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[Continued on next page]

(54) **Title**: ECG TRAINING AND SKILL ENHANCEMENT

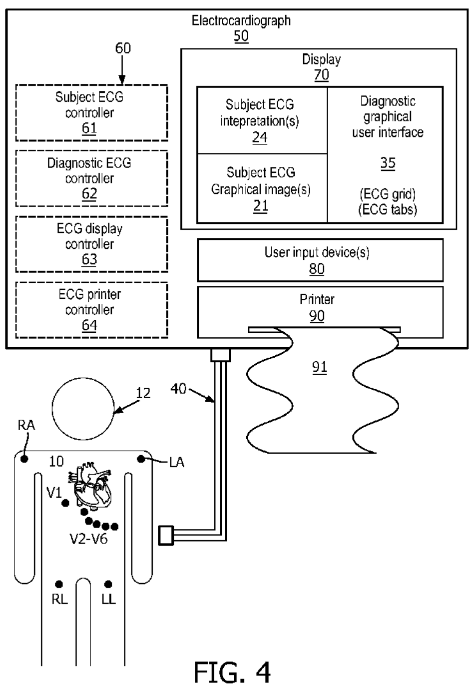

FIG. 4

(57) **Abstract**: A diagnostic electrocardiogram system employing an electrode lead system (40) for generating one or more electrode signals indicative of electrical activity of a subject heart (10). The diagnostic electrocardiogram system further employs a diagnostic electrocardiograph (50) coupled to the electrode lead system (40) for communicating (e.g., listing, displaying and/or printing a subject electrocardiogram (20) and one or more diagnostic electrocardiograms (30) designated as a morphology match to the subject electrocardiogram (20). The subject electrocardiogram (20) includes one or more interpretations of ECG features derived from the electrical activity of the subject heart (10) as indicated by the electrode signal(s) (e.g., an algorithmic interpretation and/or an electrocardiographer interpretation of the subject electrocardiogram (20)). The diagnostic electrocardiogram(s) includes one or more diagnoses of ECG features derived from recorded electrical activity of diagnosed heart(s) (11) (e.g., an algorithmic diagnosis and/or an electrocardiographer diagnosis of the diagnostic electrocardiograms(s) (30)).

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ECG TRAINING AND SKILL ENHANCEMENT

FIELD OF THE INVENTION

[0001] The present disclosure relates generally to electrocardiogram (ECG) training and skill enhancement, and more particular to systems, devices and methods for ECG training and skill enhancement by communicating (e.g., displaying, printing, linking, etc.) morphology matching ECGs from a training ECG set.

`BACKGROUND OF THE INVENTION

[0002] The skill of reading *n*-lead ECG (e.g., 12-lead ECG) typically starts with textbook examples and explanation of the ECG phenomena. More skill typically comes with supervised reading of ECG. ECG skill typically is further enhanced with practice and feedback from experts. At some point, there is no ready feedback and the electrocardiographer is on his/her own. Examples of an electrocardiographer include, but is not limited to, physicians, nurse practitioners, physician assistants, nurses, paramedics, medical assistants, trained nursing assistants and emergency medical technicians.

[0003] More particular, diagnostic ECG interpretation or “reading” an ECG is typically a skill that takes considerable time and practice to truly master. There is a large body of knowledge related to the technical aspects of ECG and most importantly, the reflection of many cardiac disorders in the ECG signal. ECG training typically starts with textbook explanations of where the signal comes from, how it is recorded and how signals from the four chambers appear in the ECG signal. The textbook instruction typically includes example ECGs in the main areas of arrhythmia and signal morphology which relates to conditions such as conduction system problems and infarction and ischemia. Some on-the-job training typically completes the training, which is typically verified with nursing or medical boards.

[0004] The problem is that training typically does not continue. Moreover, electrocardiographers usually do not get feedback on the quality or correctness of their ECG interpretation. In addition, patients frequently have a long list of comorbidities with a confusing mixture of effects simultaneously present in the ECG. Textbook ECG examples almost never include mixtures of effects because it is confusing for beginner electrocardiographers.

[0005] Electrocardiographers would benefit from a set of example ECGs to be able to look up similar ECGs to the types they do not see frequently. The problem is that the example ECGs are typically organized by ECG interpretation. Therefore, one must know the interpretation already to find a similar example.

[0006] ECG currently is the most common cardiac investigation provided in many settings including primary care, in the field or on the ambulance for suspected heart condition patients, etc. Although it is accepted as core medical practice, it is believed that only a low percentage of electrocardiographers receive formalized training and assessment in interpreting ECGs. In recent years, many electrocardiographers rely on computer algorithms to interpret the ECG for them. However, such algorithms are not perfect as they usually do not have access to the clinical context and other needed information to reliably make an accurate diagnostic. This is why, it is often mandatory in the clinical setting that all computer-interpreted ECGs be verified and appropriately corrected by an experienced electrocardiographer. More particular, although many physicians acquire the cognitive skills needed for proper interpretation of the ECG, e.g., during a fellowship or a residency program, completion of a fellowship or residency does not guarantee competence. The present disclosure can help electrocardiographers to continue their training on the job and get help with those ECGs difficult to interpret. As one having ordinary skill in the art shall appreciate in view of teachings herein, the present disclosure can have numerous other beneflts too.

SUMMARY OF THE INVENTION

[0007] The present disclosure helps an electrocardiographer (e.g., a physician, a nurse practitioner, a physician assistant, a nurse, a paramedic, a medical assistant, a trained nursing assistants and an emergency medical technicians) continue to improve his/her ECG reading skills by, e.g., offering (and/or providing, displaying, printing or otherwise communicating) a set of similar ECGs for (virtually) every (or most and/or a predefined number or percentage) ECG interpreted or "read", e.g., in a particular environment or as otherwise may be available to be tracked, stored, processed etc. Generally, it is preferable to have a relatively large number of ECGs in the training set.

[0008] In accordance with exemplary embodiments of the present disclosure, in the main application of electronic ECG editing, the inventions of the present disclosure provide and electrocardiographer with example ECGs that are similar to the ECG they are currently editing or viewing. The inventions of the present disclosure select similar ECGs by characteristics of the signal, not by correct interpretation. In that way, the electrocardiographer can see many ECGs that have a similar look but potentially different ECG interpretation because many ECG characteristics have a set of possible differential diagnoses. Not only can the electrocardiographer see differential diagnosis possibilities, they can also see the opinions of different electrocardiographers for similar ECGs because the database consists of prior ECGs from their and/or associated institution(s). In addition, the inventions of the present disclosure can provide the probability that the ECG in question is in a particular diagnostic category, such as, for example, left bundle branch block (LBBB), right bundle branch block (RBBB), left ventricular hypertrophy, right ventricular hypertrophy, left anterior fascicular block, acute myocardial infarction, prior myocardial infarction, and many others. Only the higher probabilities may be presented to the user.

[0009] One form of the inventions of the present disclosure is a diagnostic electrocardiogram system employing an electrode lead system for generating one or more electrode signals indicative of electrical activity of a subject heart. The diagnostic electrocardiogram system further employs a diagnostic electrocardiograph coupled to the electrode lead system for communicating a subject electrocardiogram and one or more diagnostic electrocardiograms determined by the diagnostic electrocardiograph as a morphology match to the subject electrocardiogram (e.g., a linking, displaying, and/or printing the morphology matched subject electrocardiogram and the diagnostic electrocardiogram(s)). The subject electrocardiogram includes one or more interpretations of ECG features derived from the electrical activity of the subject heart as indicated by the electrode signal(s) (e.g., an algorithmic interpretation and/or an electrocardiographer interpretation of the subject electrocardiogram). The diagnostic electrocardiogram(s) includes one or more diagnoses of ECG features derived from recorded electrical activity of the diagnosed heart(s) (e.g., an algorithmic diagnosis and/or an electrocardiographer diagnosis of the diagnostic electrocardiograms(s)).

[0010] The designation by the diagnostic electrocardiograph may be accomplished by the diagnostic electrocardiograph navigating a cluster tree contrasted from a training set of diagnostic electrocardiograms whereby the dimensional space of the cluster tree is derived from a linear regression modeling of ECG features of the training set of diagnostic electrocardiograms.

[0011] A second form of the inventions of the present disclosure is the aforementioned electrocardiograph employing a subject ECG controller for controlling a generation of the subject electrocardiogram. The electrocardiograph further employs a diagnostic electrocardiogram controller for controlling a determination of the diagnostic electrocardiogram(s) as a morphology match to the subject electrocardiogram.

[0012] A third form of the inventions of the present disclosure is a diagnostic electrocardiograph method involving the diagnostic electrocardiograph communicating the subject electrocardiogram informative of one or more interpretations of ECG features derived from the electrical activity of the subject heart as indicated by electrode signal(s) generated by a lead system. The diagnostic electrocardiograph method further involves diagnostic electrocardiograph further communicating the diagnostic electrocardiogram(s) determined by the diagnostic electrocardiograph as a morphology match to the subject electrocardiogram (e.g., a linking, displaying, and/or printing of the subject electrocardiogram and the morphology matched diagnostic electrocardiogram(s)). The diagnostic electrocardiogram(s) include(s) one or more diagnoses of ECG features derived from recorded electrical activity of diagnosed heart(s).

[0013] For purposes of the present disclosure, the term “electrocardiograph” broadly encompasses all devices, known prior to and subsequent to the present disclosure, for recording the electrical activity of a heart over a period of time, and the term “ECG device” broadly encompasses all stand-alone electrocardiographs and devices/systems incorporating an electrocardiograph including, but not limited to:

(1) diagnostic ECG devices (e.g., PageWriter TC cardiographs, Efficia series of cardiograph);

(2) exercise ECG devices (e.g., ST80i stress testing system);

(3) ambulatory ECG devices (Holter monitor);

(4) bed-side monitoring ECG device (e.g., IntelliVue monitors, SureSigns monitors, and Goldway monitors);

(5) hemodynamic monitoring (e.g., per Flex Cardio Physiomonitoring system);

(6) telemetry ECG device (e.g., IntelliVue MX40 monitor);

(7) automated external defibrillator and advanced life support products (e.g., HeartStart MRx and HeartStart XL deflbrillators, and Efflcia DFM100 deflbrillator/monitor);

(8) ECG management system (e.g., IntelliSpace ECG management system); and

(9) central monitoring system (e.g., PIIC iX and IntelliVue IL central monitoring systems).

[0014] Also for purposes of the present disclosure,

(1) the term “diagnostic electrocardiograph” broadly encompasses all electrocardiographs having a structural configuration incorporating inventive principles of the present disclosure as exemplary described herein, and the term “diagnostic electrocardiograph method” broadly encompasses all methods for training and/or operating a diagnostic electrocardiograph that incorporate the inventive principles of the present disclosure as exemplary described herein;

(2) terms of the art including, but not limited to, “electrocardiographer”, “electrode”, “electrocardiogram”, “ECG features”, “interpretation”, “diagnosis”, “linear regression” and “cluster tree” are to be interpreted as understood in the art of the present disclosure and as exemplary described herein;

(3) more particular to the inventions of the present disclosure, the term "electrocardiogram" broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, all types of cardiograms for recording an electrical activity of the heart including, but not limited, to a 12-lead electrocardiogram and 3-lead vectorcardiogram;

(4) the descriptive labeling for the term "electrocardiogram" herein as a "subject electrocardiogram" or as a "diagnostic electrocardiogram" facilitates a distinction between electrocardiograms as described and claimed herein without specifying or implying any additional limitation to the term "electrocardiogram";

(5) more particular to the inventions of the present disclosure, the term "interpretation" broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, one or more proposed explanation(s) of a normality and/or an abnormality of a morphology of an electrocardiogram as would be understood by those skilled in the art of the present disclosure. Examples of an interpretation of an electrocardigoram include, but are not limited to, an algorithmic interpretation of the electrocardiogram generated by an electrocardiograph and an electrocardiographer interpretation of the electrocardiogram annotated by an electrocardiographer;

(6) more particular to the inventions of the present disclosure, the term "diagnosis" broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, one or more formalized statement(s) of a normality and/or an abnormality of a morphology of an electrocardiogram as would be understood by those skilled in the art of the present disclosure. Examples of a diagnosis of an electrocardiogram include, but are not limited to, an enactment, a conflrmation, an approval, an acceptance, etc. of an algorithmic interpretation

of the electrocardiogram generated by an electrocardiograph and of an electrocardiographer interpretation of the electrocardiogram annotated by an electrocardiographer;

(7) more particular to the inventions of the present disclosure, the term “inexpensive ECG features” broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, global features and per-lead features of an electrocardiogram including, but not limited to, a QRS axis, a QRS duration, a QT interval, a Q/R/S wave amplitude, ST-segment amplitude, T-wave amplitude, and vector loop.

(8) more particular to the inventions of the present disclosure, the term “expensive ECG features” broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, ECG features derived from a comparable processing of multiple electrocardiograms including, but not limited to, a template matching, a cross correlation and a RMS difference between electrocardiograms.

(9) the term “feature vector” broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, a m-dimensional vector of ECG feature(s), $m \geq 1$ or a vector loop;

(10) the term “morphology match” broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, similarity of ECG feature(s) between corresponding electrode signal(s) of a pair of electrocardiograms with the ECG feature(s) being characteristic of a shape of the electrocardiograms;

(11) the term “diagnostic category” broadly encompasses, as understood in the art of the present disclosure and as exemplary described herein, a category representative of a particular diagnostic assessment of an electrocardiogram. Examples of a diagnostic category include, but are not limited to, (a) ventricular conduction defect including interpretation left

anterior fascicular block, left bundle branch block (LBBB), and right bundle branch block (RBBB), (b) hypertrophy including interpretation left ventricular hypertrophy, right ventricular hypertrophy, (c) ischemia and infarction including interpretation acute myocardial infarction, prior myocardial infarction and subendocardial ischemia.

(12) the term “accurate diagnosis probability” broadly encompasses, as exemplary described herein, a probability a particular diagnostic category represents an accurate diagnostic assessment of an electrocardiogram;

(13) the term “controller” broadly encompasses all structural configurations, as understood in the art of the present disclosure and as exemplary described herein, of an application specific main board or an application specific integrated circuit housed within or linked to an electrocardiograph for controlling an application of various inventive principles of the present disclosure as subsequently described herein. The structural configuration of the controller may include, but is not limited to, processor(s), computer-usable/computer readable storage medium(s), an operating system, application module(s), peripheral device controller(s), slot(s) and port(s). Any descriptive labeling of a controller herein (e.g., a “subject ECG” controller and a “diagnostic ECG” controller) serves to identify a particular controller as described and claimed herein without specifying or implying any additional limitation to the term “controller”;

(14) the term “application module” broadly encompasses a component of the controller including an electronic circuit and/or an executable program (e.g., executable software and/o firmware stored on non-transitory computer readable medium(s) for executing a specific application. Any descriptive labeling of an application module herein (e.g., a “ECG feature extractor” module and a “cluster tree generator” module) serves to identify a particular

application module as described and claimed herein without specifying or implying any additional limitation to the term “application module”;

(15) the terms “communicating” broadly encompasses all communication schemes utilized by an electrocardiograph known prior to, concurrently with and subsequently to the present disclosure for conveying an electrocardiogram to a user of the electrocardiograph. Examples of such communication schemes include, but are not limited, providing a link to the electrocardiogram, a display of the electrocardiogram and a printing of the electrocardiogram;

(16) the terms “signal” and “data” broadly encompasses all forms of a detectable physical quantity or impulse (e.g., voltage, current, or magnetic field strength) as understood in the art of the present disclosure and as exemplary described herein for transmitting information in support of applying various inventive principles of the present disclosure as subsequently described herein;

(17) any descriptive labeling for the term “signal” herein facilitates a distinction between signals as described and claimed herein without specifying or implying any additional limitation to the term “signal”; and

(17) any descriptive labeling for the term “data” herein facilitates a distinction between data as described and claimed herein without specifying or implying any additional limitation to the term “data”.

[0015] The foregoing forms and other forms of the inventions of the present disclosure as well as various features and advantages of the present disclosure will become further apparent from the following detailed description of various embodiments of the present disclosure read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the present disclosure rather than limiting, the scope of the present disclosure being deflned by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 illustrates an exemplary embodiment of a subject electrocardiograms and diagnostic electrocardiograms in accordance with the inventive principles of the present disclosure.

[0017] FIG. 2 illustrates exemplary embodiments of a subject ECG and a pair of diagnostic ECGs in accordance with the inventive principles of the present disclosure.

[0018] FIG. 3 illustrates exemplary embodiments of a subject ECG and a pair of diagnostic ECGs in accordance with the inventive principles of the present disclosure.

[0019] FIG. 4 illustrates an exemplary embodiment of a diagnostic electrocardiograph in accordance with the inventive principles of the present disclosure.

[0020] FIG. 5 illustrates an exemplary embodiment of a diagnostic ECG controller in accordance with the inventive principles of the present disclosure.

[0021] FIG. 6 illustrates a flowchart representative of an exemplary embodiment of a diagnostic electrocardiograph training method in accordance with the inventive principles of the present disclosure.

[0022] FIG. 7 illustrates an exemplary embodiment of a generation of a vector loop version of an ECG feature vector in accordance with the inventive principles of the present disclosure.

[0023] FIGS. 8A and 8B illustrate an exemplary embodiment of a construction of a cluster tree in accordance with the inventive principles of the present disclosure.

[0024] FIG. 9 illustrates a flowchart representative of an exemplary embodiment of a diagnostic electrocardiograph operational method in accordance with the inventive principles of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] To facilitate an understanding of the present disclosure, the following description of FIG. 1 teaches inventive principles of a diagnostic electrocardiogram of the present disclosure as compared to a subject electrocardiogram as known in the art of the present disclosure. More particular, the present disclosure is premised on a designation by an electrocardiograph of one or more diagnostic electrocardiograms as a morphology match to a subject electrocardiogram with the subject electrocardiogram being generated from a current ECG monitoring and/or testing by the electrocardiograph of a subject heart and with the diagnostic electrocardiogram(s) being generated from previously diagnosed ECG monitoring and/or testing of non-subject heart(s) (i.e., diagnosed heart(s)). From the description of FIG. 1, those having ordinary skill in the art of the present disclosure will appreciate how to apply the inventive principles of the present disclosure for making and using numerous and various embodiments of a diagnostic electrocardiogram of the present disclosure.

[0026] Referring to FIG. 1, a subject electrocardiogram 20 is an example of a subject electrocardiogram that may be communicated (e.g., displayed, printed, linked, etc.) by an electrocardiograph during an ECG monitoring and/or testing of a subject heart 10 via any type of lead system as known in the art of the present disclosure (e.g., a 12 lead system, a 3-lead system, etc.). Subject electrocardiogram 20 as communicated by the electrocardiograph includes graphical image(s) 21, such as, for example, a 12-lead ECG 22 as known in the art of the present disclosure, a ECG waveform 23 generated as known in the art of the present disclosure, and a vectorcardiogram (not shown) as known in the art of the present disclosure. The exemplary subject electrocardiogram 21 further includes a textual interpretation 24 of a normality or an abnormality of an ECG morphology of graphical image(s) 21 generated by an interpretation algorithm executed by the diagnostic electrocardiograph as known in the art of the present disclosure and/or by an annotated interpretation by an electrocardiographer via a graphical user interface of the associated electrocardiograph as known in the art of the present disclosure. More particularly, interpretation 24 is directed to one or more proposed explanation(s) of the normality or the abnormality of the ECG morphology of graphical image(s) 21 as would be understood by those skilled in the art of the present disclosure.

[0027] Still referring to FIG. 1, diagnostic electrocardiograms 30 are examples of an X number of diagnostic electrocardiogram(s), $X \geq 1$, that may be communicated (e.g., displayed or printed) by the electrocardiograph during the aforementioned ECG monitoring and/or testing of subject heart 10. Each diagnostic electrocardiogram 30 was generated from a previous diagnosed ECG monitoring and/or testing of a non-subject heart 11 (i.e., a diagnosed heart) via any type of lead system as known in the art of the present disclosure (e.g., a 12 lead system, a 3-lead system, etc.).

[0028] Each diagnostic electrocardiogram 30 as communicated by the electrocardiograph includes graphical image(s) 31, such as, for example, a 12-lead ECG 32 as known in the art of the present disclosure, an ECG waveform 33 generated as known in the art of the present disclosure or a vectorcardiogram as known in the art of the present disclosure. The exemplary diagnostic electrocardiograms 31 further include a textual diagnosis 34 by an electrocardiographer of a normality and/or an abnormality of the ECG morphology of graphical image(s) 31. Each ECG diagnosis 34 is directed to one or more formalized explanations of the normality and/or the abnormality of the ECG morphology of corresponding graphical image(s) 31 as would be understood by those skilled in the art of the present disclosure (e.g., an enactment, a confirmation, an approval, an acceptance, etc. of an interpretation of the diagnostic electrocardiogram).

[0029] Still referring to FIG. 1, by simultaneously communicating a subject electrocardiogram and one or more diagnostic cardiograms designated as a morphology match to the subject electrocardiogram, the present disclosure improves upon an electrocardiograph's capability to facilitate an accurate diagnosis by an electrocardiographer of the subject electrocardiogram.

[0030] For example, FIG. 2 illustrates an exemplary 12-lead ECG 22a of a subject electrocardiogram having an ECG morphology of the QRS in leads V1 through V4 that could be interpreted, algorithmically and/or via annotation, as a left bundle branch block, a left ventricular hypertrophy or a prior myocardial infarction. These possible interpretations of 12-lead ECG 22a make it difficult for anelectrocardiographer to render a diagnosis of the morphology of 12-lead ECG 22a, particularly an inexperienced electrocardiographer.

[0031] FIG. 2 further illustrates 12-lead ECGs 32(1) and 32(2) of a pair of diagnostic electrocardiograms designated by the electrocardiograph, from a sample database of roughly 10,000 diagnostic electrocardiograms, as a morphology match in view of ECG morphology of the QRS in leads V1 through V4 of 12-lead ECGs 32(1) and 32(2) essentially being the same as the ECG morphology of the QRS in leads V1 through V4 of 12-lead ECG 22a. From these morphology matches, a diagnosis of 12-lead ECG 32(1) as a left bundle branch block for example and a diagnosis of 12-lead ECG 32(2) as a left bundle branch block for example improves upon the electrocardiographer ability to render an accurate diagnosis of the ECG morphology of the QRS in leads V1 through V4 of 12-lead ECG 22a as a left bundle branch block.

[0032] By further example, FIG. 3 illustrates an exemplary 12-lead ECG 22b of a subject electrocardiogram having an ECG morphology that could be interpreted, algorithmically and/or via by annotation, as a right bundle branch block with or without ischemia (i.e., ST-segment depression and inverted T-waves). These possible interpretations of 12-lead ECG 22b make it difficult for an electrocardiographer to render a diagnosis of the morphology of 12-lead ECG 22b, particularly an inexperienced electrocardiographer.

[0033] FIG. 3 further illustrates 12-lead ECGs 32(3) and 32(4) of a pair of diagnostic electrocardiograms designated by the electrocardiograph, from a sample database of roughly 10,000 diagnostic electrocardiograms, as a morphology match in view of abnormal shapes of the QRS in leads V1 through V4 of 12-lead ECGs 32(1) and 32(2) essentially being the same as the ECG morphology of the QRS in leads V1 through V4 of 12-lead ECG 22b. From these morphology matches, a diagnosis of 12-lead ECGs 32(3) and 32(4) as a right bundle branch block with ischemia for example improves upon the electrocardiographer's ability to render an accurate diagnosis of the ECG morphology of the QRS in leads V1 through V4 of 12-lead ECG 22b as a right bundle branch block with ischemia.

[0034] As one having ordinary skill in the art of the present disclosure shall appreciate in view of the teachings of FIG. 1, whatever an interpretation of the subject electrocardiogram, the present disclosure provides confidence in an electrocardiographer in rendering a diagnosis of the subject electrocardiogram when an interpretation of the subject electrocardiogram characteristically match a diagnosis of one or more diagnostic electrocardiograms.

[0035] To further facilitate an understanding of the present disclosure, the following description of FIG. 4 teaches inventive principles of a diagnostic electrocardiograph of the present disclosure. From this description, those having ordinary skill in the art will appreciate how to apply the inventive principles of the present disclosure for making and using numerous and various embodiments of a diagnostic electrocardiograph of the present disclosure.

[0036] Referring to FIG. 4, a diagnostic electrocardiograph 50 of the present disclosure employs a control network 60, a display 70, user input device(s) 80 (e.g., button(s), dial(s), touchpad, etc.) and a printer 90. Diagnostic electrocardiograph 50 may further employ one or more additional devices as known in the art of the present disclosure (e.g., a speaker and LED status indicators).

[0037] Diagnostic electrocardiograph 50 is linked to and/or incorporates any necessary hardware/software interface to a cable connector 40 for receiving on or more electrode signal(s) from an electrode lead system connected to a subject 12 for monitoring and/or testing a subject heart 10 (e.g., a standard 12-lead system like a Mason-Likar lead system as shown or a reduced lead system like the EASI lead system).

[0038] Control network 60 includes a subject ECG controller 61, a diagnostic ECG controller 62, a ECG display controller 63 and a ECG printer controller 64 linked to or housed within diagnostic electrocardiograph 50 as shown. In practice, controllers 61-64 may be integrated to a designed degree and/or segregated as shown. Also in practice, control network 60 may include one or more additional controllers as known in the art of the present disclosure (e.g., a canopy controller, an automatic defibrillation controller, etc.).

[0039] Subject ECG controller 61 is structurally configured as known in the art of the present disclosure for controlling a generation of a subject electrocardiogram from the electrode signal(s) (e.g., a subject ECG controller commercially employed by a Holter monitor, a IntelliVue monitor, a HeartStart MRx defibrillator and a HeartStart XL defibrillator). In practice, the generation of the subject electrocardiogram by subject ECG controller 61 includes a generation of one or more subject ECG graphical image(s) (e.g., subject graphical ECG image(s) 21 of FIG. 1), and may further includes an algorithmic generation and/or electrocardiographer annotation of one or more interpretations of the subject ECG graphical image(s) (e.g., subject interpretation(s) 24 of FIG. 1.

[0040] Diagnostic ECG controller 62 is structurally configured in accordance with the inventive principles of the present disclosure for designating one or more diagnostic electrocardiograms (e.g., diagnostic electrocardiograms 30 of FIG. 1) as an morphology match to the subject electrocardiogram as will be further exemplarily described herein in connection with FIGS. 5-9.

[0041] ECG display controller 63 is structurally configured as known in the art of the present disclosure for displaying electrocardiograms (e.g., an ECG display controller commercially employed by a Holter monitor, a IntelliVue monitor, a HeartStart MRx defibrillator and a HeartStart XL defibrillator) and for displaying a graphical user interface for accessing the diagnostic electrocardiograms in accordance with the inventive principles of the present disclosure. In practice, the display of the electrocardiograms by ECG display controller 63 may include:

1. a user customization of a view of the subject ECG graphical images via user input device(s) 80 and/or a graphical user interface (not shown);

2. a user annotation of an algorithmic interpretation of a subject electrocardiogram via user input device(s) 80 and/or a graphical user interface (not shown); and/or

3. a user selection of a diagnostic electrocardiogram to be displayed via user input device(s) 80 or a diagnostic graphical user interface 25 having a grid of large thumbnail images of diagnostic electrocardiograms ("ECG grid"), a tabbed organization of diagnostic electrocardiograms ("ECG tabs") or any other icon suitable for a managed review of diagnostic electrocardiograms.

[0042] ECG printer controller 64 is structurally configured as known in the art of the present disclosure for printing electrocardiograms via user input device(s) 80 and/or a graphical user interface (not shown) (e.g., an ECG printer controller commercially employed by a Holter monitor, a IntelliVue monitor, a HeartStart MRx defibrillator and a HeartStart XL defibrillator).

[0043] To facilitate a further understanding of the present disclosure, the following description of FIG. 5 teaches inventive principles of a diagnostic ECG controller of the present disclosure. From this description, those having ordinary skill in the art will appreciate how to apply the inventive principles of the present disclosure for making and using numerous and various embodiments of a diagnostic ECG controller of the present disclosure.

[0044] Referring to FIG. 5, an embodiment 62a of diagnostic ECG controller 62 (FIG. 4) employs an ECG feature extractor 100, an ECG profile builder 110, and a cluster tree constructor 120 for purposes of training diagnostic ECG controller 62a as will be further described herein in connection with FIGS. 6-8. Diagnostic ECG controller 62 further employs a cluster tree navigator 130, an ECG morphology matcher 140 and a diagnosis category assignor 150 for operating diagnostic ECG controller 62a for monitoring/testing purposes as will be further described herein in connection with FIGS. 8 and 9. For both training and monitoring/testing purposes, diagnostic ECG controller 62a may further employ a database manager 160 and a diagnostic ECG database 170 as shown, or alternatively be in communication with database manager 160 for purposes of accessing diagnostic ECG database 170.

[0045] Diagnostic ECG database 170 stores an X number of diagnostic electrocardiograms 30 as shown. As previously described herein, each diagnostic electrocardiogram 30 is generated from a previous diagnosed ECG monitoring and/or testing of a non-subject heart (i.e., a diagnosed heart). Each diagnostic electrocardiogram 30 includes graphical image(s), such as, for example, a 12-lead ECG, an ECG waveform and/or a vectorcardiogram. Each diagnostic electrocardiogram 30 further includes an ECG diagnosis by an electrocardiographer of an ECG morphology of the graphical image(s) with each ECG diagnosis being directed to one or more formalized statements by an electrocardiographer of an ECG morphology of corresponding graphical image(s) as would be understood by those skilled in the art of the present disclosure.

[0046] Still referring to FIG. 5, ECG feature extractor 100 is structurally configured with hardware, software, firmware and/or circuitry for processing an electrocardiogram, subject or diagnostic, to calculate an inexpensive ECG feature vector ("IEFV") 101 from the electrocardiogram with IEFV 101 including a m number of inexpensive ECG features, $m \geq 1$. Examples of an inexpensive ECG feature include, but are not limited to, QRS axis, QRS duration, QT interval, Q/R/S wave amplitudes, ST-segment amplitude, T-wave amplitude and a vector loop. In practice, ECG feature extractor 100 may implement any technique for calculating inexpensive ECG features as known in the art of the present disclosure.

[0047] ECG feature extractor 100 is further structurally configured with hardware, software, firmware and/or circuitry for processing pairings of electrocardiograms, subject-diagnostic and/or diagnostic-diagnostic, and/or for processing pairings of inexpensive ECG feature vectors 101, subject-diagnostic or diagnostic-diagnostic, to calculate expensive ECG feature vectors ("EEFV") 102 between the electrocardiogram pair with EEFV 101 including a q number of expensive ECG features, $q \geq 1$. Examples of an expensive ECG feature include, but are not limited to, a template matching, a cross correlation and a RMS difference between the electrocardiogram pair. In practice, ECG feature extractor 100 may implement any technique for calculating expensive ECG features as known in the art of the present disclosure.

[0048] ECG diagnosis profiler 110 is structurally configured with hardware, software, firmware and/or circuitry for processing an inexpensive ECG feature vector 101 for each diagnostic electrocardiogram 30 and an expensive ECF feature vector 102 of each pairing of electrocardiograms 30 to build a diagnostic ECG profile vector ("DEPV") 111 including a n number of inexpensive ECG features best representative of the interpretative prowess of expensive ECG features as known in the art of the present disclosure, $m \geq n \geq 1$ (i.e., diagnostic inexpensive ECG features). In practice, ECG diagnosis profiler 110 may implement any technique for determining which inexpensive ECG features best model the expensive ECG features as known in the art of the present disclosure including, but not limited to, a linear regression of IEFVs 101 and EEFVs 102.

[0049] Cluster tree constructor 120 is structurally configured with hardware, software, firmware and/or circuitry for processing diagnostic ECG profile vector 111 to construct a cluster tree ("CT") 121 of nodes and leafs established by the profiled inexpensive ECG features. Each node will be associated with one of the profiled inexpensive ECG features and corresponding threshold value. Each leaf will be associated with one or more diagnostic electrocardiograms 30. In practice, cluster tree constructor 120 may implement any technique for constructing clustering tree 121 including, but not limited to, constructing a decision tree from a partitioned data space derived from diagnostic ECG profile vector 111 into cluster (or dense) regions and empty (or sparse) regions formed by a partitioned clustering or a hierarchical clustering.

[0050] Cluster tree navigator 130 is structurally configured with hardware, software, firmware and/or circuitry for processing inexpensive ECG feature vector 101 of a subject electrocardiogram to navigate the nodes of cluster tree 121 until reaching a leaf whereby cluster tree navigator 130 generates a nearest neighbor listing ("NNL") 131 of all of the diagnostic electrocardiogram(s) 30 associated with the reached leaf.

[0051] ECG morphology matcher 140 is structurally configured with hardware, software, firmware and/or circuitry for processing nearest neighboring listing 131 to designate one or more of the nearest neighbor diagnostic electrocardiograms 30 as an morphology match to the subject electrocardiogram whereby ECG morphology matcher 140 generates a morphology match listing ("EMML") 141 of each designated nearest neighbor diagnostic electrocardiogram 30. In practice, ECG morphology matcher 140 may implement any known technique for determining any similarity of ECG morphologies between the subject electrocardiogram and each nearest neighbor diagnostic electrocardiogram.

[0052] Diagnosis category assignor 150 is structurally configured with hardware, software, firmware and/or circuitry for processing morphology match listing 141 to assign each morphology matched diagnostic electrocardiogram to one of numerous diagnostic categories with each diagnostic category being representative of a particular diagnostic assessment of a diagnostic electrocardiogram. Examples of a diagnostic category include, but are not limited to, left bundle branch block (LBBB), right bundle branch block (RBBB), left ventricular hypertrophy, right ventricular hypertrophy, left anterior fascicular block, acute myocardial infarction and prior myocardial infarction.

[0053] Diagnosis category assignor 150 generates a diagnostic category listing ("DCA") of each diagnostic category and associated diagnostic electrocardiograms to provide a diagnostic assessment of the subject cardiogram. In practice, diagnosis category assignor 150 may further determine a probability that each listed diagnostic category represents an accurate diagnostic assessment of the subject electrocardiogram.

[0054] To facilitate a further understanding of the present disclosure, the following description of FIG. 6 teaches inventive principles of a diagnostic electrocardiograph training method of the present disclosure. From this description, those having ordinary skill in the art will appreciate how to apply the inventive principles of the present disclosure for setting up and using numerous and various embodiments of diagnostic electrocardiograph training methods of the present disclosure.

[0055] Referring to FIG. 6, a flowchart 200 is representative of a diagnostic electrocardiograph training method of the present disclosure executed during a training phase of diagnostic ECG controller 62a (FIG. 5). In practice, diagnostic ECG database 170 will typically include thousands, even millions, of a large morphology variation of diagnostic electrocardiograms 30. Flowchart 200 facilitates a partitioning of inexpensive ECG features of diagnostic electrocardiograms 30 that are best representative of possible interpretations of the morphology of diagnostic electrocardiograms 30.

[0056] Still referring to FIG. 6, a stage S202 of flowchart 200 encompasses ECG feature extractor 100 processing a set of diagnostic electrocardiograms 30 to calculate a Y number of inexpensive ECG feature vectors 101, $X \geq Y \geq 1$, (e.g., a Y-dimensional vector of inexpensive ECG features or alternatively a vector loop) and a Z number of expensive ECG feature vectors 102, $Z \geq 1$.

[0057] More particular to 12-lead electrocardiogram, in practice inexpensive ECG feature vector 101 would be made of a processed version of the lead signals instead of a set of measurements (e.g., R-wave amplitude and QRS duration). Since the number of points in the representative beat (or average beat made up of similar shaped beats, excluding noisy and ectopic beats) may be very big for an inexpensive feature vector (e.g., 12 leads X 500 points per lead), the number of points should be reduced if possible. This implementation may use (2) methods to reduce the number of points in an inexpensive ECG feature vector while still retaining the unique morphology information. First, the number of points would be reduced by changing from 12-leads which contains a fair amount of redundant information to three (3) orthogonal leads with a 12-lead ECG to Frank lead vectorcardiogram transform. This is a 4:1 reduction in points. Second, the number of points would be further reduced by using the approximation given by a multilevel wavelet decomposition. Using the approximation from the 4th level decomposition, the final number of points in the inexpensive ECG feature vector reduced to roughly 100.

[0058] FIG. 7 illustrates an exemplary transformation of a 12-lead representative beat 103 into a Frank lead representative beat 102a to be utilized as an inexpensive ECG feature vector 101 of an electrocardiogram. The Frank lead X, Y and Z signals are used to generate two dimensional vector loops from pairs of the X, Y and Z signals. In practice, pairs of vectorcardiograms may also be utilized to generate expensive ECG feature vectors 102.

[0059] In practice for stage S202, the entire database 170 of diagnostic electrocardiograms 30 or a subset thereof may be processed by ECG feature extractor 100 dependent on various factors.

[0060] For example, the calculation of the expensive ECG feature vectors 102 in practice may involve a sample of a comparison for every diagnostic electrocardiogram 30 to every other electrocardiogram 30, or a random sample for a subset of diagnostic electrocardiograms 30, or targeted groups of diagnostic electrocardiograms 30 which are expected to be within the same diagnostic groups.

[0061] Additionally, if diagnostic ECG database 70 is relatively large relative to the processing power of diagnostic ECG controller 62a (FIG. 5), then diagnostic electrocardiograms 30 may be segmented in practice by age groups and/or gender to limit a size of a resulting cluster tree.

[0062] Furthermore, diagnostic electrocardiograms 30 processed by ECG feature extractor 100 may be based in practice only on select electrocardiographers with many years of experience or proven excellence in ECG reading accuracy. This omits diagnostic electrocardiograms 30 from less experienced electrocardiographers.

[0063] Even further, those having ordinary skill in the art of the present disclosure will recognize a ECG morphology for a stress test of a subject heart is different from a morphology of a resting diagnostic ECG of the same subject heart. Nonetheless, the present disclosure is equally applicable to a relaxed monitoring and a stress testing of the same subject heart. Consequently, in practice, diagnostic ECG database 70 may be divided into a resting ECG training database resulting in a resting ECG cluster tree and a stress test training database resulting in a stress testing ECG cluster tree.

[0064] Still referring to FIG. 6, a stage S204 of flowchart 200 encompasses ECG diagnosis profiler 110 processing the *Y* number of inexpensive ECG feature vectors 101 and the *Z* number of expensive ECG feature vectors 102 to build diagnostic ECG profile vector ("DEPV") 111 including a *n* number of inexpensive ECG features best representative of the interpretative prowess of expensive ECG features.

[0065] In one embodiment of stage S204, ECG diagnosis profiler 110 implements a linear regression or another similar method to determine which inexpensive ECG features best model the expensive ECG features. For this embodiment, the dependent variables are the expensive ECG features and the independent variables are the differences in the inexpensive ECG features. The training set for this linear regression operation is the set of differences in ECG features for each diagnostic electrocardiogram 30 compared to other diagnostic electrocardiogram 30 in the training set. In the simplest case, linear regression is fitting a line to a scatter plot of points in view of having one dependent variable and multiple independent variables. After fitting a line to the data, i.e. training, the dependent variable is a linear function of the independent variables or features. The following is a model equation [1]:

$$Y = b0 + b1*x1 + b2*x2 + \ldots + bn*xn. \qquad [1]$$

where Y is the dependent variable,

where x1, x2, …, xn are the independent variables, and

b0, b1, …, bn are the coefficients determined in the training operation.

[0066] In the extreme case, the set of rows (each row is a trial and each column is a feature) is a comparison of every diagnostic electrocardiogram 30 to every other diagnostic electrocardiogram 30.

[0067] After the linear regression model is calculated, ECG diagnosis profiler 110 will generate a vector of inexpensive ECG features with a low p-value (i.e., inexpensive ECG feature(s) making a significant contribution to the dependent variable as would be recognized by one skilled in the art of the present disclosure).

[0068] Still referring to FIG. 6, a stage S206 of flowchart 200 encompasses cluster tree generator 120 processing ECG profile vector 111 to construct cluster tree 121.

[0069] In one embodiment of stage S206, cluster tree generator 120 implements a nearest neighbor algorithm having a k-d tree, which stands for k-dimensional tree. K dimensions means there are k features used in the clustering operation. This is a binary tree. Each node in the tree has two nodes below, a left node and a right node. Below these nodes are more nodes therefore each split into the left and right results in a left and right sub-tree. The termination of a branch of the tree, a leaf, is a k-dimensional data point. The left and right subtrees represent a splitting of all points below by a plane. Since there are k-dimensions, it is a hyperplane in general. As you move from the root node at the top, down level after level of the tree, the splitting at each level corresponds to splitting based on just one of the k features. Usually, the split happens about the median of that feature. All points for the subtree with a value of the particular feature higher than the median value for the subtree go on one side of the hyperplane, all the other points go to the other side of the hyperplane. Going down the levels of the tree, the splitting rotates through the features meaning that the splitting for the root node is based on the first feature, the splitting at the next level uses the next feature and so forth.

[0070] FIGS. 8A shows a clustering example of stage S206 involving twenty (20) diagnostic electrocardiograms 30 whereby three (3) diagnostic inexpensive ECG features DIEF have been determined to be best representative of the interpretative prowess of expensive ECG features (e.g., QRS axis, QRS duration and QT interval). The diagnostic inexpensive ECG features DIEF of the twenty (20) diagnostic electrocardiograms 30 are clustered within a three-dimensional data space 123 whereby a partitioning clustering is applied by cluster tree generator 120 to yield a partitioned data space 124 via feature partitions FP(1) through FP (3) (e.g., a partition based on a median or mode of each diagnostic inexpensive ECG feature).

[0071] FIG. 8B shows a construction of a clustered decision tree 121a from partitioned data space 124. Clustered decision tree 121a include nodes N1 through N7, and leaf L1 through leaf 8. Node N1 is associated with diagnostic inexpensive ECG feature DIEF(1) having a median or mode value *r*. Nodes N2 and N3 associated with diagnostic inexpensive ECG feature DIEF(2) having a median or mode value *s*. Nodes N4 through N7 are associated with diagnostic inexpensive ECG feature DIEF(3) having a median or mode value *t*.

[0072] Each leaf is associated with one or more of the twenty (20) diagnostic electrocardiograms 30 (FIG. 7A). For a simple example, leaf L1 may be associated with diagnostic electrocardiograms 30(1) through 30(3). Leaf L2 may be associated with diagnostic electrocardiograms 30(4) and 30(5). Leaf L3 may be associated with diagnostic electrocardiograms 30(6) through 30(9). Leaf L4 may be associated with diagnostic electrocardiograms 30(10). Leaf L5 may be associated with diagnostic electrocardiograms 30(11) and 30(12). Leaf L6 may be associated with diagnostic electrocardiograms 30(13) through 30(15). Leaf L7 may be associated with diagnostic electrocardiograms 30(16) through 30(18). Leaf L8 may be associated with diagnostic electrocardiograms 30(19) and 30(20).

[0073] Those skilled in the art of the present disclosure will appreciate flowchart 200 will typically involve a processing of thousands, if not millions, of diagnostic electrocardiograms 30 and FIGS. 8A and 8B were provided to demonstrate a simple example to facilitate an understanding of stage S206.

[0074] To facilitate a further understanding of the present disclosure, the following description of FIG. 8 teaches inventive principles of a diagnostic electrocardiogram operating method of the present disclosure. From this description, those having ordinary skill in the art will appreciate how to apply the inventive principles of the present disclosure for setting up and using numerous and various embodiments of diagnostic electrocardiogram operation methods of the present disclosure.

[0075] Referring to FIG. 8, a flowchart 210 is representative of a diagnostic electrocardiogram assessment method of the present disclosure executed during an activation phase of diagnostic ECG controller 62a (FIG. 5). Flowchart 210 facilitates a diagnostic assessment of a subject electrocardiogram

[0076] Still referring to FIG. 8, a stage S212 of flowchart 210 encompasses ECG feature extractor 100 processing a subject electrocardiogram (e.g., subject electrocardiogram 20 shown in FIG. 1) and diagnostic ECG profile vector 111 to generate an inexpensive ECG feature vector 101s corresponding to diagnostic ECG profile vector 111. For example, in the context of FIGS. 8A and 8B, ECG feature extractor 100 generates an inexpensive ECG feature vector 101s including diagnostic inexpensive ECG features DIEF(1) through DIEF(3).

[0077] A stage S214 of flowchart 210 encompasses cluster tree navigator 130 processing inexpensive ECG feature vector 101s to navigate the nodes of cluster tree 121 until reaching a leaf whereby cluster tree navigator 130 generates a nearest neighbor listing (“NNL”) 131 of all of the diagnostic electrocardiogram(s) 30 associated with the reached leaf. For example, in the context of FIGS. 8A and 8B, cluster tree navigator 130 may reach leaf L1 and generates a nearest neighbor listing 131 including diagnostic electrocardiograms 30(1) through 30(3).

[0078] A stage S216 of flowchart 210 encompasses ECG morphology matcher 140 processing nearest neighboring listing 131 to generate an morphology match listing (“EMML”) 141 of each designated nearest neighbor diagnostic electrocardiogram 30.

[0079] In one embodiment of stage S216, ECG morphology matcher 140 calculates the expensive ECG features between the subject electrocardiogram and each nearest neighbor diagnostic electrocardiogram 30 (e.g., a template match, cross correlation or RMS error), and determines a cross correlation between the average beat of the subject electrocardiogram and the average beats of the nearest neighbor diagnostic electrocardiograms resulting in a vector of cross correlation numbers. ECG morphology matcher 140 chooses the subset of nearest neighbor diagnostic electrocardiograms by sorting the cross correlation vector from highest to lowest and selecting the subset with the highest cross correlation(s) (i.e., most similar to the subject electrocardiogram).

[0080] For example, in the context of FIGS. 8A and 8B, ECG morphology matcher 140 may designate diagnostic electrocardiograms 30(1) and 30 (2) as morphology matches.

[0081] A stage S218 of flowchart 210 encompasses diagnosis category assignor processing morphology match listing 141 to assign each matched diagnostic electrocardiogram to a diagnostic category with each diagnostic category being representative of a particular diagnostic assessment of a diagnostic electrocardiogram and to determine a probability that each listed diagnostic category represents an accurate diagnostic assessment of the subject electrocardiogram.

[0082] In one embodiment of stage S218, the probability of diagnostic category is calculated as the frequency of the notation of that diagnostic category for the morphology matched subset of nearest neighbors. Specifically, a diagnosis of each morphology matched nearest neighbor is mapped to a broader diagnostic category. The number of times that each diagnostic category is noted is divided by the number of diagnostic electrocardiograms in the morphology matched set of nearest neighbors. That ratio is an estimate of the probability.

[0083] For example, in the context of FIGS. 8A and 8B, diagnostic electrocardiograms 30(1) and 30(2) may be mapped to a left bundle branch block and diagnostic electrocardiogram 30(2) may be further mapped to a left ventricular hypertrophy. As such, the probability of the subject electrocardiogram may be exhibiting left bundle branch block would be 66% and the probability of the subject electrocardiogram may be exhibiting left ventricular hypertrophy would be 33%.

[0084] Upon completion of flowchart 210, the morphology matched set of nearest neighbors are presented to the electrocardiographer in a grid of large thumbnail images, or a tabbed organization or some other icon that allows quick change from one diagnostic electrocardiogram to the next for fast review of all diagnostic electrocardiograms for the morphology matched subset of nearest neighbors.

[0085] Referring to FIGS. 1-9, those having ordinary skill in the art will appreciate numerous benefits of the inventions of the present disclosure including, but not limited to, an improvement of electrocardiographs in diagnostically assessing a subject electrocardiogram.

[0086] The present disclosure disclosed herein has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

[0087] Further, as one having ordinary skill in the art shall appreciate in view of the teachings provided herein, features, elements, components, etc. disclosed and described in the present disclosure/specification and/or depicted in the appended Figures may be implemented in various combinations of hardware and software, and provide functions which may be combined in a single element or multiple elements. For example, the functions of the various features, elements, components, etc. shown/illustrated/depicted in the Figures can be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions can be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which can be shared and/or multiplexed. Moreover, explicit use of the term “processor” or “controller” should not be construed to refer exclusively to hardware capable of executing software, and can implicitly include, without limitation, digital signal processor (“DSP”) hardware, memory (e.g., read only memory (“ROM”) for storing software, random access memory (“RAM”), non-volatile storage, etc.) and virtually any means and/or machine (including hardware, software, firmware, combinations thereof, etc.) which is capable of (and/or configurable) to perform and/or control a process.

[0088] Moreover, all statements herein reciting principles, aspects, and exemplary embodiments of the present disclosure, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future (e.g., any elements developed that can perform the same or substantially similar functionality, regardless of structure). Thus, for example, it will be appreciated by one having ordinary skill in the art in view of the teachings provided herein that any block diagrams presented herein can represent conceptual views of illustrative system components and/or circuitry embodying the principles of the invention. Similarly, one having ordinary skill in the art should appreciate in view of the teachings provided herein that any flow charts, fiow diagrams and the like can represent various processes which can be substantially represented in computer readable storage media and so executed by a computer, processor or other device with processing capabilities, whether or not such computer or processor is explicitly shown.

[0089] Having described preferred and exemplary embodiments of diagnostic electrocardiographs and operating methods thereof, (which embodiments are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons having ordinary skill in the art in view of the teachings provided herein, including the appended Figures and claims. It is therefore to be understood that changes can be made in/to the preferred and exemplary embodiments of the present disclosure which are within the scope of the present disclosure and exemplary embodiments disclosed and described herein.

[0090] Moreover, it is contemplated that corresponding and/or related systems incorporating and/or implementing the device or such as may be used/implemented in a device in accordance with the present disclosure are also contemplated and considered to be within the scope of the present disclosure. Further, corresponding and/or related method for manufacturing and/or using a device and/or system in accordance with the present disclosure are also contemplated and considered to be within the scope of the present disclosure.

Claims

1. A diagnostic electrocardiogram system, comprising:

an electrode lead system (40) for generating at least one electrode signal indicative of electrical activity of a subject heart (10); and

a diagnostic electrocardiograph (50) coupled to the electrode lead system (40),

wherein the diagnostic electrocardiograph (50), responsive to a generation of the at least one electrode signal by the electrode lead system (40), is structurally configured to communicate a subject electrocardiogram (20) and at least one diagnosed electrocardiogram (30) designated as a morphology match to the subject electrocardiogram (20),

wherein the subject electrocardiogram (20) includes at least one interpretation of ECG features derived from the electrical activity of the subject heart (10) as indicated by the at least one electrode signal, and

wherein the at least one diagnosed electrocardiogram (30) includes at least one diagnosis of ECG features derived from recorded electrical activity of at least one diagnosed heart (11).

2. The diagnostic electrocardiogram system of claim 1,

wherein at least one interpretation of ECG features derived from the electrical activity of the subject heart (10) as indicated by the at least one electrode signal includes at least one of an algorithmic interpretation and an electrocardiographer interpretation; and wherein the at least one diagnosis of ECG features derived from recorded electrical activity of at least one diagnosed heart (11) includes at least one of an algorithmic diagnosis and an electrocardiographer diagnosis.

3. The diagnostic electrocardiogram system of claim 1,

wherein the diagnostic electrocardiograph (50) includes a subject electrocardiogram controller (61) and a diagnostic electrocardiogram controller (62);

wherein the subject electrocardiogram controller (61), responsive to the generation of the at least one electrode signal by the electrode lead system (40), is structurally configured to control the generation of the subject electrocardiogram (20); and

wherein the diagnostic electrocardiogram controller (62), responsive to a generation of the subject electrocardiogram (20) by the subject electrocardiogram controller (61), is structurally configured to control the designation of the at least one diagnosed electrocardiogram (30) as the morphology match to the subject electrocardiogram (20).

4. The diagnostic electrocardiogram system of claim 3,

wherein the diagnostic electrocardiogram controller (62) is structurally configured to access a cluster tree constructed from a training set of diagnosed electrocardiograms (30) informative of a plurality of diagnoses of ECG features derived from recorded electrical activity of a plurality of diagnosed hearts (11); and

wherein the diagnostic electrocardiogram controller (62) is structurally configured to control a navigation of the cluster tree to designate the at least one diagnosed electrocardiogram

(30) from the training set of diagnosed electrocardiogram (30) as the morphology match to the subject electrocardiogram (20).

5. The diagnostic electrocardiogram system of claim 4,

wherein the diagnostic electrocardiogram controller (62) is structurally configured to control an assignment of the at least one diagnosed electrocardiogram (30) into a least one diagnostic category representative of at least one diagnostic assessment of the subject electrocardiogram (20).

6. The diagnostic electrocardiogram system of claim 5,

wherein, for a plurality of diagnostic categories, the diagnostic electrocardiogram controller (62) is structurally configured to control a determination of an accurate diagnosis probability for each diagnostic category.

7. The diagnostic electrocardiogram system of claim 1,

wherein the diagnostic electrocardiograph (50) includes a display (70) and an electrocardiogram display controller (63); and

wherein the electrocardiogram display controller (63) is structurally configured to control a communication by the display of the subject electrocardiogram (20) and the at least one diagnostic electrocardiogram.

8. The diagnostic electrocardiogram system of claim 1,

wherein the diagnostic electrocardiograph (50) includes a printer (90) and an electrocardiogram printer controller (64); and

wherein the electrocardiogram printer controller is structurally configured to control a communication by the printer of the subject electrocardiogram (20) and the at least one diagnostic electrocardiogram.

9. A diagnostic electrocardiograph (50), comprising:

a subject electrocardiogram controller (61),

wherein the subject electrocardiogram controller (61), responsive to at least one electrode signal indicative of electrical activity of a subject heart (10), is structurally configured to control a generation of a subject electrocardiogram (20) including at least one interpretation of ECG features derived from the electrical activity of the subject heart (10) as indicated by the at least one electrode signal; and

a diagnostic electrocardiogram controller (62),

wherein the diagnostic electrocardiogram controller (62), responsive to the generation of the subject electrocardiogram (20) by the subject electrocardiogram controller (61), is structurally configured to control a designation of at least one diagnosed electrocardiogram (30) as a morphology match to the subject electrocardiogram (20),

wherein the at least one diagnosed electrocardiogram (30) includes at least one diagnosis of ECG features derived from recorded electrical activity of at least one diagnosed heart (11).

10. The diagnostic electrocardiograph (50) of claim 9,

wherein at least one interpretation of ECG features derived from the electrical activity of the subject heart (10) as indicated by the at least one electrode signal includes at least one of an algorithmic interpretation and an electrocardiographer interpretation; and

wherein the at least one diagnosis of ECG features derived from recorded electrical activity of at least one diagnosed heart (11) includes at least one of an algorithmic diagnosis and an electrocardiographer diagnosis.

11. The diagnostic electrocardiograph (50) of claim 9,

wherein the diagnostic electrocardiogram controller (62) is structurally configured to access a cluster tree constructed from a training set of diagnosed electrocardiograms (30) informative of a plurality of diagnoses of ECG features derived from recorded electrical activity of a plurality of diagnosed hearts (11); and

wherein the diagnostic electrocardiogram controller (62) is structurally configured to control a navigation of the cluster tree to designate the at least one diagnosed electrocardiogram (30) as the morphology match to the subject electrocardiogram (20).

12. The diagnostic electrocardiograph (50) of claim 11,

wherein the diagnostic electrocardiogram controller (62) is structurally configured to control an assignment of the at least one diagnosed electrocardiogram (30) into a least one diagnostic category representative of at least one diagnostic assessment of the subject electrocardiogram (20).

13. The diagnostic electrocardiograph (50) of claim 12,

wherein, for a plurality of diagnostic categories, the diagnostic electrocardiogram controller (62) is structurally configured to control a determination of an accurate diagnosis probability of each diagnostic category.

14. The diagnostic electrocardiograph (50) of claim 9, further comprising:

a display and an electrocardiogram display controller (63),

wherein the electrocardiogram display controller (63) is structurally configured to control a communication by the display (50) of the subject electrocardiogram (20) and the at least one diagnostic electrocardiogram.

15. The diagnostic electrocardiograph (50) of claim 9, further comprising:

a printer and an electrocardiogram printer controller (64),

wherein the electrocardiogram display controller (63) structurally configured to control a communication by the printer (90) of the subject electrocardiogram (20) and the at least one diagnostic electrocardiogram.

16. A diagnostic electrocardiograph method, comprising:

a diagnostic electrocardiograph (50) communicating a subject electrocardiogram (20) informative of at least one interpretation of ECG features derived from the electrical activity of the subject heart (10) as indicated by the at least one electrode signal generated by an electrode lead system; and

the diagnostic electrocardiograph (50) communicating at least one diagnostic electrocardiogram designated as a morphology match to the subject electrocardiogram (20), wherein the at least one diagnosed electrocardiogram (30) includes at least one diagnosis of ECG features derived from recorded electrical activity of at least one diagnosed heart (11).

17. The diagnostic electrocardiograph method of claim 16, wherein:

the diagnostic electrocardiograph (50) generates the subject electrocardiogram (20) responsive to the generating of the at least one electrode by the electrode lead system (40); and

the diagnostic electrocardiograph (50) designating the at least one diagnostic electrocardiogram as a morphology match to the generated subject electrocardiogram (20) responsive to the generating by the diagnostic electrocardiograph (50) generating the subject electrocardiogram (20).

18. The diagnostic electrocardiograph method of claim 16,

wherein the diagnostic electrocardiograph (50) designates the at least one diagnostic electrocardiogram as the morphology match to the generated subject electrocardiogram (20) including

the diagnostic electrocardiograph (50) navigating a cluster tree to designate the at least one diagnostic electrocardiogram as the morphology match to the subject electrocardiogram (20); and

wherein the cluster tree is constructed from a training set of diagnosed electrocardiograms (30) informative of a plurality of diagnoses of ECG features derived from recorded electrical activity of a plurality of diagnosed hearts (11).

19. The diagnostic electrocardiograph method of claim 18,

wherein the diagnostic electrocardiograph (50) designating the at least one diagnostic electrocardiogram as the morphology match to the generated subject electrocardiogram (20) further includes:

the diagnostic electrocardiograph (50) assigning the at least one diagnostic electrocardiogram into a least one diagnostic category representative of at least one diagnostic assessment of the subject electrocardiogram (20).

20. The diagnostic electrocardiograph method of claim 19,

wherein the diagnostic electrocardiograph (50) designating the at least one diagnostic electrocardiogram as the morphology match to the generated subject electrocardiogram (20) further includes:

for a plurality of diagnostic categories, the diagnostic electrocardiograph (50) determining an accurate diagnosis probability of each diagnostic category.

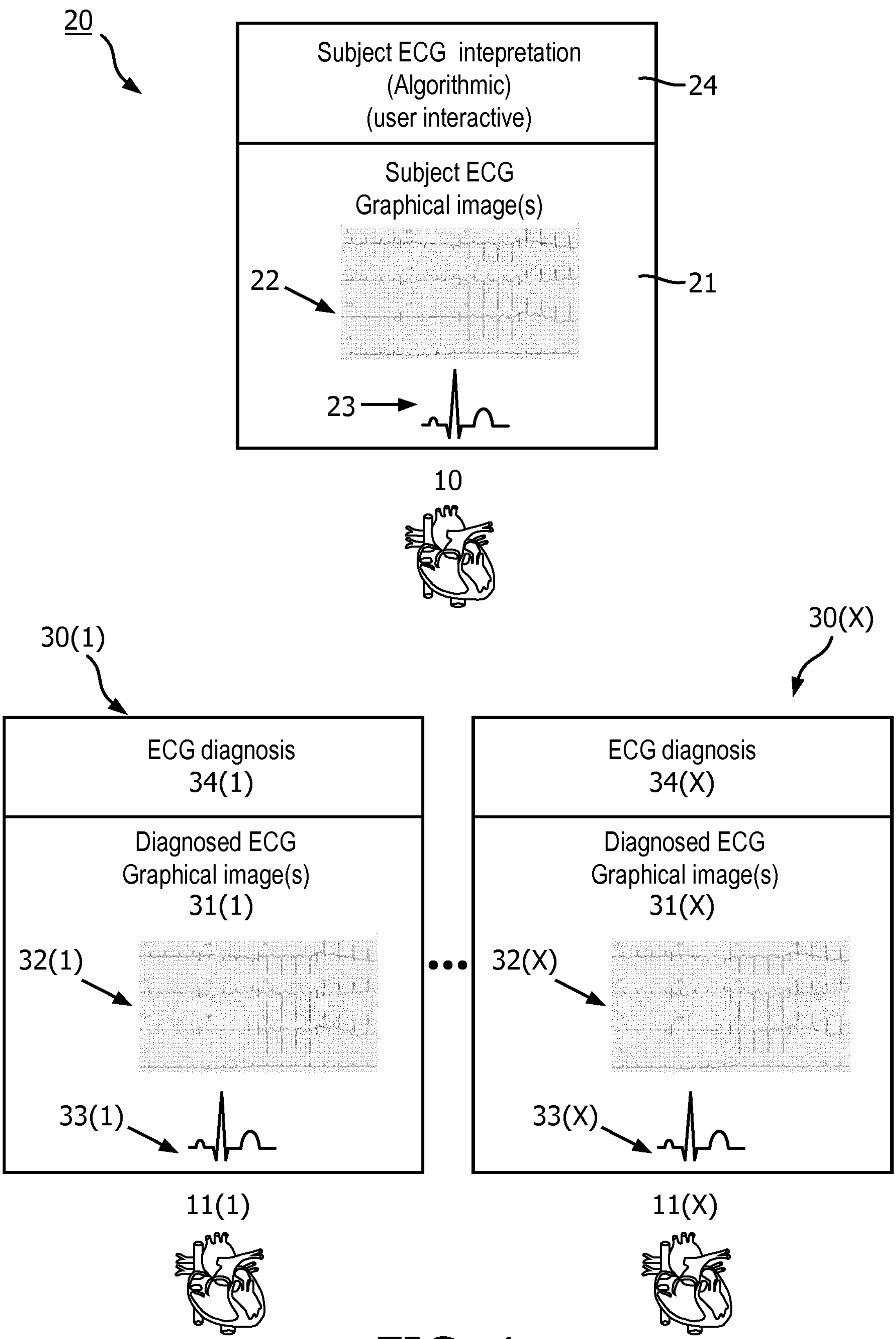

20
Subject ECG intepretation
(Algorithmic)
(user interactive)
24
Subject ECG
Graphical image(s)
22
21
23
10
30(1)
30(X)
ECG diagnosis
34(1)
ECG diagnosis
34(X)
Diagnosed ECG
Graphical image(s)
31(1)
Diagnosed ECG
Graphical image(s)
31(X)
32(1)
32(X)
33(1)
33(X)
11(1)
11(X)

FIG. 1

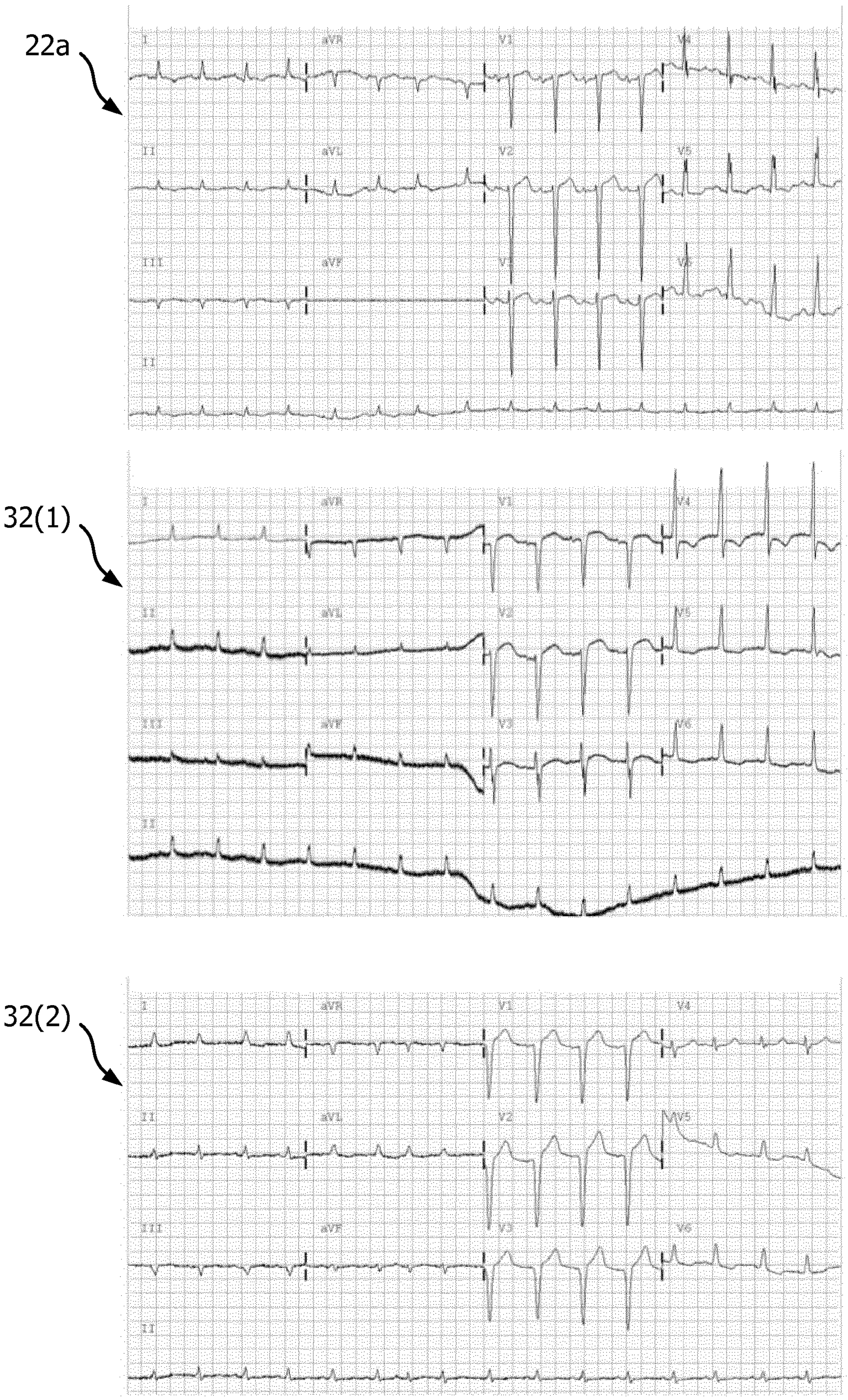


FIG. 2

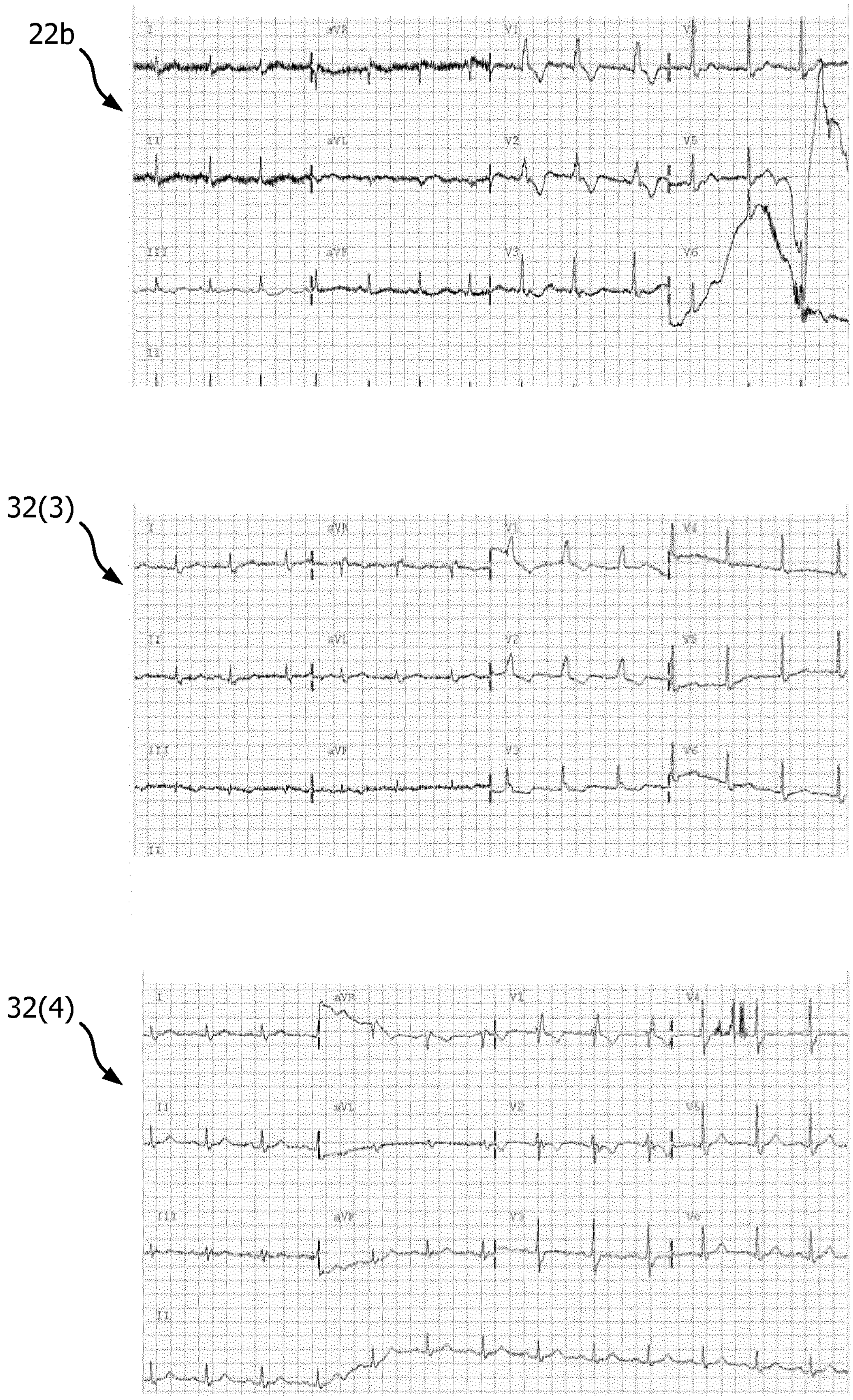
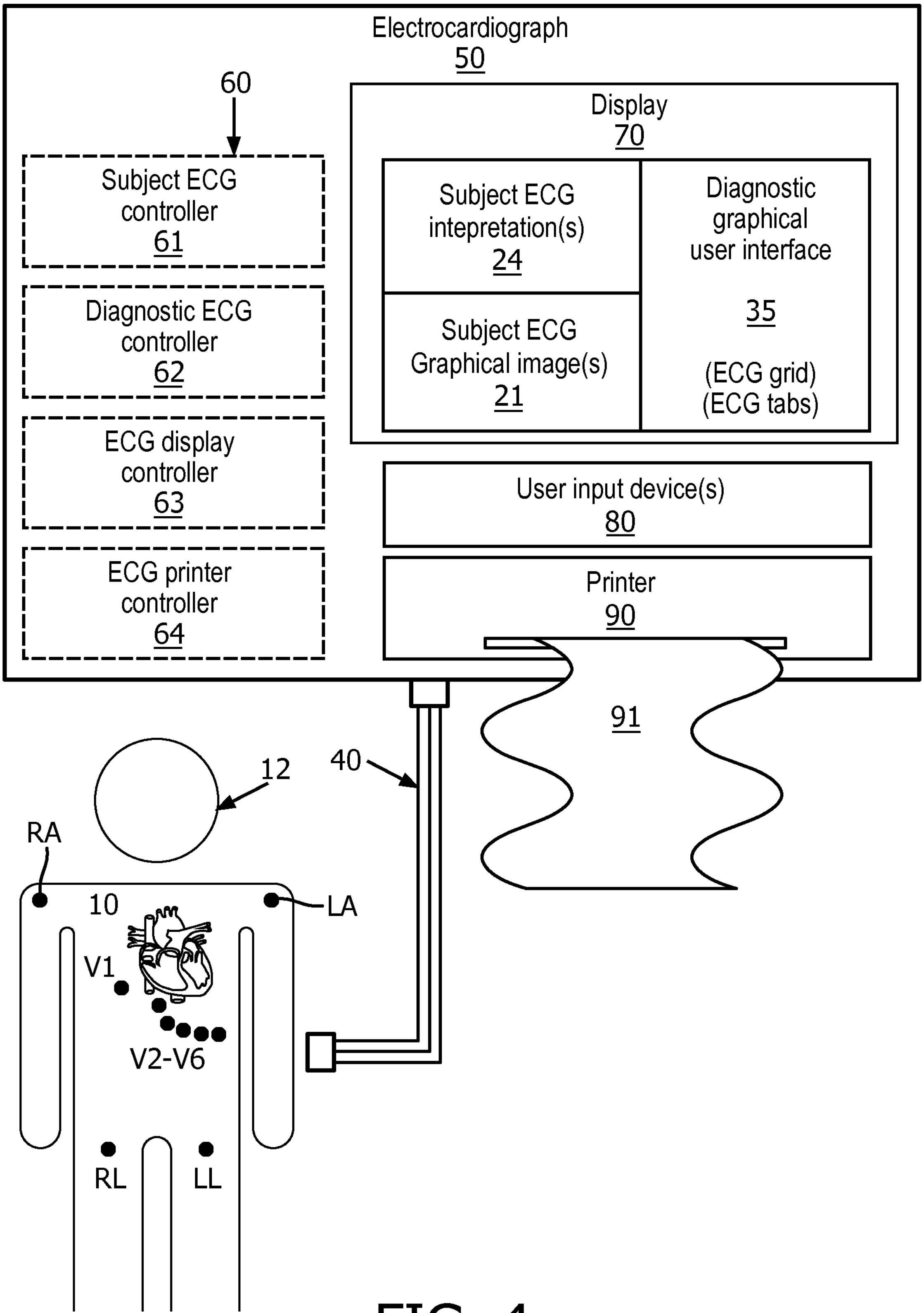


FIG. 3



Electrocardiograph
50
60
Subject ECG controller
61
Diagnostic ECG controller
62
ECG display controller
63
ECG printer controller
64
Display
70
Subject ECG intepretation(s)
24
Subject ECG Graphical image(s)
21
Diagnostic graphical user interface
35
(ECG grid)
(ECG tabs)
User input device(s)
80
Printer
90
91
40
12
RA
10
LA
V1
V2-V6
RL
LL

FIG. 4

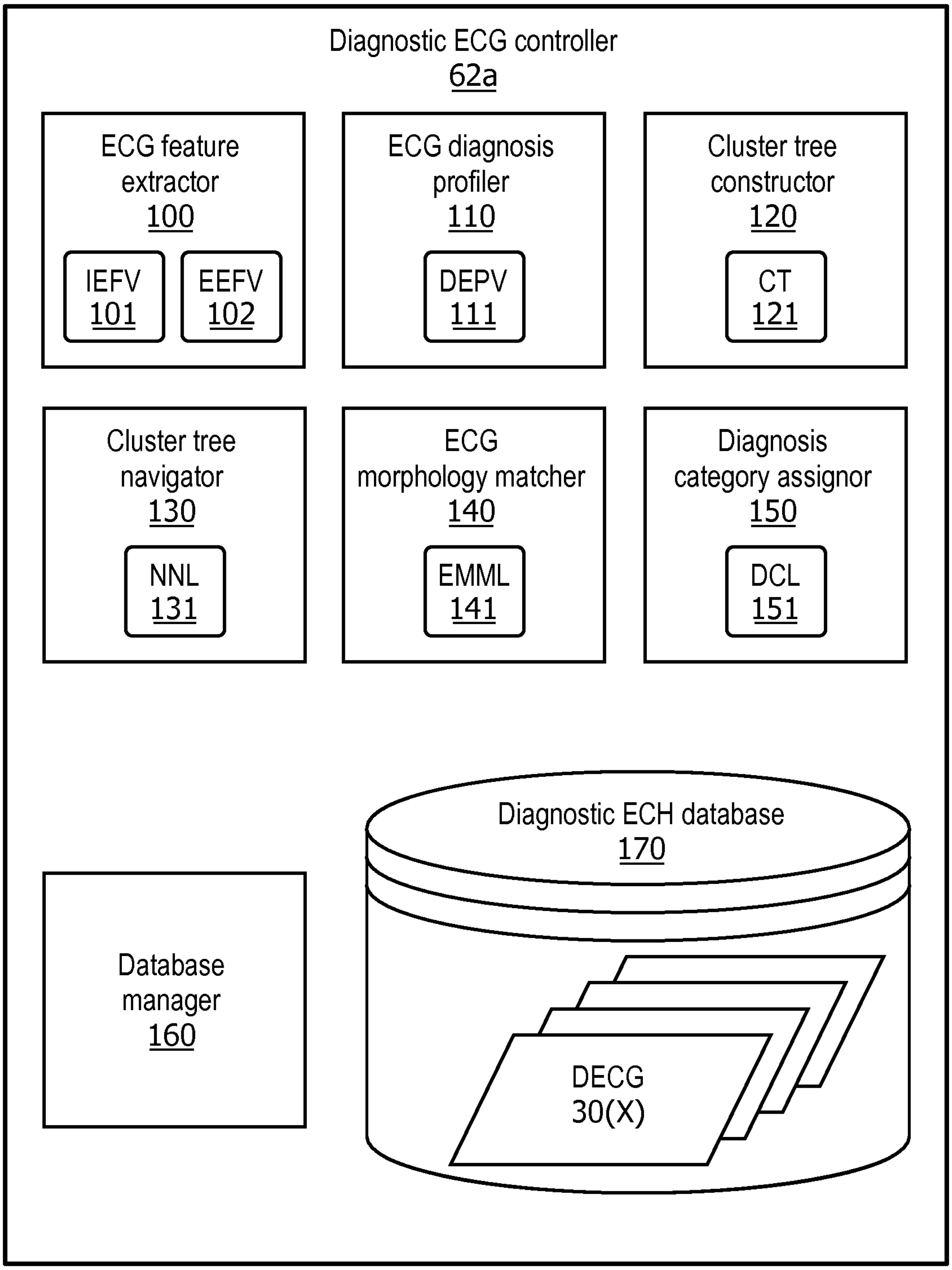

Diagnostic ECG controller
62a
ECG feature extractor
100
IEFV
101
EEFV
102
ECG diagnosis profiler
110
DEPV
111
Cluster tree constructor
120
CT
121
Cluster tree navigator
130
NNL
131
ECG morphology matcher
140
EMML
141
Diagnosis category assignor
150
DCL
151
Database manager
160
Diagnostic ECH database
170
DECG
30(X)

FIG. 5

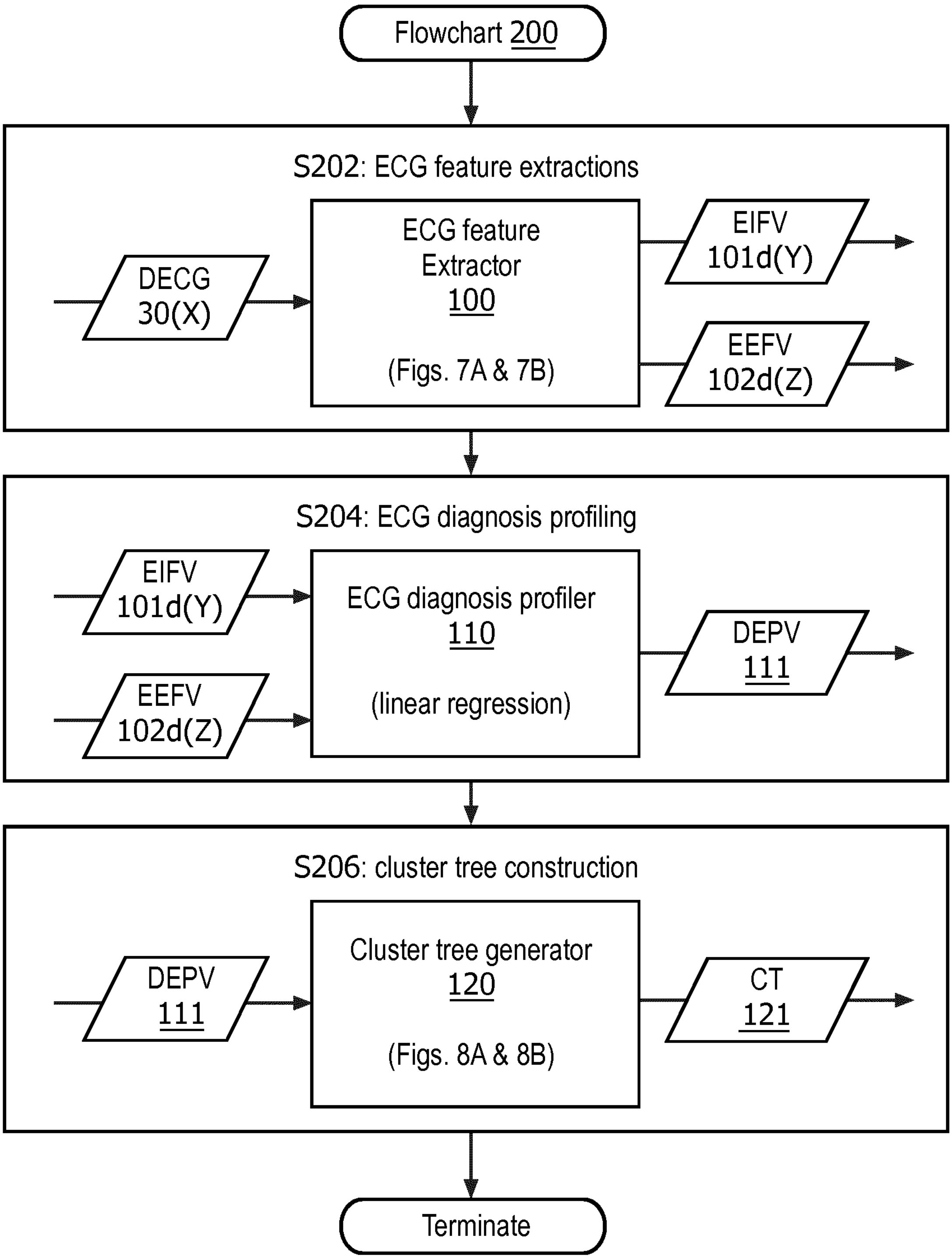

Flowchart 200
S202: ECG feature extractions
DECG
30(X)
ECG feature
Extractor
100
(Figs. 7A & 7B)
EIFV
101d(Y)
EEFV
102d(Z)
S204: ECG diagnosis profiling
EIFV
101d(Y)
EEFV
102d(Z)
ECG diagnosis profiler
110
(linear regression)
DEPV
111
S206: cluster tree construction
DEPV
111
Cluster tree generator
120
(Figs. 8A & 8B)
CT
121
Terminate

FIG. 6

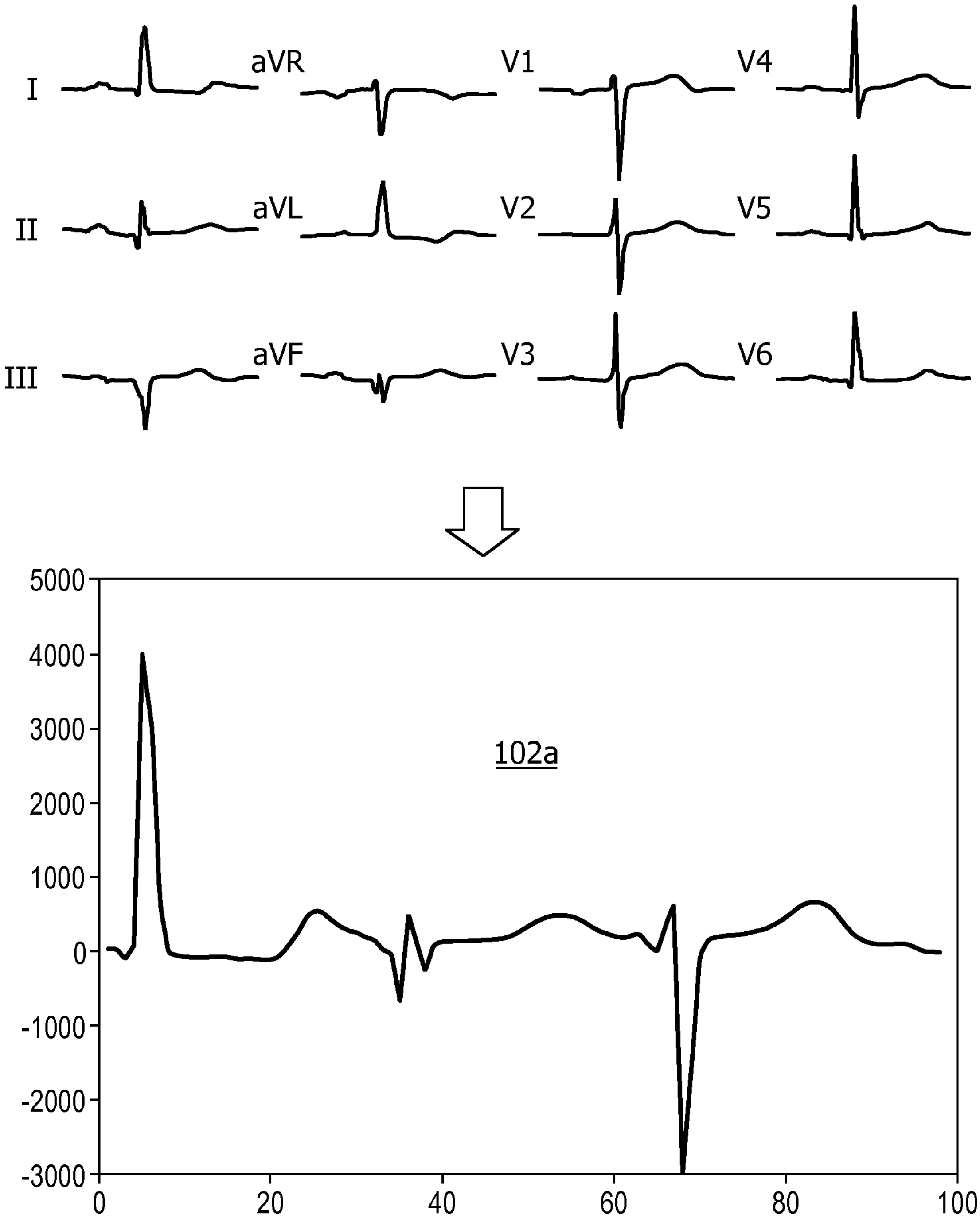

I
aVR
V1
V4
II
aVL
V2
V5
III
aVF
V3
V6
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
0
20
40
60
80
100
102a

FIG. 7

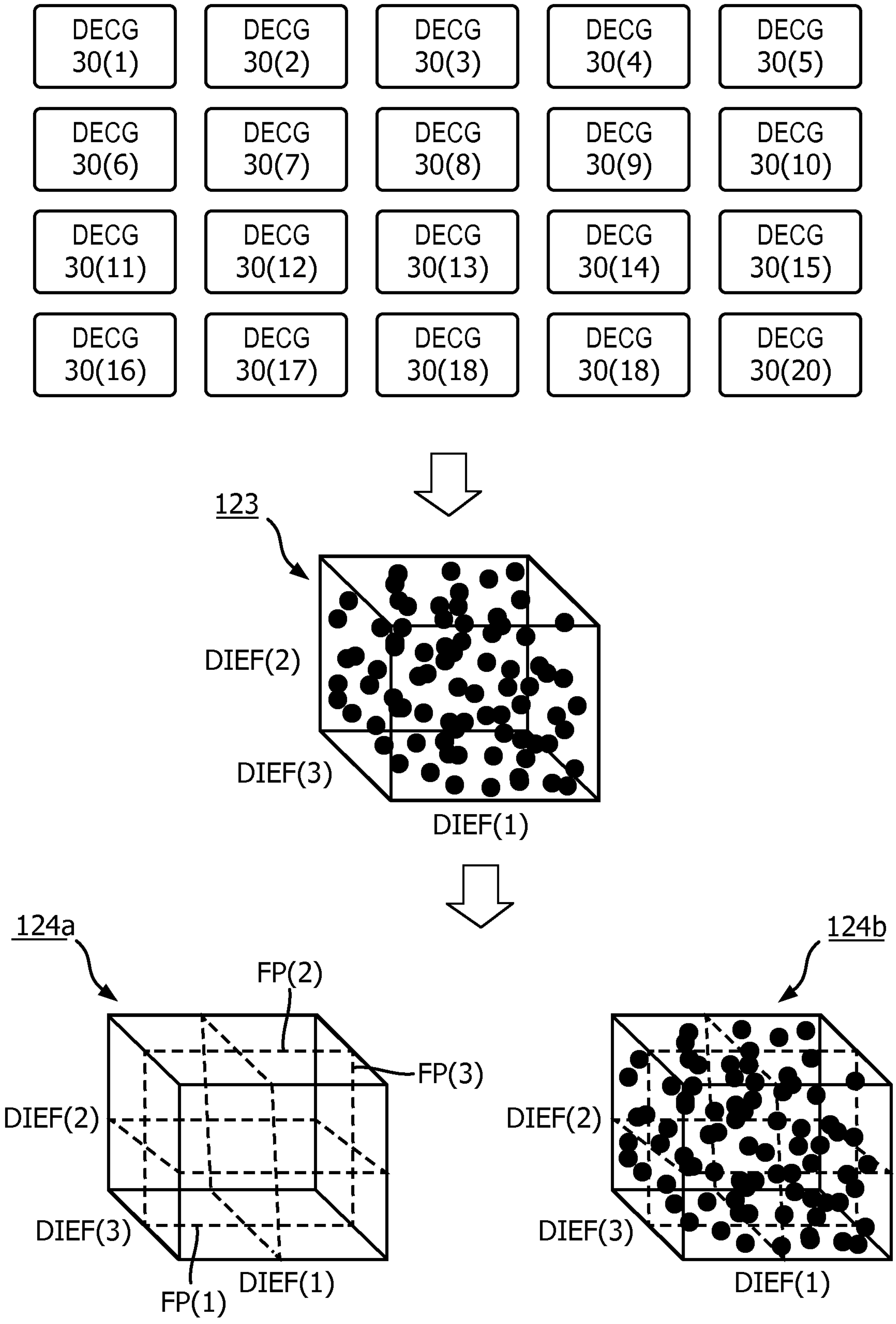

DECG 30(1)
DECG 30(2)
DECG 30(3)
DECG 30(4)
DECG 30(5)
DECG 30(6)
DECG 30(7)
DECG 30(8)
DECG 30(9)
DECG 30(10)
DECG 30(11)
DECG 30(12)
DECG 30(13)
DECG 30(14)
DECG 30(15)
DECG 30(16)
DECG 30(17)
DECG 30(18)
DECG 30(18)
DECG 30(20)
123
DIEF(2)
DIEF(3)
DIEF(1)
124a
FP(2)
FP(3)
DIEF(2)
DIEF(3)
FP(1)
DIEF(1)
124b
DIEF(2)
DIEF(3)
DIEF(1)

FIG. 8A

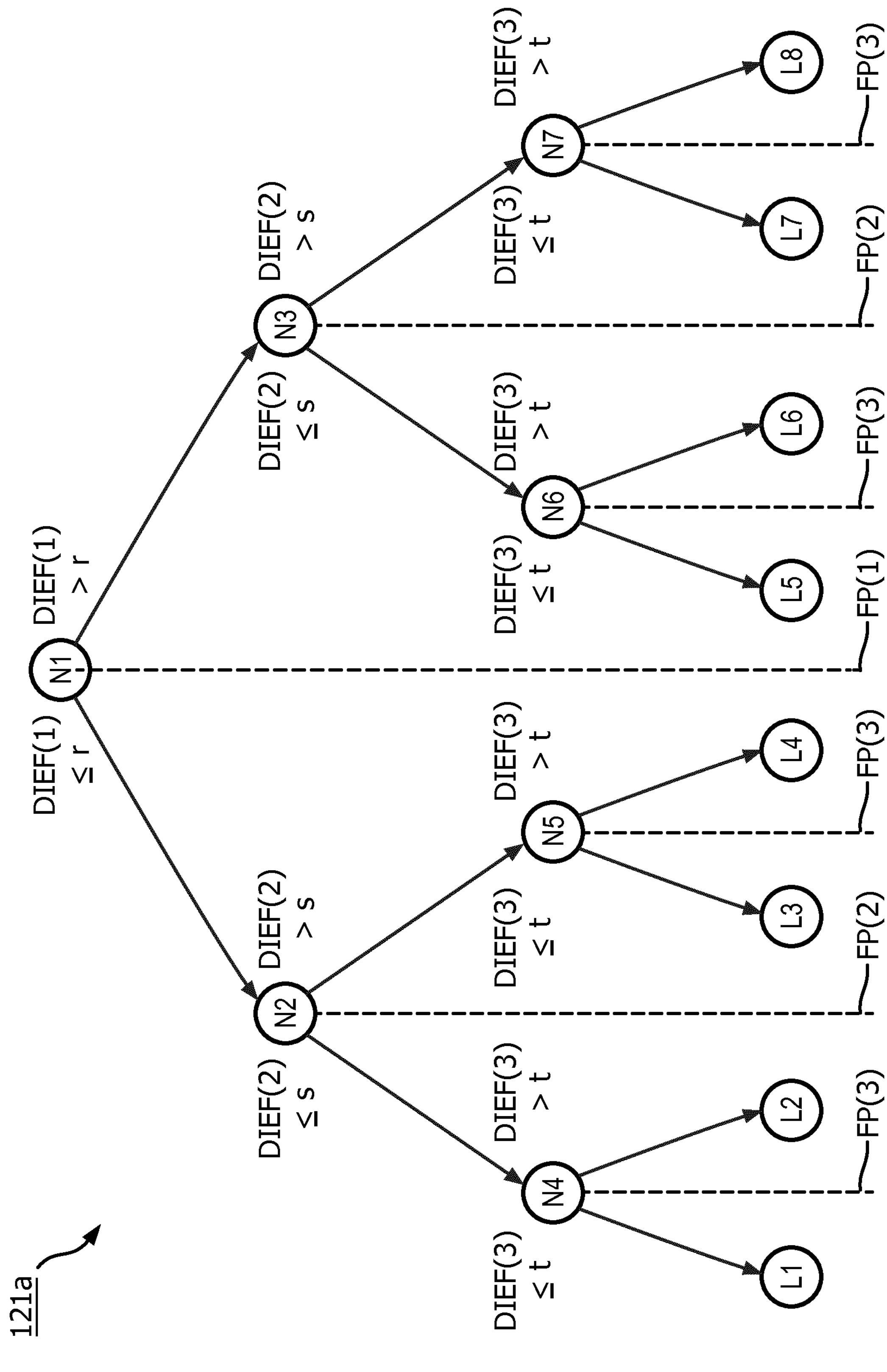

121a
N1
DIEF(1) ≤ r
DIEF(1) > r
N2
N3
DIEF(2) ≤ s
DIEF(2) > s
DIEF(2) ≤ s
DIEF(2) > s
N4
N5
N6
N7
DIEF(3) ≤ t
DIEF(3) > t
DIEF(3) ≤ t
DIEF(3) > t
DIEF(3) ≤ t
DIEF(3) > t
DIEF(3) ≤ t
DIEF(3) > t
L1
L2
L3
L4
L5
L6
L7
L8
FP(3)
FP(2)
FP(3)
FP(1)
FP(3)
FP(2)
FP(3)

FIG. 8B

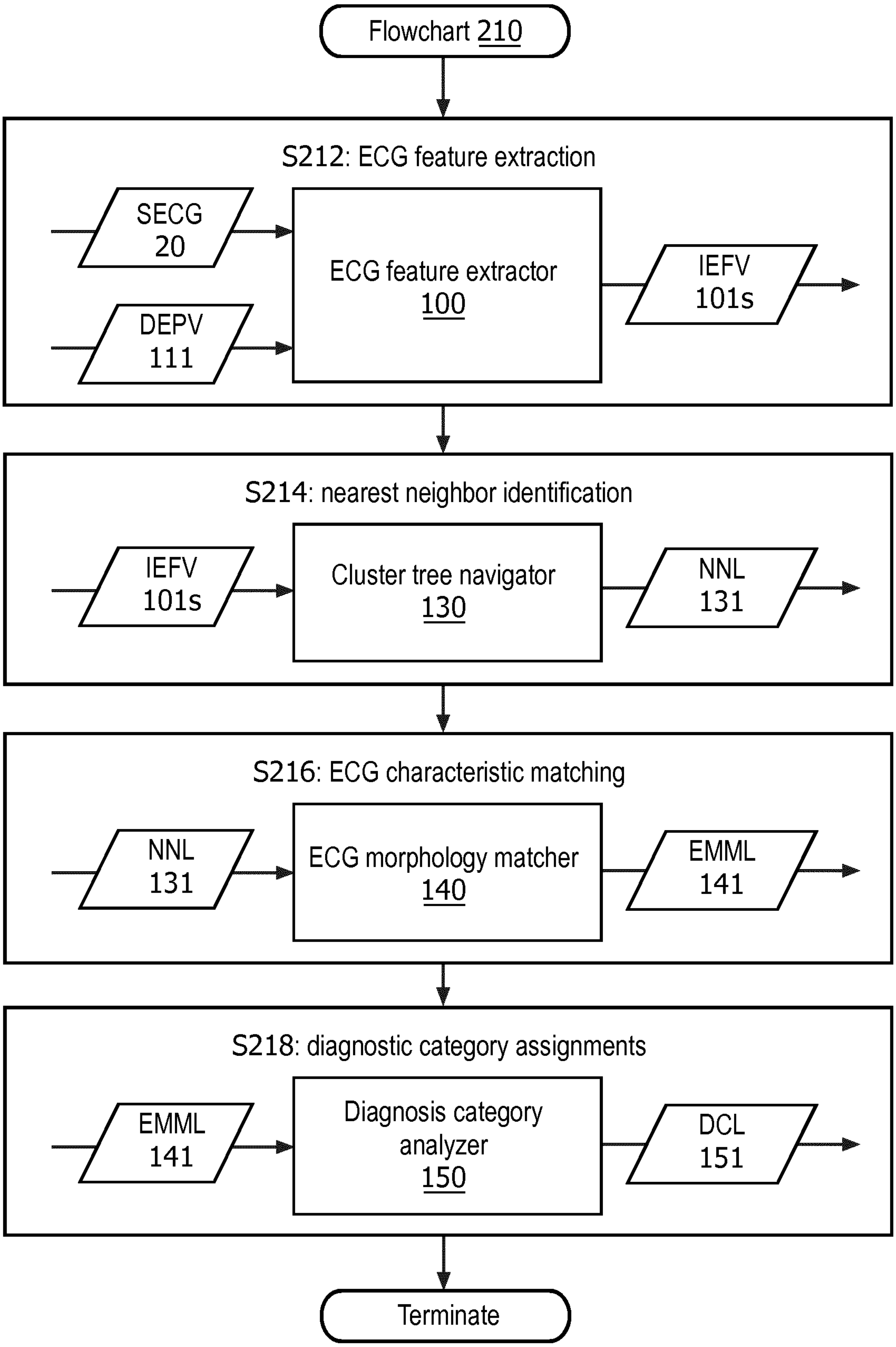

Flowchart 210
S212: ECG feature extraction
SECG 20
DEPV 111
ECG feature extractor 100
IEFV 101s
S214: nearest neighbor identification
IEFV 101s
Cluster tree navigator 130
NNL 131
S216: ECG characteristic matching
NNL 131
ECG morphology matcher 140
EMML 141
S218: diagnostic category assignments
EMML 141
Diagnosis category analyzer 150
DCL 151
Terminate

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/059049

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/0402 G06F19/00 G01N21/359 A61B5/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B G06F G01N

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

Electronic data base consulted during the international search (name of data base and, where 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.
X	US 2012/041277 A1 (EBADOLLAHI SHAHRAM [US] ET AL) 16 February 2012 (2012-02-16) paragraph [0027] - paragraph [0029]; figure 1 paragraph [0030] - paragraph [0034]; figure 2 paragraph [0036] - paragraph [0037]; figure 3 -----	1-20

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[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
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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
22 June 2017	30/06/2017

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

4

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KRISZTIAN BUZA ET AL: "Fast Classification of Electrocardiograph Signals via Instance Selection", HEALTHCARE INFORMATICS, IMAGING AND SYSTEMS BIOLOGY (HISB), 2011 FIRST IEEE INTERNATIONAL CONFERENCE ON, IEEE, 26 July 2011 (2011-07-26), pages 9-16, XP032066450, DOI: 10.1109/HISB.2011.26 ISBN: 978-1-4577-0325-6 the whole document figure 4 -----	1-20

4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/059049

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012041277 A1	16-02-2012	NONE	

patsnap

专利名称(译)	心电图培训和技能提升		
公开(公告)号	EP3442410A1	公开(公告)日	2019-02-20
申请号	EP2017717440	申请日	2017-04-14
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	GREGG RICHARD EARL BABAEIZADEH SAEED		
发明人	GREGG, RICHARD, EARL BABAEIZADEH, SAEED		
IPC分类号	A61B5/0402 G06F19/00 G01N21/359 A61B5/00		
CPC分类号	A61B5/0402 A61B5/7246 A61B5/7264 A61B5/7267 G16H30/20 G16H50/20 G16H50/50 G16H50/70 G16H70/20 A61B5/0408		
代理机构(译)	穆勒，FRANK		
优先权	62/323616 2016-04-15 US 62/349809 2016-06-14 US		
外部链接	Espacenet		

摘要(译)

一种诊断心电图系统，其采用电极引线系统（40），用于产生指示受试者心脏（10）的电活动的一个或多个电极信号。诊断心电图系统还采用耦合到电极引线系统（40）的诊断心电图仪（50），用于通信（例如，列出，显示和/或打印对象心电图（20）和一个或多个指定为诊断心电图（30）的诊断心电图（30）。形态匹配主题心电图（20）。主题心电图（20）包括由电极信号指示的主题心脏（10）的电活动导出的ECG特征的一种或多种解释（例如，算术解释和/或心电图师对主题心电图的解释（20）。诊断心电图包括从诊断的心脏的记录的电活动导出的ECG特征的一个或多个诊断（11）（例如，算法）诊断和/或心电图诊断诊断心电图（30））。