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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
02 January 2020 (02.01.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/002133 A1

(51) International Patent Classification:
A61B 5/00 (2006.01) *A61B 5/0245* (2006.01)
A61B 5/024 (2006.01) *A61B 5/0428* (2006.01)

(21) International Application Number:
PCT/EP2019/066424

(22) International Filing Date:
21 June 2019 (21.06.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/690,457 27 June 2018 (27.06.2018) US

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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, JO, 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,

(54) Title: METHODS AND APPARATUS FOR ADMINISTERING MEASUREMENTS USING A MULTI-ELECTRODE, SINGLE-LEAD PATCH

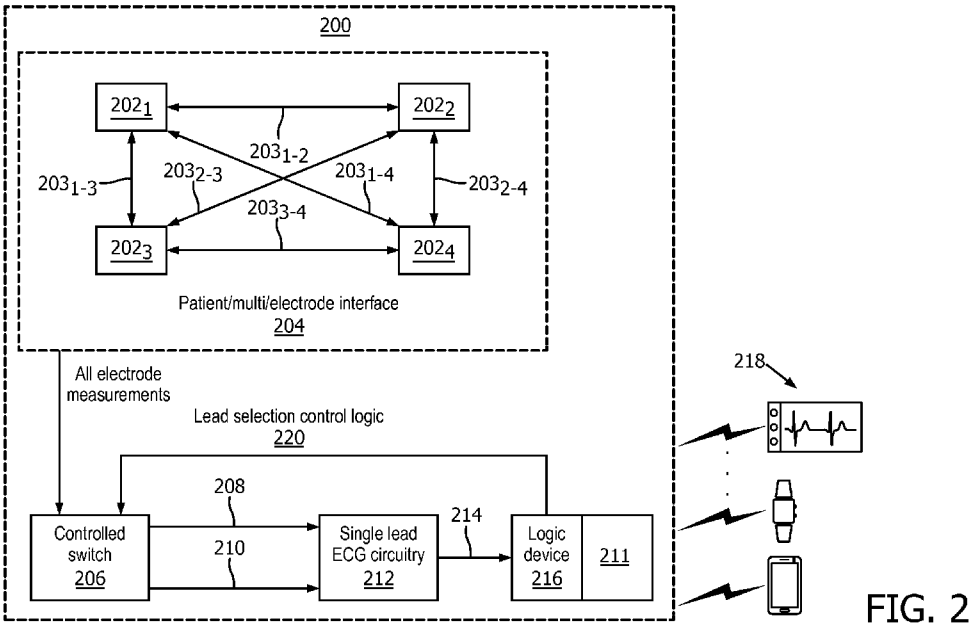


FIG. 2

(57) Abstract: Apparatus, systems, and techniques are described herein for measuring patient electrical activity. In various embodiments, a non-invasive electrocardiogram ("ECG") apparatus may include: a substrate (204) affix-able to skin of a patient; at least three electrodes (202) positioned on the substrate to contact the skin of the patient, wherein the electrodes define a plurality of vectors (203) between them, each vector defined by a respective candidate pair of the electrodes; a logic device (216) that selects a suitable vector for use with an ECG test; a controlled switch (206) to receive a command from the logic device to select the candidate pair of electrodes that define the suitable vector and output a corresponding differential signal (208/210); and single lead ECG circuitry (212) to receive the differential signal from the controlled switch and provide output to the logic device based on differential signal.

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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).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

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

METHODS AND APPARATUS FOR ADMINISTERING MEASUREMENTS USING A MULTI-ELECTRODE, SINGLE-LEAD PATCH

Technical Field

[0001] Various embodiments described herein are directed generally to health care. More particularly, but not exclusively, various methods and apparatus disclosed herein relate to selecting electrodes that are then utilized to perform physiological measurements, such as electrocardiogram ("ECG") measurements.

Background

[0002] Single-lead ECG measurement devices are highly dependent on lead vector orientation between a pair of electrodes to obtain a clean (low noise), discernable signal for measurement and analysis. This is largely affected by variations in the patient's own anatomy such as the alignment of the heart in the chest, fat distribution and/or skin impedance. Conventional disposable single-lead ECG patches can be wasted by trying to locate the proper electrode orientation given patient-to-patient variability.

[0003] Conventional multi-lead (e.g., 3-, 5-, 6- and 12-lead) ECG measurement devices utilize multiple vectors across the heart and often default to the strongest signal when calculating heart rate and performing arrhythmia analyses. This is beneficial if an electrode dries (high impedance leading to a noisy or lost signal) or falls off, which may interrupt monitoring. However, since the ECG is a differential measurement, when an electrode becomes compromised in a conventional single lead ECG measurement device, the device is unusable.

Summary

[0004] Devices, apparatus, and techniques are described herein relating to application of a patch with a plurality of electrodes that define multiple selectable vectors, such as ECG vectors, to choose from. Being able to select from multiple different vectors greatly mitigates issues raised by anatomical differences from person-to-person, such as the need to search for proper placement, location, or orientation. The patch can be applied by the patient or by an untrained family member without the requirement of a clinician applying the patch. The redundancy of the multiple selectable vectors allows for flexibility when implementing accurate monitoring of

various medical parameters, such as ECG. For example, if one of the electrodes of the patch dries out or lifts off the skin due to poor adhesion, it is still possible to perform ECG monitoring. Various embodiments in this disclosure address this problem by facilitating selection from multiple different pairs of electrodes, with each electrode pair defining a selectable vector.

[0005] Apparatus described herein are further able to utilize lead redundancy by toggling from lead to lead to search for the strongest signal between electrodes and/or a most suitable vector for analysis using lead selection control logic. This is not an option for existing single lead ECGs. The more electrodes on the patch, the more redundancy possible due to the increased availability of selectable vectors between pairs of electrodes.

[0006] Apparatus and devices described herein are lower cost than conventional multiple lead ECG devices, while allowing for the flexibility of conventional multiple lead ECG devices. Additionally, cost and size savings in circuitry are achieved by only measuring one signal at a time, which is a beneficial characteristic for a disposable wearable. In some embodiments, a signal between each electrode pair of the plurality of electrodes on the patch may be measured through the use of a controlled switch, which enables any electrode pair to be selected for use in obtaining a physiological measurement.

[0007] The same advantages afforded to ECG measurements using techniques described herein may also be afforded to bio impedance measurements such as respiration, galvanic skin response and an impedance check of the lungs to monitor fluid, which is an early warning sign for congestive heart failure. Additional embodiments of this disclosure can be used for pet and livestock monitoring. Many cats, dogs and horses are placed on ECG monitoring systems to screen for various abnormalities.

[0008] In various embodiments, A non-invasive electrocardiogram, ("ECG") apparatus may include: a substrate affix-able to skin of a patient; at least three electrodes positioned on one side of the substrate to contact the skin of the patient, wherein the at least three electrodes define a plurality of vectors between them, each vector of the plurality of vectors defined by a respective candidate pair of the at least three electrodes; a logic device that performs a lead vector selection process based on one or more signal strengths between one or more candidate pairs of the at least three electrodes to select a suitable vector from the plurality of vectors for use with an ECG test; a controlled switch to receive a command from the logic device to select the candidate pair of electrodes that define the suitable vector and output a corresponding differential signal from the

candidate pair of electrodes that define the suitable vector; and single lead ECG circuitry to receive as input the differential signal from the controlled switch and provide output to the logic device based on the received input.

[0009] In various embodiments, the apparatus may further include a communication interface. In various embodiments, the logic device may be further configured to: determine a heart rate based on the provided output; and provide, via the communication interface, information indicative of the determined heart rate to a remote computing device. In various embodiments, the information may cause the remote computing device to display the heart rate. In various embodiments, the logic device may be further configured to provide information indicative of the provided output to a remote computing device, wherein the information indicative of the provided output causes the remote computing to display a heart rate of the patient.

[0010] In various embodiments, the logic device may be further configured to perform analysis on the output provided by the single lead ECG circuitry to detect an arrhythmia. In various embodiments, the controlled switch may take the form of a multiplexer. In various embodiments, the received input may take the form of a voltage measured at a first of the pair of electrodes that together define the selected suitable vector and a voltage measured at a second of the pair of electrodes that together define the selected suitable vector.

[0011] In another aspect, a method of measuring electrical activity of the heart of a patient may include: affixing a substrate to skin of the patient, wherein the substrate includes at least three electrodes positioned on one side of the substrate to contact the skin of the patient, wherein the at least three electrodes define a plurality of vectors between them, each vector of the plurality of vectors defined by a respective candidate pair of the at least three electrodes; performing a lead vector selection process based on two or more signal strengths between two or more candidate pairs of the at least three electrodes to select a suitable vector from the plurality of vectors for measuring the electrical activity of the heart of the patient; operating a controlled switch to select the candidate pair of electrodes that define the suitable vector, wherein the controlled switch outputs a corresponding differential signal from the selected candidate pair of electrodes that define the suitable vector; and determining the electrical activity of the heart of the patient based on the corresponding differential signal.

Brief Description of the Drawings

[0012] In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating various principles of the embodiments described herein.

[0013] Fig. 1 schematically illustrates one example of how apparatus configured with selected aspects of the present disclosure may be deployed on a patient, in accordance with various embodiments.

[0014] Fig. 2 schematically illustrates one example of components that may be employed in one of the embodiments of the present disclosure.

[0015] Fig. 3 illustrates an example method for performing selected aspects of the present disclosure, in accordance with various embodiments.

[0016] Fig. 4 illustrates another example method for performing selected aspects of the present disclosure, in accordance with various embodiments.

Detailed Description

[0017] Embodiments of this disclosure facilitate lead selection from a plurality of electrodes on a patch or other similar substrate. In various embodiments, the electrodes may be isolated from each other electrically. Each pair of electrodes (also referred to herein as a "candidate pair" may form a vector through the patient's body by which voltage is measured between the first electrode and the second electrode in the candidate pair. For example, electricity (e.g., current, voltage) travels through the patient's body tissue in various directions, including along vectors defined by electrode pairs. Additionally or alternatively, in some embodiments, a bioimpedance signal may be measured through the use of current being applied to the patient through the isolated electrodes. This ensures that the most suitable electrodes, e.g., with the highest signal strength, are selected for performance of a physiological measurement, such as ECG or bioimpedance signal. This device can be applied in many scenarios where an ECG is used (hospital, ambulatory, home) by anyone (patient, family member, clinician) for wearable applications with improved confidence that a usable signal can be obtained without having to reapply the patch for the duration of use. This design, while geared for low-cost disposable applications, could be extended to reusable ECGs by allowing the electrodes to be removable. There are also veterinary applications where animals (dogs, cats, horses) are equipped with

wearable ECGs. Additionally, any physiological signal requiring electrodes such an impedance based measurements also benefit from this disclosure.

[0018] More generally, applicants have recognized and appreciated that it would be beneficial to receive reliable measurements from a plurality of electrodes located on a substrate such as a patch, even if one or more electrodes are inoperable on the same patch.

[0019] Referring now to Figure 1, a user 101 is depicted wearing an apparatus 200 configured with selected aspects of the present disclosure. In various embodiments, user 101 may wear apparatus 200 at various locations on her body, preferably on the user's chest, but it can also be applied to her back, neck, etc. In various embodiments, apparatus 200 may be configured to communicate with one or more remote computing devices, e.g., using wired and/or wireless communication interface 211 that employs technologies such as Wi-Fi, Bluetooth, Ethernet, etc. For example, in Fig. 1, apparatus 200 is in wireless communication with a computing device taking the form of a smart phone 218 carried by user 101. In this example, smart phone 218 receives, via the wireless communication channel, electrocardiogram ("ECG") measurements from apparatus 200 and displays information indicative of those measurements on its display.

[0020] Fig. 2 schematically depicts in more detail than Fig. 1 one example of components that may be included with apparatus 200, in accordance with various embodiments. In Fig. 2, apparatus 200 includes a multi-electrode patient interface 204 on which a plurality of electrodes $202_{1\text{-}4}$ are positioned, a controlled switch 206 (e.g., a multiplexor or "MUX"), single lead ECG circuitry 212 and a logic device 216. While four electrodes $202_{1\text{-}4}$ are depicted in Fig. 2, this is not meant to be limiting. The number of electrodes is scalable to any number above two. Each pair of electrodes $<202_X, 202_Y>$ defines a selectable vector $203_{X\text{-}Y}$ between them. For example, one vector defined between first electrode 202_1 and third electrode 202_3 is designated as $203_{1\text{-}3}$. Another vector defined between third electrode 202_3 and second electrode 202_2 is designated as $203_{2\text{-}3}$. And so forth.

[0021] The logic device 216 may take various forms, such as one or more processors, a field-programmable gate array ("FPGA"), an application-specific integrated circuit ("ASIC"), and so forth. In various embodiments, logic device 216 may be configured to select one or more vectors 203 from the plurality of vectors using a lead selection control signal 220 to controlled switch 206, as part of what will be referred to herein as a "lead vector selection process." The selected

vector 203 may include the pair of electrodes 202 that define endpoints to the selected vector 203.

[0022] In some embodiments, the logic device 216 may send lead selection logic commands 220 to the controlled switch 206 to sequentially toggle through each candidate pair of electrodes 202, such that a corresponding sequence of differential signals 208/210 are provided to single-lead ECG circuitry 212. In various embodiments, the sequence of differential signals 208/210 may cause single lead ECG circuitry 212 to output a corresponding sequence of ECG signals 214 that are received as input by logic device 216 as part of a feedback loop.

[0023] Based on one or more characteristics (e.g., signal strength, desired health measurement) of each of the sequence of ECG signals 214 received by logic device 216, logic device 216 may identify a suitable ECG signal 214 associated with a particular vector 203 between particular pair of electrodes 202. An ECG signal may be determined to be suitable in various ways. For example, in some embodiments, the strongest ECG signal 214 of the sequence of ECG signals received by logic device 216 may be selected. Additionally or alternatively, in some embodiments, the first ECG signal 214 of the sequence of ECG signals received by logic device 216 that satisfies some criterion, such as the first ECG signal 214 satisfying a signal strength threshold, the first ECG signal 214 satisfying a signal-to-noise threshold, etc., may be selected, so that not necessarily every candidate pair of electrodes 202 need be tested.

[0024] The first selected electrode's measurement 208 and the second selected electrode's measurement 210 (collectively the differential signal) are transmitted by controlled switch 206 as inputs to single lead ECG circuitry 212. In various embodiments, single-lead ECG circuitry 212 may be configured to condition the differential raw signals 208/210, and hence may include one or more amplifiers and/or filters. In some embodiments, single-lead ECG circuitry 212 may be configured to protect a patient from leakage current and provide further protection to the device from electrostatic discharge (ESD) and defibrillation. In some embodiments, single-lead ECG circuitry 212 may additionally or alternatively include an analog-to-digital convertor, such that output of the single-lead ECG circuitry 212 takes the form of a single-ended ECG signal 214. In various embodiments, the ECG signal 214 may be sent from the single-lead ECG circuitry 212 to the logic device 216. In some embodiments, data indicative of the ECG signal 214, such as the raw signal, may be transmitted by the logic device 216 using wireless and/or wired communications to one or more remote computing devices 218, such as a mobile phone, smart

watch, medical device, etc. These remote devices may be configured to provide audio and/or visual output indicative of the ECG signal or various information derived therefrom, such as a heart rate, one or more detected arrhythmias, etc.

[0025] The patient/multi-electrode interface 204 represents the point at which the device 200 electrically couples to the patient's skin. In various embodiments, patient/multi-electrode interface 204 may take the form of a substrate such as a patch with adhesive on one surface (e.g., on the same surface that hosts the electrodes 202) that is usable to affix patient/multi-electrode interface 204 to the patient's skin. However, this is not meant to be limiting. Patient/multi-electrode interface 204 may take other forms in other embodiments, such as non-adhesive generally-planar devices (e.g., plates), a surface of a mobile computing device (e.g., a smart phone or smart watch) that includes a plurality of electrodes, etc. Other components in Fig. 2 may or may not also be positioned on patient/multi-electrode interface 204.

[0026] The use of more than two electrodes allows for [n(n-1)]/2 possible selectable vectors 203. For example, in Fig. 2, there are four electrodes 202 and this quantity of electrodes allows for up to six vectors using the [n(n-1)]/2 formula with n = 4 electrodes. When a vector 203 is selected for use in a measurement such as an ECG measurement, measurements obtained from the electrodes 202 at each endpoint of the selected vector 203 are used. The first selected electrode's measurement 208 and the second selected electrode's measurement 210 are transmitted by the controlled switch 206 to single lead ECG circuitry 212, as described previously.

[0027] In various embodiments, the controlled switch 206 may take the form of a digitally controlled analog switch that allows for any electrode to pair with any other electrode to form the differential signal fed into the single-lead ECG circuit. For example, in the embodiment shown in Fig. 2, a dual 4:1 multiplexer ("mux") is used as the controlled switch 206. However, this is not meant to be limiting. For example, an embodiment with eight electrodes may use a dual 8:1 mux.

[0028] Fig. 3 depicts an example method 300 for practicing selected aspects of the present disclosure, in accordance with various embodiments. While operations of method 300 are shown in a particular order, this is not meant to be limiting. One or more operations may be reordered, omitted or added. At block 302, a substrate such as a patch (e.g., 204) may be affixed to skin of a patient (e.g., 101) at various locations, such as on the patient's chest, back, arm(s), leg(s), neck,

etc. As noted previously, in some embodiments the substrate is affixed by way of a biocompatible adhesive that is applied to one side of the substrate. As noted above, the substrate may include three or more electrodes, with each candidate pair of electrodes forming a vector by which voltage is measured between the first electrode and the second electrode in the candidate pair of electrodes using the internal body tissue of the patient as the method in which the voltage travels from the first electrode to the second electrode. In other embodiments, a bioimpedance signal may be measured through the use of current being applied to the patient through the isolated electrodes.

[0029] At block 304, one or more components, such as logic device 216 in combination with controlled switch 206 and/or single-lead ECG circuitry 212, may perform a lead vector selection process. One non-limiting example of a lead selection process is depicted in Fig. 4. Based on the lead selection process, at block 306, a suitable vector defined by a pair of the three or more electrodes is selected.

[0030] At block 308, the controlled switch 206 may be operated to select (e.g., obtain voltage measurements from) the pair of electrodes that defines the suitable vector selected at block 306, such that controlled switch 206 outputs, e.g., to single-lead ECG circuitry 212, a differential signal. For example, in some embodiments, logic device 216 may send a lead selection control logic command 220 to controlled switch 206 that causes controlled switch 206 to provide, as output to single-lead ECG circuitry 212, a differential signal (208/210) between the electrode pair defining the suitable vector selected at block 306.

[0031] Based on the differential signal, at block 310, electrical activity of the patient's heart may be determined, e.g., by logic device 216 and/or by a remote computing device (e.g., 218) to which logic device 216 transmits data. For example, logic device 216 itself may determine a heart rate, detect an arrhythmia, etc., or may transmit raw data to a remote computing device that may determine heart rate, detect an arrhythmia, etc. At block 312, information indicative of the electrical activity of the patient's heart may be output, e.g., as an ECG signal waveform, numerically, etc., in visual, audible, or even haptic form. In some embodiments, if an anomaly such as an arrhythmia is detected, one or more alerts may be raised, e.g., by logic device 216 and/or a remote computing device 218, that may be acted upon by the patient and/or by medical personnel.

[0032] Fig. 4 depicts an example method 400/302 for performing a lead vector selection process (i.e., block 304 of Fig. 3. While operations of method 400/302 are shown in a particular order, this is not meant to be limiting. One or more operations may be reordered, omitted or added. At block 402, a determination may be made, e.g., by logic device 216, of whether there are any untested candidate pairs of electrodes (202). If the answer is yes, then at block 404, a next candidate pair of electrodes may be set as the current candidate pair. For example, logic device 216 may instruct controlled switch 206 to allow signals from the current candidate pair of electrodes to pass through, and to block signals from other electrodes.

[0033] At block 406, voltage may be measured across a vector defined by the current candidate pair of electrodes. In other embodiments configured for measuring a bioimpedance signal, current may be applied to the patient through the electrodes. At block 408, it may be determined, e.g., by logic device 216 based on a signal received from single-lead ECG circuitry 212, whether one or more criteria are satisfied. In some embodiments the criteria may include a minimum signal strength being satisfied, in which case any signal that satisfies the threshold may be sufficient to obtain a physiological measurement. In some embodiments, the criterion may be correlated to the Signal Quality Index (SQI), which is a measurement of ECG signal quality based on a signal-to-noise ratio. If the answer at block 408 is no, then method 400 may proceed back to block 402, and the loop defined by blocks 402-408 may repeat. However, if the answer at block 408 is yes, then at block 410 (which may correspond to block 306 of Fig. 3), the vector defined by the current pair of electrodes may be selected, e.g., by logic device 216, as the suitable vector. Method 400 may then pass control back to block 308 of Fig. 3.

[0034] In other embodiments, suitable vectors may be selected differently. For example, in some embodiments, all possible vectors between all possible pairs of electrodes may be tested, and the vector having the strongest signal strength may be selected. Additionally or alternatively, in some embodiments, a predetermined vector defined by a particular pair of electrodes may be selected based on the intended application. For example, if electrical activity through a particular vector of the patient's body needs to be measured, then electrodes that define a corresponding vector may be selected.

[0035] While several inventive embodiments have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or structures for

performing the function and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the inventive embodiments described herein. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the inventive teachings is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific inventive embodiments described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, inventive embodiments may be practiced otherwise than as specifically described and claimed. Inventive embodiments of the present disclosure are directed to each individual feature, system, article, material, kit, and/or method described herein. In addition, any combination of two or more such features, systems, articles, materials, kits, and/or methods, if such features, systems, articles, materials, kits, and/or methods are not mutually inconsistent, is included within the inventive scope of the present disclosure.

[0036] All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

[0037] The indefinite articles “a” and “an,” as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean “at least one.”

[0038] The phrase “and/or,” as used herein in the specification and in the claims, should be understood to mean “either or both” of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with “and/or” should be construed in the same fashion, i.e., “one or more” of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the “and/or” clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to “A and/or B”, when used in conjunction with open-ended language such as “comprising” can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally

including elements other than A); in yet another embodiment, to both A and B (optionally including other elements); etc.

[0039] As used herein in the specification and in the claims, "or" should be understood to have the same meaning as "and/or" as defined above. For example, when separating items in a list, "or" or "and/or" shall be interpreted as being inclusive, i.e., the inclusion of at least one, but also including more than one, of a number or list of elements, and, optionally, additional unlisted items. Only terms clearly indicated to the contrary, such as "only one of" or "exactly one of," or, when used in the claims, "consisting of," will refer to the inclusion of exactly one element of a number or list of elements. In general, the term "or" as used herein shall only be interpreted as indicating exclusive alternatives (i.e. "one or the other but not both") when preceded by terms of exclusivity, such as "either," "one of," "only one of," or "exactly one of." "Consisting essentially of," when used in the claims, shall have its ordinary meaning as used in the field of patent law.

[0040] As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

[0041] It should also be understood that, unless clearly indicated to the contrary, in any methods claimed herein that include more than one step or act, the order of the steps or acts of the method is not necessarily limited to the order in which the steps or acts of the method are recited.

[0042] In the claims, as well as in the specification above, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" shall be closed or semi-closed transitional phrases, respectively, as set forth in the United States Patent Office Manual of Patent Examining Procedures, Section 2111.03. It should be understood that certain expressions and reference signs used in the claims pursuant to Rule 6.2(b) of the Patent Cooperation Treaty ("PCT") do not limit the scope.

CLAIMS

What is claimed is:

1. A non-invasive electrocardiogram, ("ECG") apparatus comprising:

a substrate (204) affix-able to skin of a patient;

at least three electrodes (202) positioned on one side of the substrate to contact the skin of the patient, wherein the at least three electrodes define a plurality of vectors (203) between them, each vector of the plurality of vectors defined by a respective candidate pair of the at least three electrodes;

a logic device (216) that performs a lead vector selection process based on one or more signal strengths between one or more candidate pairs of the at least three electrodes to select a suitable vector from the plurality of vectors for use with an ECG test;

a controlled switch (206) to receive a command from the logic device to select the candidate pair of electrodes that define the suitable vector and output a corresponding differential signal (208/210) from the candidate pair of electrodes that define the suitable vector; and

single lead ECG circuitry (212) to receive as input the differential signal from the controlled switch and provide output to the logic device based on the received input.

2. The apparatus of claim 1, further comprising a communication interface (211).

3. The apparatus of claim 2, wherein the logic device is further configured to:

determine a heart rate based on the provided output; and

provide, via the communication interface, information indicative of the determined heart rate to a remote computing device (218);

wherein the information causes the remote computing device to display the heart rate.

4. The apparatus of claim 2, wherein the logic device is further configured to provide information indicative of the provided output to a remote computing device, wherein the information indicative of the provided output causes the remote computing to display a heart rate of the patient.

5. The apparatus of claim 1, wherein the logic device is further configured to perform analysis on the output provided by the single lead ECG circuitry to detect an arrhythmia.

6. The apparatus of claim 1, wherein the controlled switch comprises a multiplexer.

7. The apparatus of claim 1, wherein the received input takes the form of a voltage measured at a first of the pair of electrodes that together define the selected suitable vector and a voltage measured at a second of the pair of electrodes that together define the selected suitable vector.

8. A method of measuring electrical activity of the heart of a patient, the method comprising:

affixing (302) a substrate (204) to skin of the patient, wherein the substrate includes at least three electrodes (202) positioned on one side of the substrate to contact the skin of the patient, wherein the at least three electrodes define a plurality of vectors (203) between them, each vector of the plurality of vectors defined by a respective candidate pair of the at least three electrodes;

performing (304) a lead vector selection process based on two or more signal strengths between two or more candidate pairs of the at least three electrodes to select a suitable vector from the plurality of vectors for measuring the electrical activity of the heart of the patient;

operating (308) a controlled switch (206) to select the candidate pair of electrodes that define the suitable vector, wherein the controlled switch outputs a corresponding differential signal (208/210) from the selected candidate pair of electrodes that define the suitable vector; and

determining (310) the electrical activity of the heart of the patient based on the corresponding differential signal.

9. The method of claim 8, further comprising transmitting information indicative of the differential signal to a remote computing device (218) via a communication interface (211).

10. The method of claim 9, further comprising determining a heart rate based on the differential signal, wherein the information indicative of the differential signal that is transmitted to the remote computing device includes the determined heart rate.

11. The method of claim 9, further comprising providing information indicative of the differential signal to the remote computing device to cause the remote computing to display a heart rate of the patient.

12. The method of claim 8, further comprising performing analysis on the differential signal detect an arrhythmia.

13. The method of claim 8, wherein the controlled switch comprises a multiplexer.

14. The method of claim 8, wherein the differential signal comprises a voltage measured at a first of the pair of electrodes that together define the selected suitable vector and a voltage measured at a second of the pair of electrodes that together define the selected suitable vector.

15. The method of claim 8, wherein performing the lead vector selection process includes sequentially measuring voltage across at least two of the plurality of vectors.

16. The method of claim 15, wherein performing the lead vector selection process further comprises determining whether a measurement obtained when measuring the voltage across a given vector satisfies a criterion.

17. The method of claim 16, wherein the criterion comprises satisfaction of a signal strength threshold.

18. A system comprising:

a substrate (204) affix-able to skin of a patient;

at least three electrodes (202) positioned on one side of the substrate to contact the skin of the patient, wherein the at least three electrodes define a plurality of vectors (203) between them, each vector of the plurality of vectors defined by a respective candidate pair of the at least three electrodes;

a logic device (216) that performs a lead vector selection process based on one or more signal strengths between one or more candidate pairs of the at least three electrodes to select a suitable vector from the plurality of vectors for use with an ECG test;

a controlled switch (206) to receive a command from the logic device to select the candidate pair of electrodes that define the suitable vector and output a corresponding differential signal (208/210) from the candidate pair of electrodes that define the suitable vector;

single lead ECG circuitry (212) to receive as input the differential signal from the controlled switch and provide output to the logic device based on the received input; and

a computing device in wireless communication with the logic device, wherein the computing device is configured to provide audio or visual output indicative of the output.

19. The system of claim 18, wherein the computing device is configured to display a heart rate of the patient.

20. The system of claim 18, wherein the computing device is configured to analyze the differential signal detect an arrhythmia.

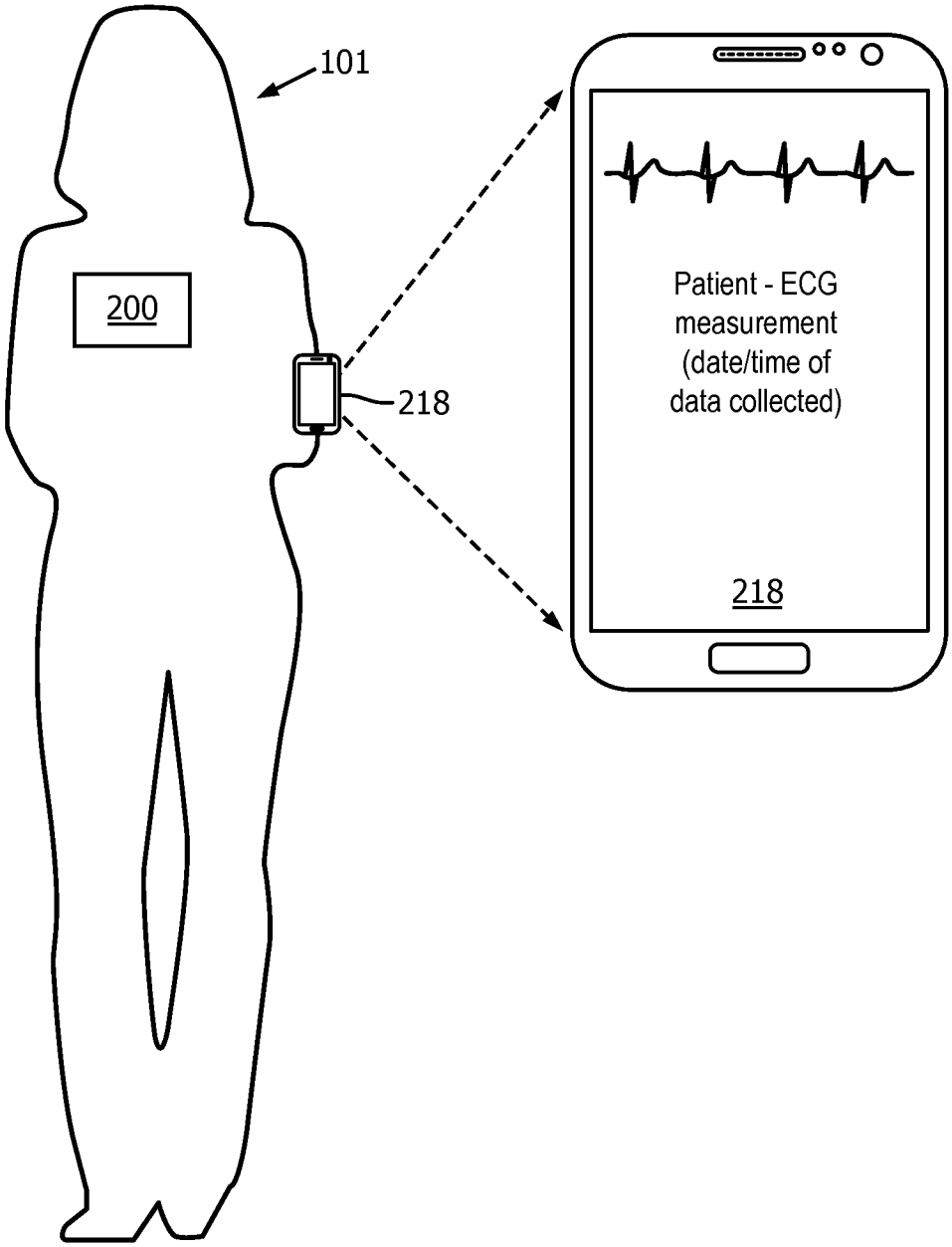

101
200
218
Patient - ECG measurement (date/time of data collected)
218

FIG. 1

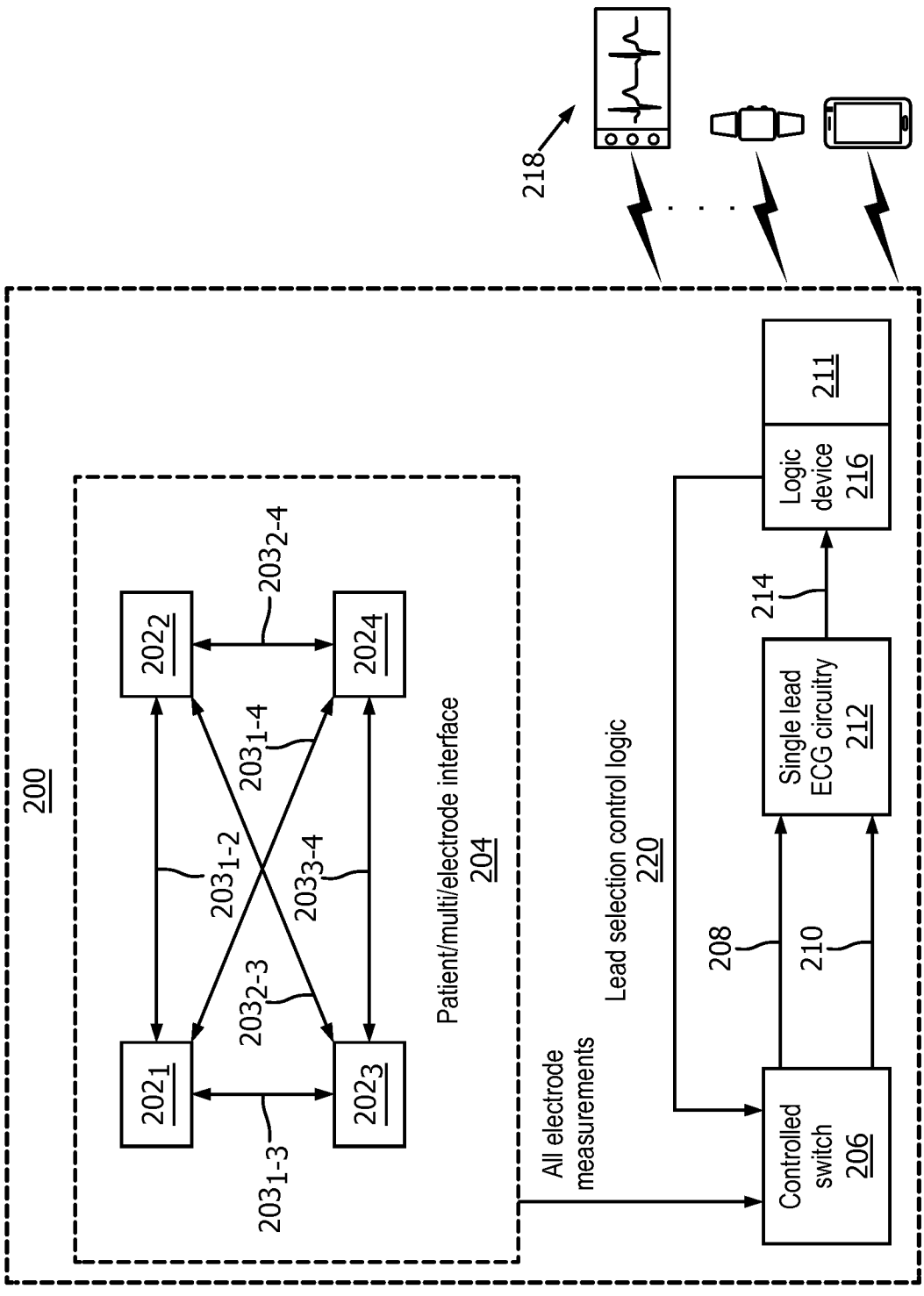

200
218
Patient/multi/electrode interface
204
202_1
202_2
202_3
202_4
203_{1-2}
203_{1-3}
203_{1-4}
203_{2-3}
203_{2-4}
203_{3-4}
All electrode measurements
Lead selection control logic
220
Controlled switch
206
208
210
Single lead ECG circuitry
212
214
Logic device
216
211

FIG. 2

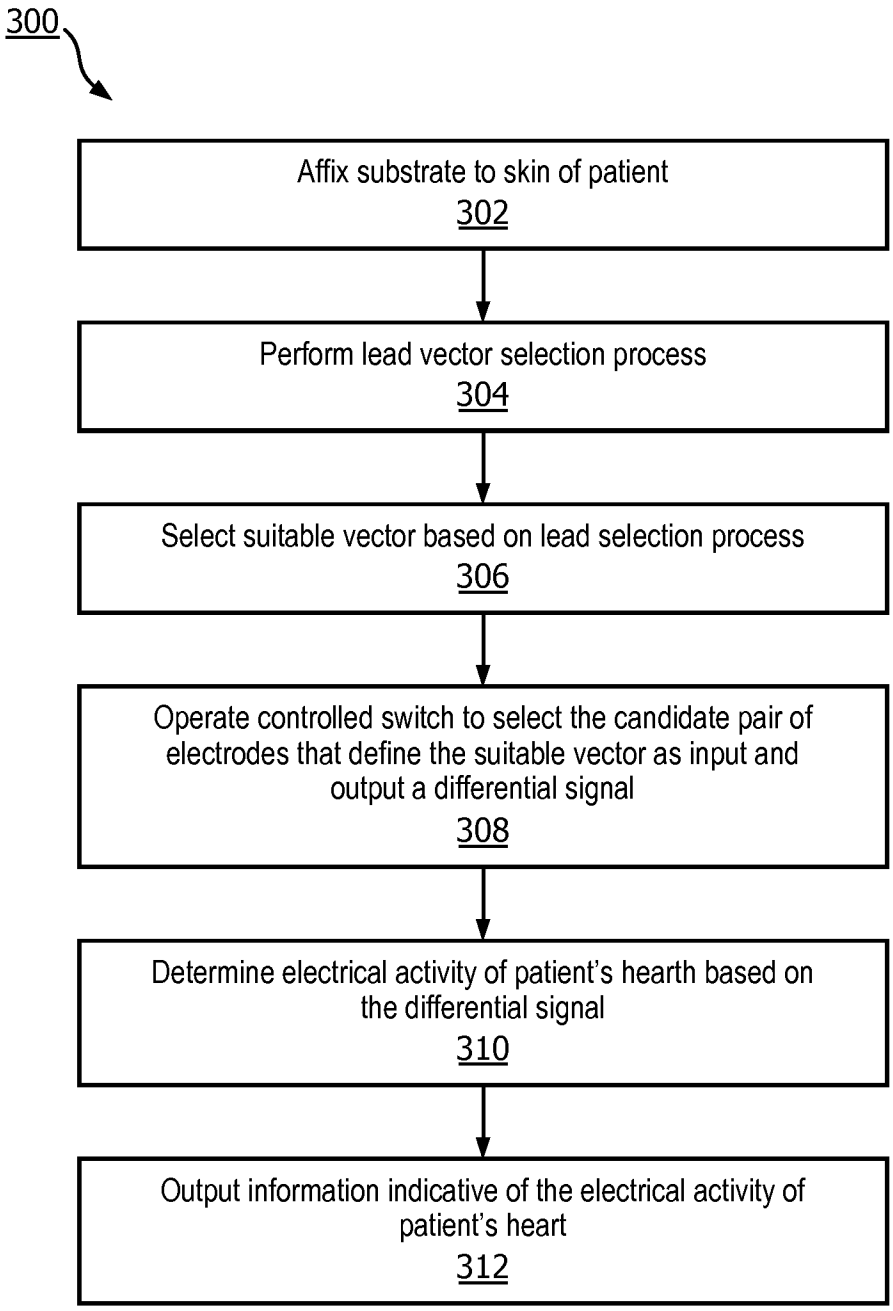

300
Affix substrate to skin of patient
302
Perform lead vector selection process
304
Select suitable vector based on lead selection process
306
Operate controlled switch to select the candidate pair of electrodes that define the suitable vector as input and output a differential signal
308
Determine electrical activity of patient's hearth based on the differential signal
310
Output information indicative of the electrical activity of patient's heart
312

FIG. 3

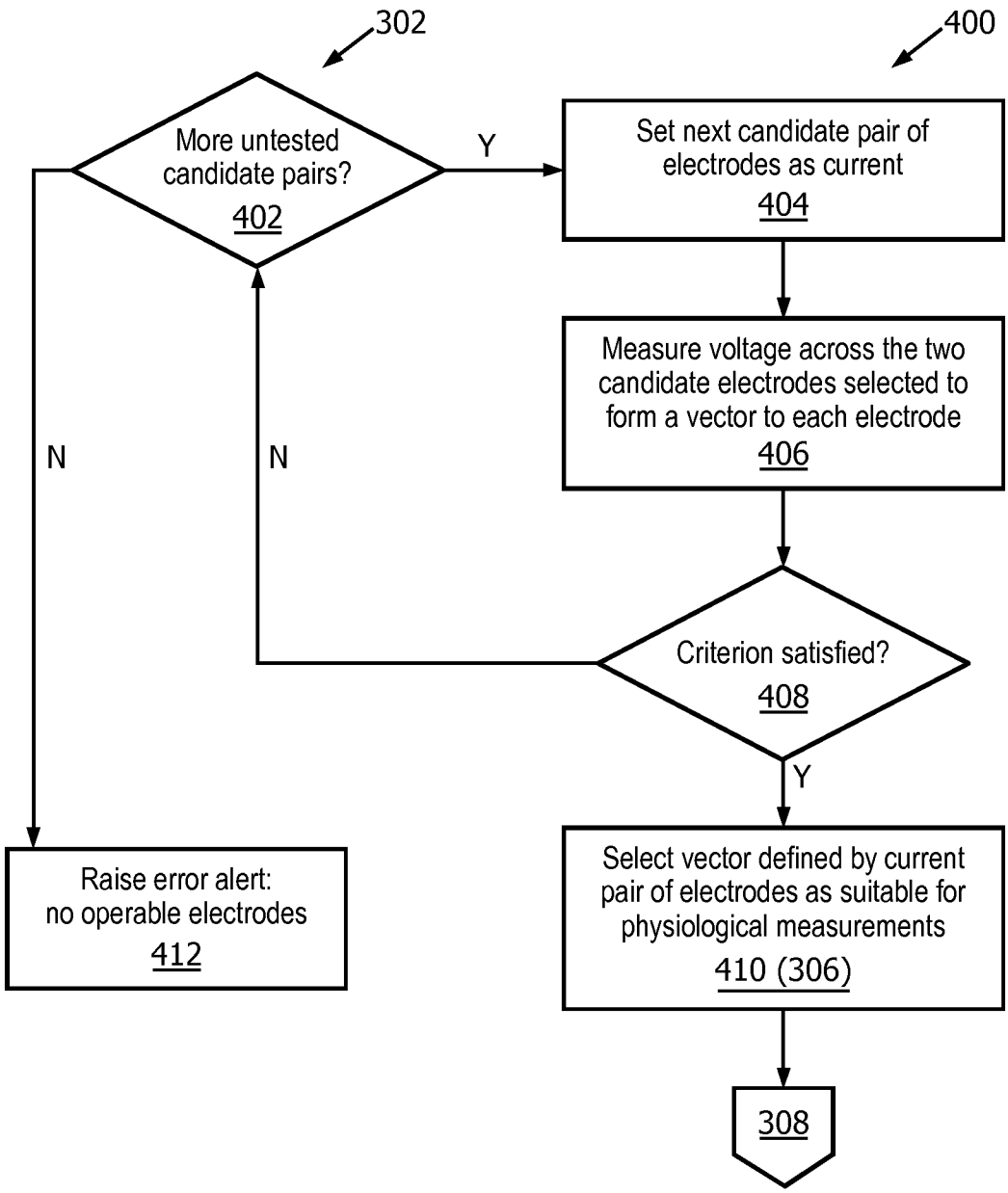

302
400
More untested candidate pairs?
402
Y
Set next candidate pair of electrodes as current
404
Measure voltage across the two candidate electrodes selected to form a vector to each electrode
406
N
N
Criterion satisfied?
408
Y
Raise error alert: no operable electrodes
412
Select vector defined by current pair of electrodes as suitable for physiological measurements
410 (306)
308

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/066424

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/00 A61B5/024 A61B5/0245 A61B5/0428
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 2017/113053 A1 (BRISBEN AMY JEAN [US] ET AL) 27 April 2017 (2017-04-27) paragraph [0023] - paragraph [0028] paragraph [0050] - paragraph [0055] paragraph [0062] - paragraph [0067] paragraph [0097] - paragraph [0103] paragraph [0111] figures 2, 6, 8, 15	1-20

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

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 September 2019	18/09/2019

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/066424

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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