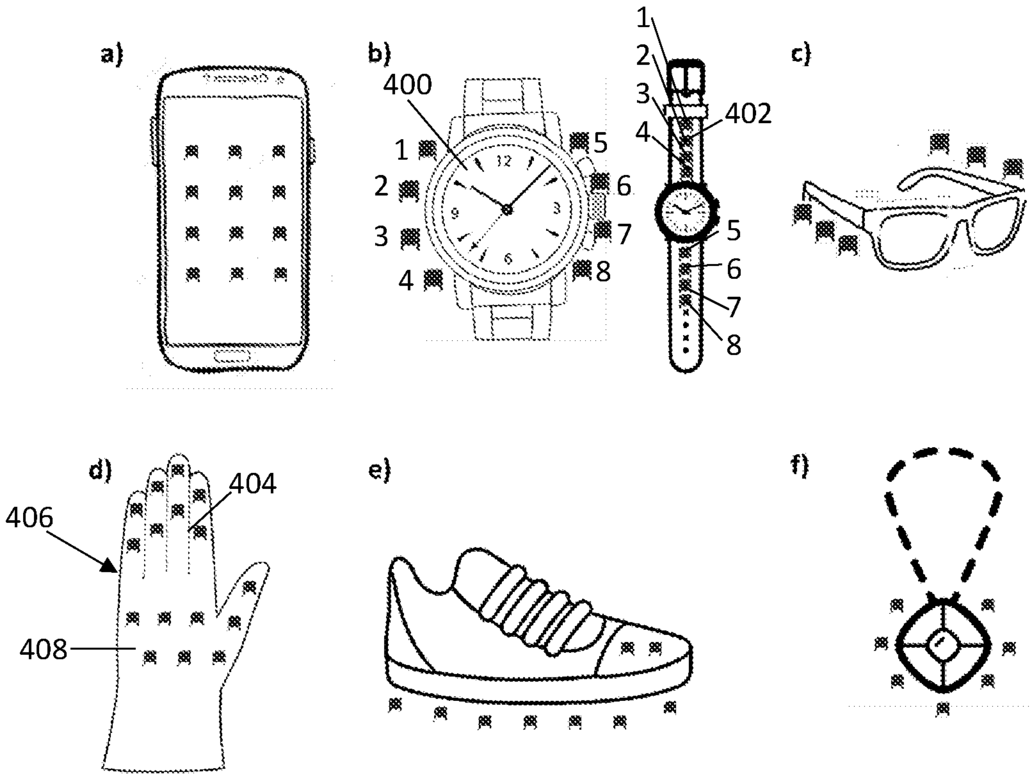


Figure 4

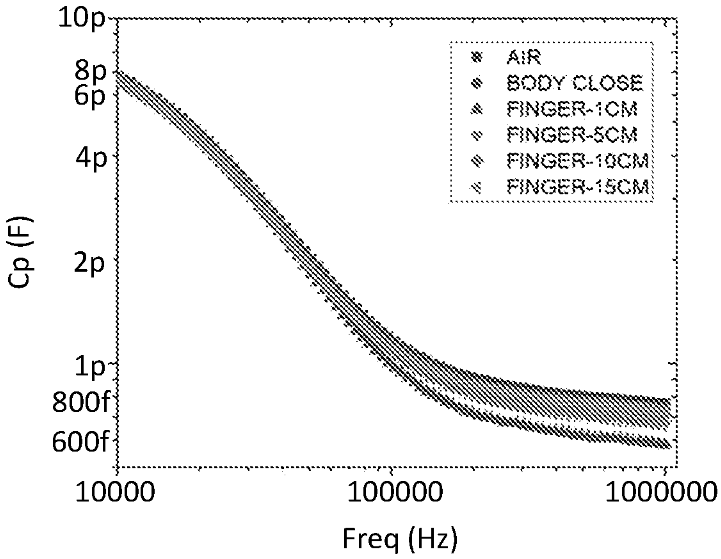


Figure 5a

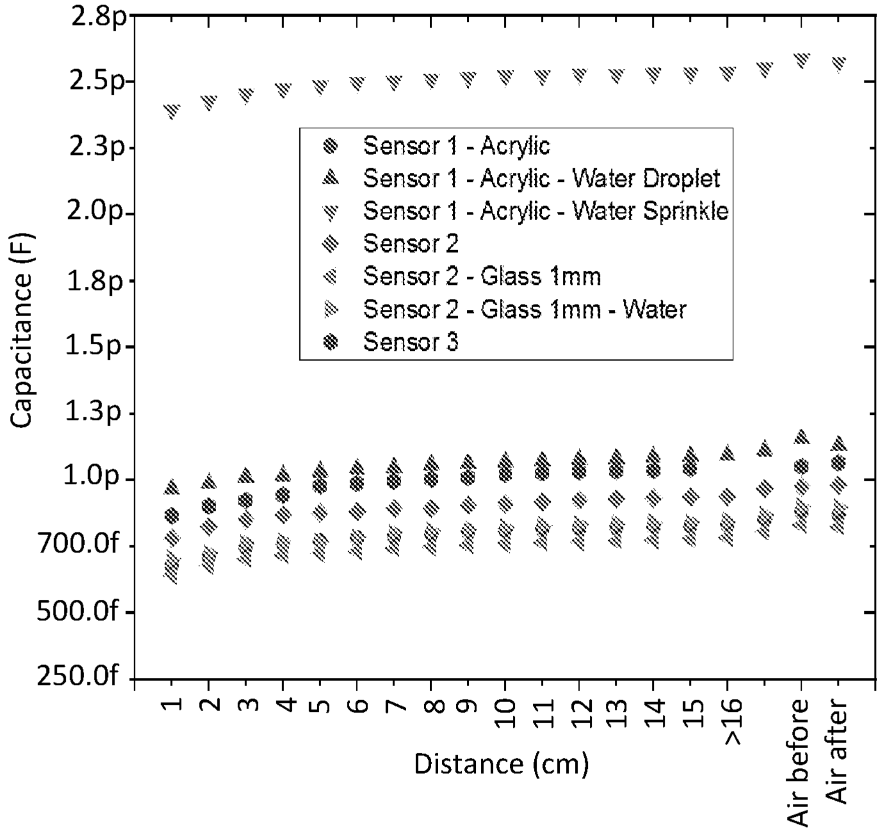


Figure 5b

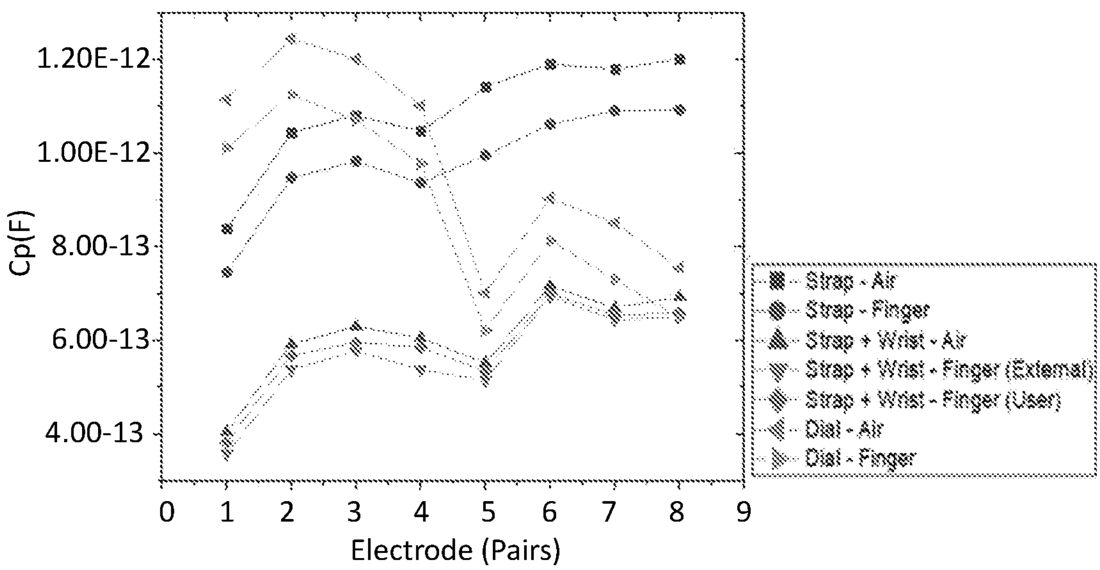


Figure 6

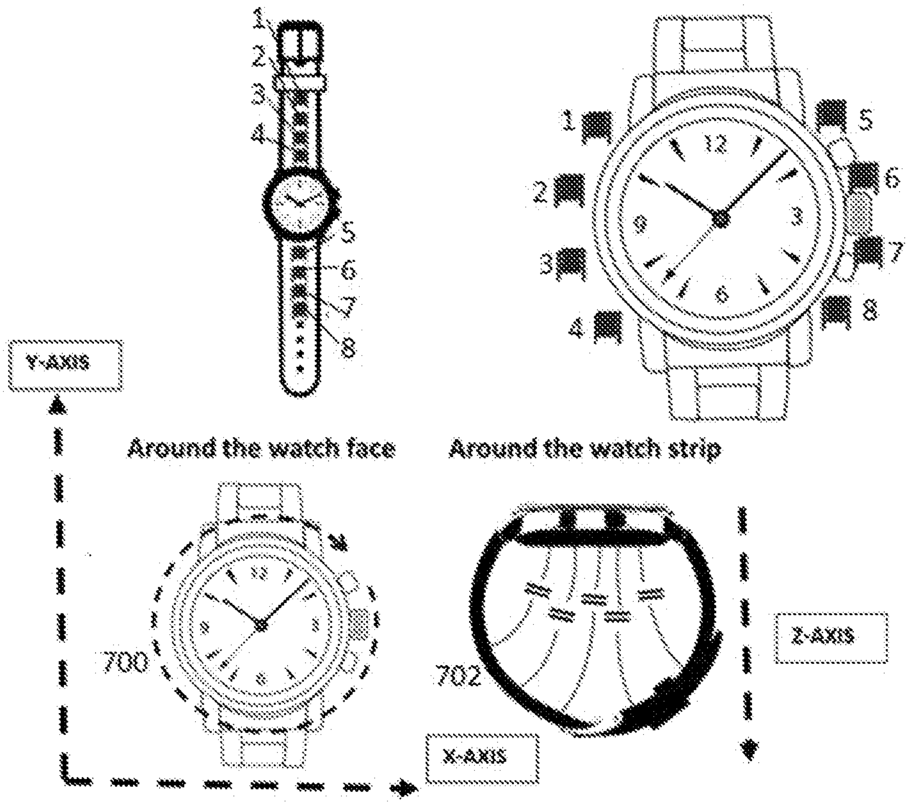


Figure 7

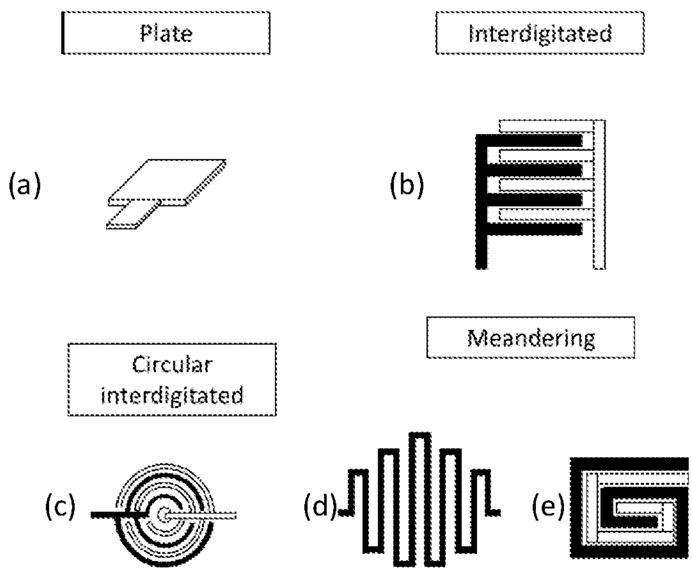


Figure 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2020/050487

A. CLASSIFICATION OF SUBJECT MATTER

G06F 3/044 (2006.01) G06F 3/01 (2006.01) G06N 20/00 (2019.01)

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F, G06N

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)
FAMPAT: wearable, capacitance, change, proximity, variation, gesture, action, machine learning and like terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/0188938 A1 (DESELAERS T. AND CARBUNE V.) 5 July 2018 Para. [0023]-[0037], [0046], [0056]-[0058], [0061]-[0064], [0074], [0112]; fig. 1	1-20
X	US 2009/0326833 A1 (RYHANEN T. ET AL.) 31 December 2009 Abstract; para. [0005]-[0006], [0012], [0050]-[0055], [0059]-[0062], [0069]-[0080], [0088], [0097]-[0099][0111]; fig. 1a, 1b, 5, 11	1-20
X	US 2016/0091980 A1 (BARANSKI A. ET AL.) 31 March 2016 Para. [0029], [0038], [0049]-[0052], [0064], [0066]-[0070]; fig. 1A, 1C, 8	1-20
X	US 2015/0177836 A1 (OUCHI K. ET AL.) 25 June 2015 Abstract; para. [0002], [0030], [0032], [0056], [0059]-[0060], [0066], [0071]; fig. 8	1-20
A	WO 2014/030129 A1 (ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE (EPFL)) 27 February 2014 Pg. 1 lines 11-25; pg. 11 lines 29-31; fig. 11	-

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"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
18/11/2020 *(day/month/year)*	*18/11/2020* *(day/month/year)*

Name and mailing address of the ISA/SG
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SG2020/050487

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

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