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(54) SYSTEM FOR PROVIDING AN ELECTRICAL ACTIVITY MAP USING OPTICAL SHAPE SENSING

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(57) **ABSTRACT**

The invention relates to a system (**1**) for providing an electrical activity map of the heart by means of electrical signals acquired by a plurality of surface electrodes (**9**). A surface electrodes positions determination unit (**4**, **6**, **13**) determines positions of the plurality of surface electrodes by means of optical shape sensing localization. The optical shape sensing element may comprise a wand (**4**), or alternatively an optical shape sensing fiber embedded in the vest comprising the surface electrodes. The position of a cardiac structure may be determined using ultrasound. An electrical activity map determination unit (**16**) determines the electrical activity map at the cardiac structure based on the measured electrical signals, the determined positions of the plurality of electrodes and the position of the cardiac structure, in particular, of the epicardial surface. Since optical shape sensing is used for determining the positions of the plurality of surface electrodes and not, for instance, x-rays, the electrical activity map can be determined, without necessarily applying an x-ray radiation dose.

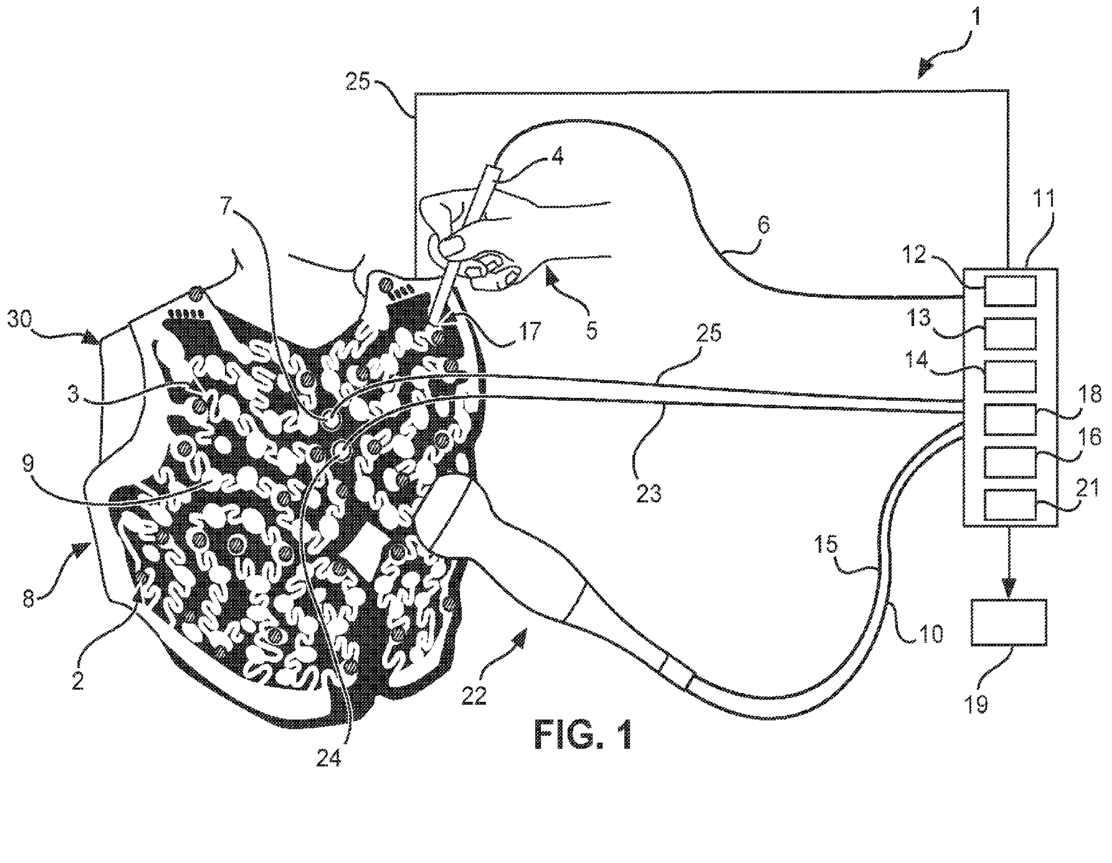

FIG. 1

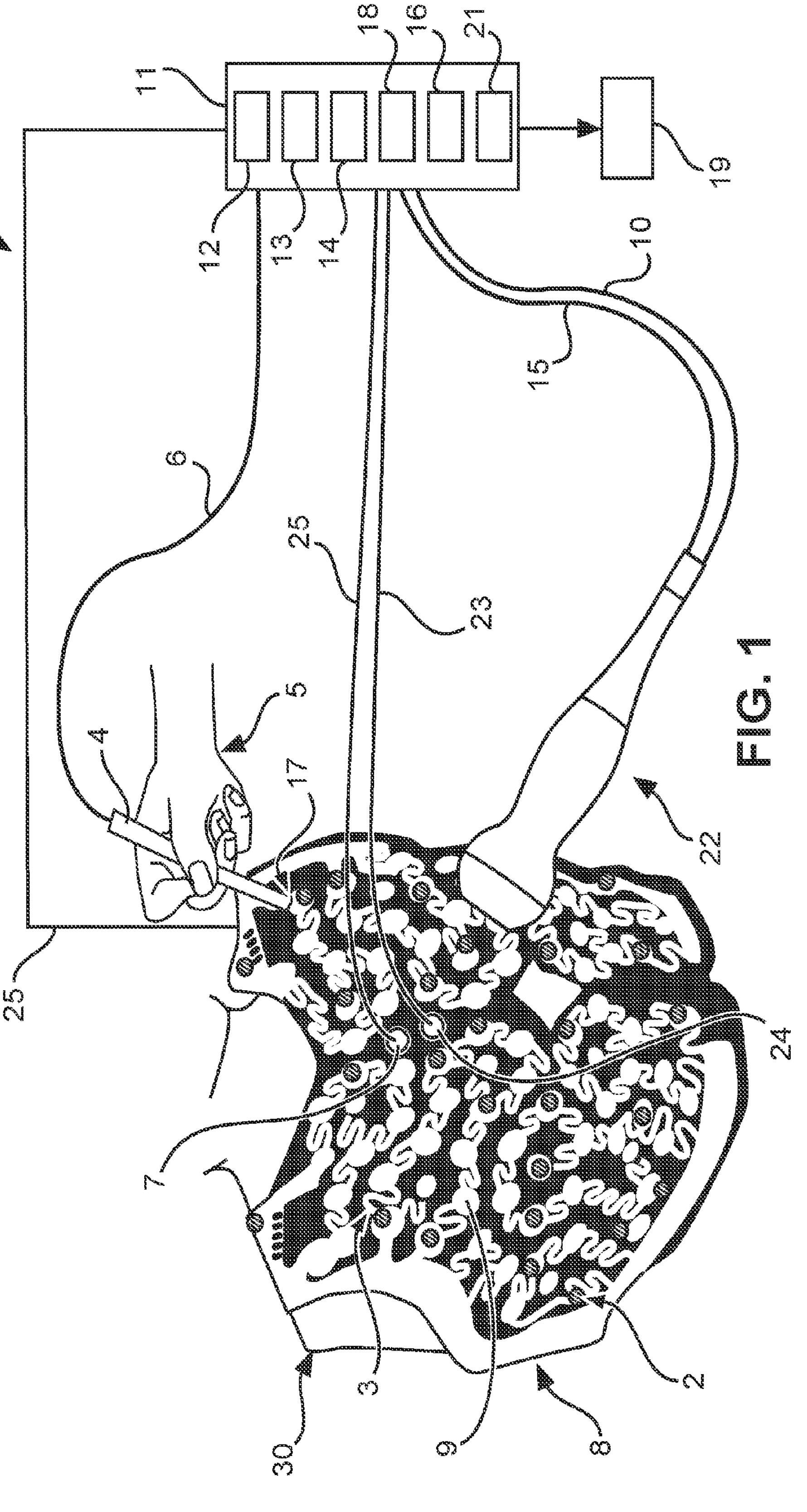

FIG. 1

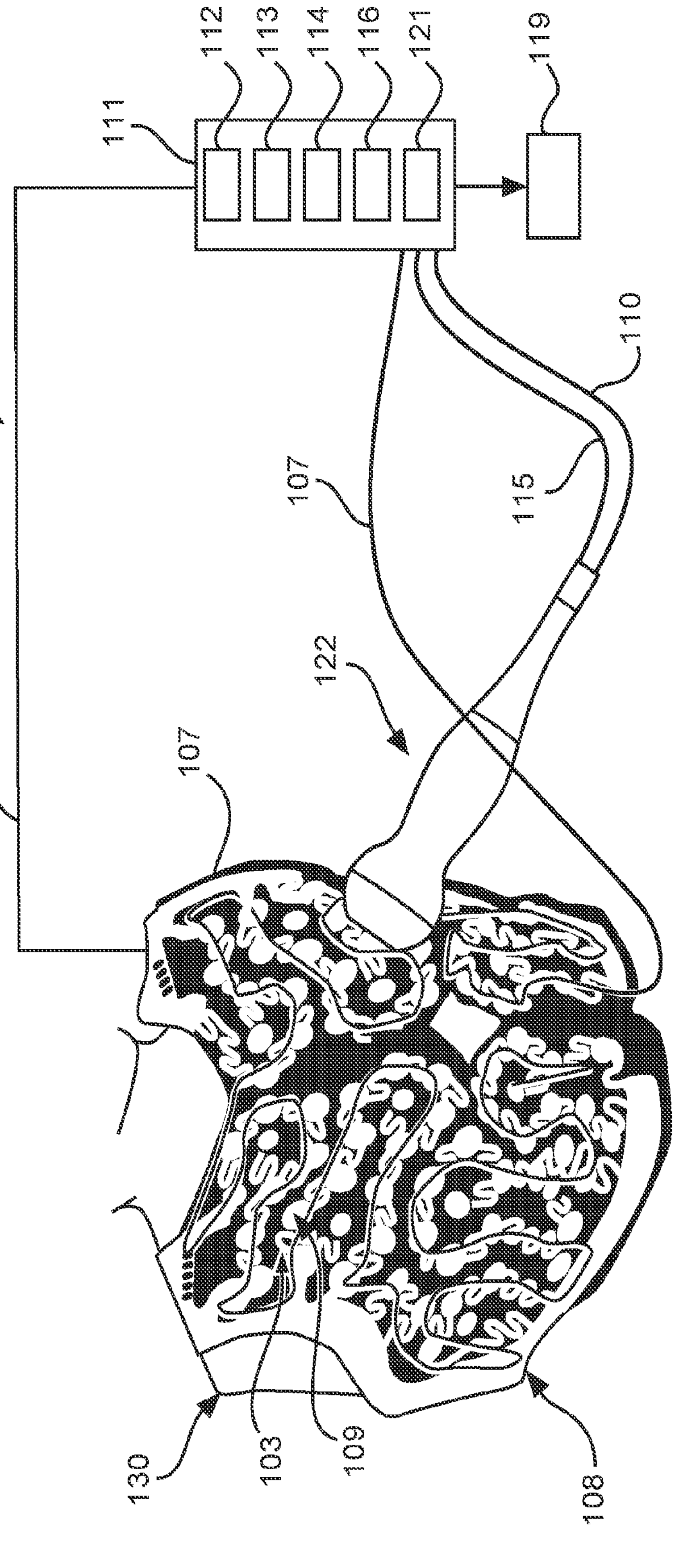
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FIG. 2

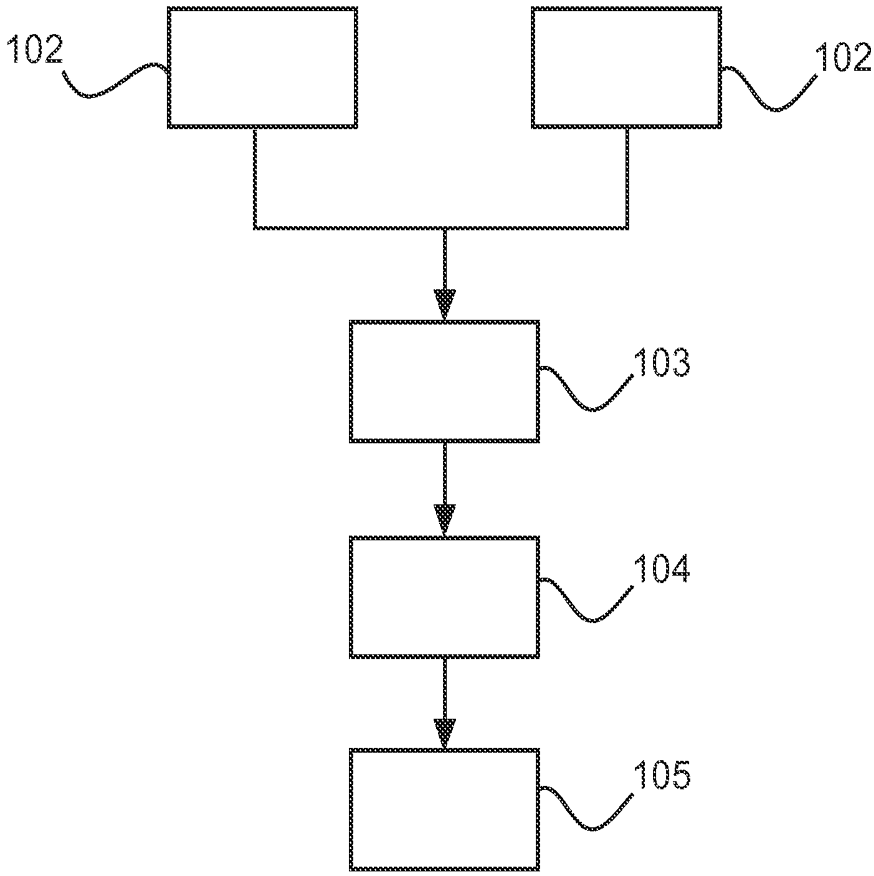

FIG. 3

SYSTEM FOR PROVIDING AN ELECTRICAL ACTIVITY MAP USING OPTICAL SHAPE SENSING

FIELD OF THE INVENTION

[0001] The invention relates to a system, a method and a computer program for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being. The invention relates further to a vest comprising the plurality of surface electrodes.

BACKGROUND OF THE INVENTION

[0002] The article "Noninvasive Characterization of Epicardial Activation in Humans With Diverse Atrial Fibrillation Patterns" by P. S. Cuculich et al., Circulation, Journal of the American Heart Association, 122, pages 1364 to 1372 (2010) discloses a system comprising an electrode vest with surface electrodes for measuring electrical potentials on an outer surface of a person. The system further comprises a reconstruction unit for reconstructing epicardial electrical potentials based on i) a spatial relation between the heart surface and the surface electrodes on the outer surface of the person and ii) the measured electrical potentials. The spatial relation between the heart surface and the surface electrodes on the outer surface of the person are obtained by acquiring an x-ray computed tomography image showing both, the heart surface and the surface electrodes on the outer surface of the person. By acquiring the x-ray computed tomography image a relatively high radiation dose is applied to the person.

SUMMARY OF THE INVENTION

[0003] It is an object of the present invention to provide a system, a method and a computer program for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being, wherein the radiation dose applied to the person can be reduced, in particular, can be eliminated. It is a further object of the present invention to provide a vest for being worn by a living being and for being used for providing the electrical activity map.

[0004] In a first aspect of the present invention a system for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being is presented, the system comprising:

[0005] a surface electrodes positions determination unit for determining positions of the plurality of surface electrodes by means of optical shape sensing localization,

[0006] a cardiac structure position determination unit for determining a position of a cardiac structure of the living being,

[0007] an electrical activity map determination unit for determining the electrical activity map at the cardiac structure based on the electrical signals measured on the outer surface of the living being, the determined positions of the plurality of electrodes and the determined position of the cardiac structure.

[0008] Since the positions of the plurality of surface electrodes are determined by means of optical shape sensing localization, these positions can be determined without necessarily acquiring a computed tomography image showing the plurality of surface electrodes. This allows reducing, in particular, eliminating, the x-ray radiation dose applied to the living being for generating an electrical activity map of the heart.

[0009] The cardiac structure is preferentially the epicardial surface of the heart.

[0010] If the cardiac structure is three-dimensional, in particular, if the cardiac structure is the three-dimensional epicardial surface, the position of the cardiac structure preferentially defines the position of each point of the cardiac structure at which the electrical activity map should be determined. Thus, for instance, if the cardiac structure position determination unit determines the position of the epicardial surface, it determines at least the positions of the points on the epicardial surface for which an electrical potential should be determined for generating the electrical activity map.

[0011] The plurality of surface electrodes can be regarded as being an element of the system or it can be regarded as being a separate element, wherein the system is adapted to use the electrical signals of the surface electrodes for providing the electrical activity map.

[0012] The plurality of surface electrodes can be incorporated in a vest that can be worn by the living being. The living being is preferentially a person, but the living being can also be an animal.

[0013] The cardiac structure position determination unit comprises preferentially an ultrasound unit for generating an ultrasound signal being indicative of the position of the cardiac structure and a cardiac structure position calculation unit for calculating the position of the cardiac structure based on the ultrasound signal. The ultrasound unit is preferentially a transthoracic echo probe or a transesophageal echo probe. If the ultrasound unit is a transthoracic echo probe or a transesophageal echo probe, an ultrasound image of the heart showing the epicardial surface can be acquired with high quality, thereby allowing the cardiac structure position calculation unit to determine the position of the epicardial surface being the preferred cardiac structure with high accuracy.

[0014] In an embodiment the cardiac structure position calculation unit is adapted to perform a segmentation procedure for segmenting the cardiac structure in the ultrasound image for detecting the cardiac structure. In another embodiment the cardiac structure position calculation unit is adapted to provide an anatomical cardiac model being an anatomical model of a heart including the cardiac structure and to adjust the cardiac model to the ultrasound image of the heart for detecting the cardiac structure. The adjustment can just be a rotation and/or translation and optionally a scaling of the cardiac model, or it can also include a deformation of the cardiac model. The cardiac model is preferentially a generalized cardiac model, i.e. a cardiac model which is, before being adjusted, not specific for a certain person or animal. It can be determined by, for instance, averaging segmented hearts of a group of living beings, which may be segmented in medical images.

[0015] It is further preferred that the ultrasound unit is equipped with an optical shape sensing sensor for generating an optical shape sensing signal being indicative of the position of the ultrasound unit, wherein the cardiac structure position calculation unit is adapted to determine the position of the cardiac structure based on the optical shape sensing signal and the ultrasound signal. The optical shape sensing sensor is preferentially an optical shape sensing fiber, which may be partly arranged within the ultrasound unit. This allows determining the position of the ultrasound unit by optical shape sensing, without applying, for instance, x-rays to the person. In particular, if the ultrasound signal represents an ultrasound image of the heart, the epicardial surface in the ultrasound image can be segmented for determining the position of the epicardial surface within the ultrasound image and this determined position of the epicardial surface can be related to a reference position, i.e. it can be determined within a reference coordinate system, based on the position of the ultrasound unit known from the optical shape sensing signal.

[0016] In an embodiment the surface electrodes positions determination unit comprises a spatial relation providing unit for providing spatial relations between the positions of the plurality of surface electrodes and positions of reference marks, wherein the ultrasound unit is adapted to be brought into contact with the reference marks, wherein the optical shape sensing sensor is adapted to generate a respective optical shape sensing signal while being in contact with a respective reference mark for generating an optical shape sensing signal being indicative of the position of the respective reference mark, and wherein the surface electrodes positions determination unit comprises a surface electrodes positions calculation unit for calculating the positions of the surface electrodes depending on the optical shape sensing signals and the spatial relations. Thus, the ultrasound unit can be used for two purposes, determining the position of the cardiac structure and determining the positions of the plurality of surface electrodes. This reduces the number of elements needed for determining the electrical activity map of the heart.

[0017] In an embodiment the surface electrodes positions determination unit comprises a) a spatial relations providing unit for providing spatial relations between the positions of the plurality of surface electrodes and positions of reference marks, b) an optical shape sensing element for generating an optical shape sensing signal being indicative of the position of the tip of the optical shape sensing element while being in contact with a respective reference mark, in order to generate an optical shape sensing signal being indicative of the position of the respective reference mark, and c) a surface electrodes positions calculation unit for calculating the positions of the surface electrodes depending on the optical shape sensing signal and the spatial relations. The optical shape sensing element can comprise a wand and an optical shape sensing fiber connected to the wand, wherein the tip of the optical shape sensing element is the tip of the wand. Thus, a user can touch the reference marks with the wand and determine the positions of the reference marks by determining the positions of the tip of the wand, while the tip is brought into contact with the different reference marks. The optical shape sensing element can be adapted to, for example, continuously generate an optical shape sensing signal, or to generate an optical shape sensing signal only after a user has requested an optical shape sensing signal via an input unit like a button to be pressed. The tip can also be provided with a pressure sensitive sensor for detecting whether the tip is in contact with an element or not, wherein the optical shape sensing element can be adapted to generate an optical shape sensing signal, when the pressure sensitive sensor detects that the tip is in contact with a reference mark.

[0018] The system can further comprise a movement determination unit for determining a movement of the living being, wherein the surface electrodes positions determination unit can be adapted to determine the positions of the plurality of surface electrodes depending on the determined movement. The movement determination unit can comprise an optical shape sensing sensor for being attached to the living being at an attachment location and for generating an optical shape sensing signal being indicative of an actual position of the optical shape sensing sensor and a movement calculation unit for calculating a movement of the living being depending on the generated optical shape sensing signal. One or several optical shape sensing sensors can be used for determining the movement of the living being. The optical shape sensing sensors can be adapted to be directly attached to the living being or to be attached to another means being attached to the living being. The other means can be, for instance, a vest comprising the plurality of the surface electrodes or patches that can be put on, for example, a person's thorax. Considering a possible movement of the person while determining the electrical activity map of the heart can reduce corresponding possible inaccuracies in the electrical activity map.

[0019] In an embodiment the surface electrodes positions determination unit comprises a) an optical shape sensing sensor for generating optical shape sensing signals being indicative of the position of the optical shape sensing sensor, b) a spatial relation providing unit for providing spatial relations between the positions of the optical shape sensing sensor and the positions of the surface electrodes, and c) a surface electrodes positions calculation unit for calculating the positions of the surface electrodes depending on the generated optical shape sensing signals and the spatial relations. In this embodiment the optical shape sensing sensor can be incorporated into a vest which also comprises the plurality of surface electrodes, wherein the spatial relations between the optical shape sensing sensor and the plurality of surface electrodes are known and stored in the spatial relation providing unit. This allows determining the positions of the surface electrodes without using, for instance, an optical shape sensing wand touching the different surface electrodes. For instance, an electrical activity map can be generated just by using the vest with the one or several optical shape sensing sensors and an ultrasound unit also being equipped with an optical shape sensing sensor such that the position of the ultrasound unit relative to the surface electrodes can be determined by optical shape sensing, preferentially without requiring further means for determining the positions of the surface electrodes and the cardiac structure. Since less elements are needed for generating the electrical activity map, the process for determining the electrical activity map to be performed by, for instance, a physician can be simplified.

[0020] In a further aspect of the present invention a vest for being worn by a living being is presented, the vest being adapted to be used for providing an electrical activity map, the vest comprising:

[0021] a plurality of surface electrodes for being arranged on an outer surface of the living being, when the vest is worn by the living being, and for acquiring electrical signals from the heart of the living being,

[0022] an optical shape sensing sensor for generating an optical shape sensing signal being indicative of the position of the optical shape sensing sensor and for providing the optical shape sensing signal to a surface electrodes positions determination unit.

[0023] In a further aspect of the present invention a method for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being is presented, the method comprising:

[0024] determining positions of the plurality of surface electrodes by means of optical shape sensing localization by a surface electrodes positions determination unit,

[0025] determining a position of a cardiac structure of the living being by a cardiac structure position determination unit,

[0026] determining the electrical activity map at the cardiac structure based on the electrical signals measured on the outer surface of the living being, the determined positions of the plurality of electrodes and the determined position of the cardiac structure by an electrical activity map determination unit.

[0027] In a further aspect of the present invention a computer program for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being is presented, the computer program comprising program code means for causing a system as defined in claim **1** to carry out the steps of the method as defined in claim **12**, when the computer program is run on a computer controlling the system.

[0028] It shall be understood that the system of claim **1**, the method of claim **12** and the computer program claim **13** have similar and/or identical preferred embodiments, in particular, as defined in the dependent claims.

[0029] It shall be understood that a preferred embodiment of the invention can also be any combination of the dependent claims with the respective independent claim.

[0030] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] In the following drawings:

[0032] FIG. **1** shows schematically and exemplarily an embodiment of a system for providing an electrical activity map of the heart of a living being,

[0033] FIG. **2** shows schematically and exemplarily a further embodiment of a system for providing an electrical activity map of the heart of the living being, and

[0034] FIG. **3** shows a flowchart exemplarily illustrating an embodiment of a method for providing an electrical activity map of the heart of a living being.

DETAILED DESCRIPTION OF EMBODIMENTS

[0035] FIG. **1** shows schematically and exemplarily an embodiment of a system for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being. The system **1** comprises an optical shape sensing element **4**, **6** for generating an optical shape sensing signal being indicative of the position of the tip **17** of the optical shape sensing element **4**, **6** while being in contact with a respective reference mark **2**, in order to generate an optical shape sensing signal being indicative of the position of the respective reference mark **2**. In particular, the living being **30** being, in this embodiment, a person wears a vest **8** with surface electrodes **9** and reference marks **2**. A user like a physician can use the optical shape sensing element **4**, **6** such that the tip of the optical shape sensing element **4**, **6** consecutively touches the different reference marks **2** of the vest **8**, in order to determine the positions of the reference marks **2**. The vest **8** is electrically connected with a determination system **11** via an electrical connection **25**, in order to transmit the electrical signals acquired by the surface electrodes **9** to the electrical activity map determination unit **16**.

[0036] The optical shape sensing element **4**, **6** comprises a wand **4**, which can be held by a hand **5** of a user, with the tip **17** for being brought in contact with different reference marks **2** and an optical shape sensing fiber **6** being connected to the wand **4**. The optical shape sensing element **4**, **6** can be adapted to, for example, continuously generate an optical shape sensing signal or to generate an optical shape sensing signal only after a user has requested an optical shape sensing signal via an input unit like a button to be pressed. The tip can also be provided with a pressure sensitive sensor for detecting whether the tip is in contact with an element or not, wherein the optical shape sensing element can be adapted to generate an optical shape sensing signal, when the pressure sensitive sensor detects that the tip is in contact with a reference mark.

[0037] The system **1** comprises a further optical shape sensing element, i.e. an optical shape sensing sensor **7**, **26** for being attached to the person **30** at an attachment location and for generating an optical shape sensing signal being indicative of the actual position of the optical shape sensing sensor **7**, **26**. In this embodiment this optical shape sensing sensor comprises a reference patch **7** connected to an optical shape sensing fiber **26**, wherein the generated optical shape sensing signal is indicative of the position of the reference patch **7**.

[0038] The optical shape sensing signal from the optical shape sensing sensor **7**, **26**, which is indicative of the position of the reference patch **7**, and the optical shape sensing signal from the optical shape sensing element **4**, **6**, which is indicative of the position of the tip **17** of the optical shape sensing element **4**, **6**, are provided to a surface electrodes positions calculation unit **13** of the determination system **11**. The surface electrodes positions calculation unit **13** is adapted to determine the three-dimensional positions of the reference marks **2** with respect to the reference patch **7** based on the provided optical shape sensing signals. For determining the positions of the reference marks **2** known optical shape sensing localization method can be used like the optical shape sensing methods disclosed in WO 2011/141830 A1, which is herewith incorporated by reference.

[0039] After the positions of the reference markers **2** have been determined, the surface electrodes positions calculation unit **13** determines the positions of the surface electrodes **9** depending on the determined positions of the reference marks **2** and known spatial relations between the positions of the plurality of surface electrodes **9** and the positions of the reference marks **2** provided by a spatial relation providing unit **12**.

[0040] Thus, the wand **4** with the optical shape sensing fiber **6** is used to measure the positions of the reference marks **2** in the three-dimensional space with respect to the reference patch **7**. By going from one reference mark **2** to another reference mark **2** and recording the three-dimensional positions, a three-dimensional distribution of the reference marks **2** and thus, since the spatial relations between the reference marks **2** and the surface electrodes **9** being connected by tortuous wires **3** are known, the three-dimensional distribution of the vest electrodes can be reconstructed. The wand **4** with the optical shape sensing fiber **6**, the spatial relations providing unit **12** and the surface electrodes positions calculation **13** can therefore be regarded as being components of a surface electrodes positions determination unit for determining the positions of a plurality of surface electrodes by means of optical shape sensing localization.

[0041] The system **1** further comprises an ultrasound unit **22** for generating an ultrasound signal being indicative of the position of the cardiac structure within the person **30**. The ultrasound signal is provided to the determination system **11** via the electrical connection **15**. In this embodiment the ultrasound unit is a transthoracic echo probe **22** for generating an ultrasound signal representing a three-dimensional ultrasound image of the heart. In another embodiment the ultrasound unit can also be another probe like a transesophageal echo probe.

[0042] The ultrasound signal is provided to a cardiac structure position calculation unit **14** for calculating the position of the cardiac structure based on the ultrasound signal. In particular, the cardiac structure calculation unit **14** is adapted to detect the cardiac structure in the ultrasound image and to calculate the position of the cardiac structure based on the cardiac structure detected in the ultrasound image. For instance, the cardiac structure position calculation unit **14** can be adapted to perform a segmentation procedure for segmenting the cardiac structure being, in this embodiment, the epicardial surface, in the ultrasound image for detecting the cardiac structure. The cardiac structure position calculation unit can also be adapted to provide an anatomical cardiac model being an anatomical model of a heart including the cardiac structure, i.e. in this embodiment including the epicardial surface, and to adjust the cardiac model to the ultrasound image of the heart for detecting the cardiac structure. The cardiac model is preferentially a generalized cardiac model, i.e. a cardiac model which is, before being adjusted, not specific for a certain person or animal. It can be determined by, for instance, averaging of segmented hearts of a group of living beings, which may be segmented in medical images. In order to allow the cardiac structure position calculation unit to calculate the position of the detected cardiac structure, the cardiac structure position calculation unit **14** further receives an optical shape sensing signal from the ultrasound unit **22**. The ultrasound unit **22** is equipped with an optical shape sensing sensor **10** for generating the optical shape sensing signal being indicative of the position of the ultrasound unit **22**, wherein the cardiac structure position calculation unit **14** is adapted to determine the position of the ultrasound unit **22** with respect to the position of the reference patch **7** based on the optical sensing signals received from the optical shape sensing sensor **10** of the ultrasound unit **22**, which is an optical shape sensing fiber, and from the optical shape sensing sensor comprising the reference patch **7** and the optical shape sensing fiber **26** connected to the patch **7**. The position of the cardiac structure, i.e. in this embodiment of the epicardial surface, is then determined based on the determined three-dimensional position of the ultrasound unit **22** and the determined position of the cardiac structure within the ultrasound image acquired by the ultrasound unit **22**.

[0043] Thus, an ultrasound probe **22** with an optical shape sensing fiber **10** is used to image the cardiac anatomy, wherein the optical shape sensing fiber **10**, which is preferentially embedded in the ultrasound probe **22**, is used to measure the location of the ultrasound probe **22** with respect to the reference patch **7**, thus ensuring that the location of the cardiac anatomy as imaged by the ultrasound probe **22** and the positions of the surface electrodes **9** in three-dimensional space are known with respect to each other. In other words, since in this embodiment the positions of the surface electrodes **9** and of the epicardial surface are determined with respect to the same reference being the reference patch **7**, the spatial relation between the surface electrodes **9** and the epicardial surface is known. In other embodiments, the positions of the surface electrodes and the position of, for instance, the epicardial surface can be determined with respect to another reference. The optical shape sensing sensor **10**, the cardiac structure position calculation unit **14** and the ultrasound unit **22** with the electrical connection **15** for transferring the ultrasound signal can be regarded as being elements of a cardiac structure position determination unit for determining a position of a cardiac structure like the epicardial surface of the person **30**.

[0044] The system further comprises a movement determination unit for determining a movement of the person **30**, wherein the surface electrodes positions calculation unit **13** is adapted to determine the positions of the plurality of surface electrodes **9** also depending on the determined movement. The movement determination unit comprises a further patch **24**, a further optical shape sensing fiber **23** attached to the patch **24** and a movement calculation unit **18**. The movement calculation unit **18** receives an optical shape sensing signal being indicative of the position of the further patch **24** attached to the vest **8**, wherein for providing this optical shape sensing signal the patch **24** is connected with the optical shape sensing fiber **23**. The movement calculation unit **18** calculates the position of the patch **24** at different times from the received optical shape sensing signal, in order to determine the movement of the person **30**.

[0045] One or several optical shape sensing sensors, for instance, one or several patches with optical shape sensing fibers, can be used for determining the movement of the person **30**. The optical shape sensing sensors for determining the movement of the person can be adapted to be directly attached to the person. For instance, the optical shape sensing sensors, in particular, patches connected to optical shape sensing fibers, can be put on a person's thorax. Alternatively or in addition, the optical shape sensing sensors can be attached to another means being attached to the person. The other means can be, as shown in FIG. **1**, a vest comprising the plurality of surface electrodes.

[0046] The system **1** further comprises an electrical activity map determination unit **16** for determining the electrical activity map at the cardiac structure, i.e. in this embodiment on the epicardial surface, based on the electrical signals measured on the outer surface of the person **30**, the determined positions of the plurality of electrodes **9** and the determined position of the cardiac structure. For determining the electrical activity map well known methods can be used like the methods disclosed in the article "Electrocardiographic Imaging (ECGI): A Noninvasive Imaging Modality for Cardiac Electrophysiology and Arrhythmia" by Ramanathan et al., Nature Medicine 10, 422-428 (2004) or disclosed in U.S. Pat. No. 7,471,971, which are herewith incorporated by reference. Moreover, known products from the companies CardioInsight Technologies and Amycard can be used for determining the electrical activity map at the cardiac structure, i.e. in this embodiment on the epicardial surface, based on the electrical signals measured on the outer surface of the person, the determined positions of the plurality of electrodes and the determined position of the cardiac structure.

[0047] The determination system **11** further comprises an analysis unit **21** for analyzing the electrical activity map for determining electrophysiological mechanisms of certain cardiac arrhythmias. Moreover, in addition or alternatively the analysis unit **21** may be adapted to analyze the electrical activity behaviour of cardiac dyssnychrony in heart failure patients as disclosed in the articles "Noninvasive Characterization of Epicardial Activation in Humans with Diverse Atrial Fibrillation Patterns" by P. S. Cuculich et al., Circulation 122, 1364-1372 (2010), "Electrocardiographic Imaging of Ventricular Bigeminy in a Human Subject" by Y. Wang et al., Circulation Arrhythmia and Electrophysiology 1, 74-75 (2008) and "Electrocardiographic Imaging of Cardiac Resynchronization Therapy in Heart Failure: Observations of Variable Electrophysiological Responses" by P. Jia et al., Heart Rhythm Journal 3, 296-310 (2006), which are herewith incorporated by reference.

[0048] In particular, the analysis unit can be adapted to perform at least one of following analyses based on the electrical activity map: determination of an anatomical position of ectopi foci, determination of an anatomical position of ventricular re-entries, distinguishing between re-entry or focal ventricular tachycardia and assessing of its localizations, assessing re-connection of pulmonary vein conduction and localization of culprit pulmonary veins, and assessment of effects of antiarrhythmic drugs.

[0049] The electrical activity map of the heart and optionally results of the analysis can be shown on a display unit **19**.

[0050] FIG. **2** shows schematically and exemplarily a further embodiment of a system for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being. Also in this embodiment the living being is a person **130** wearing a vest **108** with a plurality of electrodes **109** connected by tortuous wires **103**. The surface electrodes **109** are used for acquiring electrical signals at the outer surface of the person **130**, wherein the acquired electrical signals are provided to a determination system **111** via an electrical connection **125**.

[0051] The vest **108** comprises an optical shape sensing fiber **107** for providing an optical shape sensing signal being indicative of the position of each portion of the optical shape sensing fiber **107** within the vest **108**. An ultrasound unit **122** with an optical shape sensing fiber **110** and an electrical connection **115** for providing ultrasound signals to the determination system **111** is used for generating a three-dimensional ultrasound image of the heart of the person **130**. The ultrasound unit **122** with the optical shape sensing fiber **110** and the electrical connection **115** is similar to the ultrasound unit **22** with the optical shape sensing fiber **10** and the electrical connection **15** described above with reference to FIG. **1**.

[0052] The determination system **111** comprises a spatial relation providing unit **112** for providing a spatial relation between the optical shape sensing fiber **107** within the vest **108** and the surface electrodes **109**. This spatial relation is used together with the optical shape sensing signal, which is provided by the optical shape sensing fiber **107** and which is indicative of the position of each portion of the optical shape sensing fiber **107** within the vest **108**, for determining the position of the surface electrodes **109** incorporated into the vest **108**. Thus, the shape of at least one optical shape sensing fiber **107**, which is embedded in a specific pattern in the vest **108**, can be measured for determining the position of each portion of the optical shape sensing fiber **107** within the vest **108**. The locations of the surface electrodes **109** with respect to the optical shape sensing fiber **107** are known from the spatial relation provided by the spatial relation providing unit **112**. Therefore, a surface electrodes positions calculation unit **113** can calculate the three-dimensional distribution of the surface electrodes **109** by measuring the three-dimensional shape of the optical fiber **107**. The optical shape sensing fiber **107**, the spatial relation providing unit **112** and the surface electrodes positions calculation unit **113** can therefore be regarded as being elements of a surface electrodes positions determination unit for determining positions of the plurality of surface electrodes **109** by means of optical shape sensing localization.

[0053] The determination system **111** further comprises a cardiac structure position calculation unit **114** for calculating the position of the cardiac structure, i.e. in this embodiment of the epicardial surface, based on the optical shape sensing signal received from the vest optical shape sensing fiber **107**, the optical shape sensing signal received from the ultrasound optical shape sensing fiber **110** and the ultrasound signal acquired by the ultrasound unit **122**. In particular, the ultrasound signal is a three-dimensional ultrasound image of the heart of the person **130**, wherein the cardiac structure position calculation unit **114** is adapted to segment the epicardial surface in the three-dimensional ultrasound image for determining the position of the epicardial surface within this image. The position of this epicardial surface with respect to the position of the surface electrodes **109** is then determined by determining the position of the ultrasound unit **122** with respect to the position of the optical shape sensing fiber **107**. Thus, the ultrasound unit **122**, which can be regarded as being an ultrasound probe wand, is used to image the cardiac anatomy, wherein the optical shape sensing fiber **110**, which is embedded in the ultrasound unit **122**, is used to measure the location of the ultrasound unit **122** with respect to the optical shape sensing fiber **107** embedded in the vest **108**, thereby ensuring that the location of the cardiac anatomy, i.e. in this embodiment of the epicardial surface, as imaged by the ultrasound unit **122** and the position of the surface electrodes **109** are known in the three-dimensional space. The optical shape sensing fiber **110**, the cardiac structure calculation determination unit **114** and the ultrasound unit **122** with the electrical connection **115** for transferring the ultrasound signals can be regarded as being elements of a cardiac structure position determination unit for determining a position of a cardiac structure of the person **130**.

[0054] The determination system **111** further comprises an electrical activity map determination unit **116** and an analysis unit **121**, which are similar to the electrical activity map determination unit **16** and the analysis unit **21**, respectively, described above with reference to FIG. **1**. Also the display unit **119** is similar to the display unit **19** described above with reference to FIG. **1**.

[0055] In the following an embodiment of a method for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes at an outer surface of the living being will exemplarily be described with reference to a flowchart shown in FIG. **3**.

[0056] In step **101**, the positions of the plurality of surface electrodes are determined by the surface electrodes positions determination unit by means of optical shape sensing localization. For instance, the wand **4** with the connected optical shape sensing fiber **6** described above with reference to FIG. **1** is used for determining the three-dimensional positions of reference marks of a vest worn by a person by using optical shape sensing. A surface electrodes positions calculation unit can then calculate the three-dimensional positions of the electrodes of the vest based on the determined three-dimensional positions of the reference marks and provided spatial relations between the reference marks and the surface electrodes incorporated in the vest. Alternatively, an optical shape sensing fiber **107** embedded in the vest worn by the person can be used for determining the three-dimensional position of the surface electrodes as described above with reference to FIG. **2**. In particular, the three-dimensional position of each portion of the optical shape sensing fiber **107** within the vest **108** can be determined by optical shape sensing, wherein the surface electrodes positions calculation unit can calculate the three-dimensional positions of the surface electrodes based on the determined three-dimensional position of each portion of the optical shape sensing fiber **107** within the vest **108** and a provided spatial relation between the optical shape sensing fiber within the vest and the surface electrodes embedded in the vest.

[0057] In step **102**, the position of a cardiac structure of the person **30** is determined. In this embodiment the position of the epicardial surface is determined. For instance, the ultrasound unit with the optical shape sensing sensor described above with reference to FIGS. **1** and **2** is used for generating a three-dimensional ultrasound image showing the epicardial surface, wherein the cardiac structure position calculation unit can calculate the three-dimensional position of the epicardial surface based on, for example, a segmentation of the epicardial surface in the three-dimensional ultrasound image and the position of the ultrasound unit determined by optical shape sensing localization. Steps **101** and **102** can be performed in an arbitrary order, i.e. they can be performed consecutively or simultaneously.

[0058] In step **103**, the electrical activity map determination unit determines the electrical activity map at the cardiac structure, i.e., in this embodiment, on the epicardial surface, based on the electrical signals measured on the outer surface of the person, the positions of the plurality of surface electrodes determined in step **101** and the position of the cardiac structure determined in step **102**. In step **104**, the analysis unit analyzes the electrical activity map, in order to determine, for example, electrophysiological mechanisms of certain cardiac arrhythmias. In step **105**, the electrical activity map and optionally also results of the analysis are shown on the display unit.

[0059] In the embodiment of the method for providing an electrical activity map of the heart described above with reference to FIG. **3** it is assumed that the electrical signals on the outer surface of the person have been measured already and are provided to the electrical activity map determination unit for allowing the electrical activity map determination unit to determine the electrical activity map. In another embodiment the measurement of the electrical signals on the outer surface of the person can also be a part of the method for providing the electrical activity map, wherein in this case a corresponding electrical signals measurement step is performed before step **103**.

[0060] Electrocardiographic mapping (ECM) is a method where body surface signals, i.e. electrical signals like electrical potentials measured at the outer surface of the person, which are measured by a multitude of electrodes covering the entire human thorax, are used to calculate the activation of the epicardial surface of the heart. The electrodes are surface electrodes, i.e. electrodes measuring electrical signals at the surface of the person, and they are contained in the vest that is tightly attached to the skin of the thorax by an adhesive. Alternatively or in addition, the vest can comprise elastic textiles for tightly fitting the vest to the skin of the thorax. Since the position of the epicardial heart surface and the positions of the surface electrodes have been determined, the three-dimensional spatial relations between the epicardial heart surface and the surface electrodes are known. This enables the electrical activity map determination unit to compute an accurate single beat electrical activation pattern on the epicardial heart surface being the electrical activity map. The system described above with reference to FIG. **1** can therefore provide a non-invasive method for rapid assessment, i.e. within seconds to real time, of cardiac electrical activation. This electrocardiographic mapping can be performed, for example, during an electrophysiological procedure or during interventional cardiology procedures in a corresponding laboratory. However, the electrocardiographic mapping can also be performed for pre-interventional or post-interventional follow-up diagnostic procedures. In particular, the electrocardiographic mapping can be used to assess effects of antiarrhythmic drugs at certain points during a course of drug use and may be used for performing a high resolution electrocardiographic analysis.

[0061] The systems described above with reference to FIGS. **1** and **2** allow a rapid assessment of the three-dimensional positions of the vest electrodes, i.e. of the surface electrodes, by means of optical shape sensing localization and the assessment of the three-dimensional cardiac anatomy in relation to the three-dimensional positions of the vest electrodes by means of a transthoracic or transesophageal echo probe that is localized in the three-dimensional space by means of optical shape sensing localization. The systems can be used as an advanced electrocardiography tool with epicardial activation diagnosis capabilities.

[0062] Preferentially, the configuration of the electrodes in the electrocardiography mapping vest within the vest fabric is known. In an embodiment, in particular in the embodiment described above with reference to FIG. **1**, within the vest are a plurality of landmark points, i.e. reference marks, that can be visually identified, for instance, by having a certain color and/or shape. The positions of electrodes in relation to the landmark points are known as well. After putting on the vest to the person the three-dimensional positions of the landmark points can be determined by touching the landmarks by means of the wand equipped with the optical shape sensing sensor. The number and distribution of the landmark points are preferentially such that the relative positions of all electrodes in relation to the landmarks and therefore in relation to a frame of reference can be calculated based on the known positions of the electrodes within the fabric and in relation to the landmarks. To avoid person motion distortion, one or more additional optical shape sensing sensors can be temporally added to the vest or attached to patches that are put somewhere on the patient's thorax to compensate for the person movement.

[0063] Preferentially, the ultrasound unit is used for reconstructing a transthoracic or transesophageal three-dimensional representation of the person's cardiac anatomy. This reconstruction can be based on three-dimensional imaging of the heart and subsequent segmentation of the cardiac structures or by matching a generalized three-dimensional cardiac model to the three-dimensional ultrasound image, wherein optionally the generalized three-dimensional cardiac model can be deformed. The ultrasound probe is equipped with optical shape sensing localization as well, thus allowing to correlate the three-dimensional cardiac anatomy with the vest electrode positions. In an embodiment the ultrasound based cardiac anatomy assessment is performed before or after the vest electrodes positions assessment. In both cases optical shape sensing sensors temporally added to the vest or attached to a patch that is put somewhere on the patient's thorax can be used to relate the ultrasound probe position and therefore the three-dimensional cardiac anatomy to the vest electrode positions.

[0064] In an embodiment, in particular in the embodiment described above with reference to FIG. **2**, the electrode vest can be equipped with one or more optical shape sensing fibers, wherein the positions of the vest electrodes are identified and therefore known in relation to the one or more optical shape sensing fibers. Through assessing the three-dimensional shape of the one or more optical shape sensing fibers the three-dimensional positions of the vest electrodes can be calculated. Also in this embodiment the position of the cardiac anatomy is determined as described above by using an ultrasound probe, wherein in this embodiment the position of the ultrasound probe is registered with the position of the vest electrodes by using the optical shape sensing signals from the one or more optical shape sensing fibers within the vest and from the optical shape sensing sensor of the ultrasound probe.

[0065] Although in the embodiment described above with reference to FIG. **1** an additional wand **4** equipped with an optical shape sensing fiber **6** is used for determining the three-dimensional positions of reference marks **2**, in another embodiment this additional wand **4** with the optical shape sensing fiber **6** is not needed. Instead, the ultrasound probe **22** can be used for determining the three-dimensional positions of the reference marks **2**. Thus, a user like a physician can move the ultrasound probe **22** from reference mark to reference mark, in order to determine the three-dimensional positions of these reference mark by optical shape sensing localization. These three-dimensional positions of the reference marks are then used by the surface electrodes position calculation unit for determining the three-dimensional positions of the surface electrodes as described above. The same ultrasound probe **22** can then be used for providing an ultrasound signal being indicative of the cardiac structure, in particular, being indicative of the epicardial surface, in order to determine the position of the epicardial surface.

[0066] The ultrasound probe is preferentially used through an opening in the vest directly on the skin of the thorax, or before the vest is put on by the person. In the embodiment described above with reference to FIG. **1**, the ultrasound probe **22** may be used on the skin of the thorax for acquiring an ultrasound image of the heart before the vest is put on by the person, but after a reference patch being connected to an optical shape sensing fiber for determining the position of the reference patch is applied to the skin of the thorax.

[0067] The locations of the surface electrodes of the vest can be determined by means of Fiber Optic Shape Sensing and Localization (FOSSL) technology, for example, based on Fiber Bragg Gratings. The vest may contain one or more fibers with such grating that allow the full three-dimensional shape and location of the fibers to be determined. By knowing the spatial relation between each of the surface electrodes and a relevant fiber, the location of each of the electrodes can be determined. This can then be realized without any x-ray or magnetic resonance based localization of the surface electrodes. Moreover, the ultrasound probe can be a three-dimensional transesophageal or micro transthoracic ultrasound probe which can be used to reconstruct the heart. Furthermore, the FOSSL technology can be used to localize the probe by means of such a fiber, in particular, in a catheter. The FOSSL technology can be used to localize the surface electrodes as described above.

[0068] The systems described above with reference to FIGS. **1** and **2** provide an electrocardiographic mapping based on a three-dimensional assessment of vest electrode positions by means of optical shape sensing localized vest electrodes and based on a three-dimensional cardiac anatomy assessment of optical shape sensing localized ultrasound imaging. The system can therefore provide an electrocardiographic diagnostic tool that can be used for obtaining, for instance, pre-interventional and post-interventional information that is not obtainable by known electrocardiographic systems. For example, information can be provided such as reasonably accurate positions of ectopic foci, reasonable accurate positions of ventricular re-entries, information that distinguishes between re-entry or focal ventricular tachycardia and its localizations, information about re-connection of pulmonary vein conduction and localization of culprit pulmonary veins, in order to be at least able to distinguish between left and right pulmonary veins, and information about effects of antiarrhythmic drugs, in particular, of changes in use of antiarrhythmics drugs.

[0069] Although in above described embodiments, in particular, in FIGS. **1** and **2**, the vest has a certain distribution of electrodes, it should be noted that the electrodes in the vest are only schematically and exemplarily indicated in FIGS. **1** and **2**, i.e., for instance, they can be distributed differently within the vest. The vest preferentially comprises several hundreds of the electrodes covering the entire thorax of the person.

[0070] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

[0071] In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

[0072] A single unit or device may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

[0073] Calculations like the calculation of the surface electrodes positions, the calculation of the cardiac structure position, the calculation of the electrical activity map and/or the analysis of the electrical activity map performed by one or several units or devices can be performed by any other number of units or devices. The calculations and/or the analysis of the electrical activity map and/or the control of the system for providing an electrical activity map in accordance with the method for providing an electrical activity map can be implemented as program code means of a computer program and/or as dedicated hardware.

[0074] A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium, supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

[0075] Any reference signs in the claims should not be construed as limiting the scope.

[0076] The invention relates to a system for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being. A surface electrodes positions determination unit determines positions of the plurality of surface electrodes by means of optical shape sensing localization and an electrical activity map determination unit determines the electrical activity map at the cardiac structure based on the measured electrical signals, the determined positions of the plurality of electrodes and a position of a cardiac structure, in particular, of the epicardial surface. Since optical shape sensing is used for determining the positions of the plurality of surface electrodes and not, for instance, x-rays, the electrical activity map can be determined, without necessarily applying an x-ray radiation dose.

1-**13**. (canceled)

14. A vest for being worn by a living being, the vest being adapted to be used for providing an electrical activity map, the vest comprising:

a plurality of surface electrodes for being arranged on an outer surface of the living being, when the vest is worn by the living being, and for acquiring electrical signals from the heart of the living being,

an optical shape sensing fiber for generating an optical shape sensing signal being indicative of the three-dimensional shape of the optical shape sensing fiber and for providing the optical shape sensing signal to a surface electrodes positions calculation unit.

15. A system for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being, wherein a vest as defined in claim **14** is worn by the living being and comprises the plurality of surface electrodes, the system comprising:

a spatial relation providing unit for providing spatial relations between an optical shape sensing fiber of the vest and the surface electrodes,

a surface electrodes positions calculation unit for calculating the positions of the surface electrodes depending on the three-dimensional shape of the optical shape sensing fiber as indicated by an optical shape sensing signal provided by the optical shape sensing fiber and the provided spatial relation,

a cardiac structure position determination unit for determining a position of a cardiac structure of the living being, wherein the cardiac structure position determination unit comprises a cardiac structure position calculation unit for calculating the position of the cardiac structure based on a) an ultrasound signal received from an ultrasound unit equipped with an optical shape sensing sensor, wherein the ultrasound signal is indicative of the position of the cardiac structure, and b) an optical shape sensing signal received from the optical shape sensing sensor of the ultrasound unit, wherein the optical shape sensing signal is indicative of the position of the ultrasound unit,

an electrical activity map determination unit for determining the electrical activity map at the cardiac structure based on the electrical signals measured on the outer surface of the living being, the determined positions of the plurality of electrodes and the determined position of the cardiac structure.

16. The system as defined in claim **14**, wherein the cardiac structure position determination unit comprises the ultrasound unit for generating the ultrasound signal being indicative of the position of the cardiac structure, wherein the ultrasound unit is equipped with the optical shape sensing sensor for generating the optical shape sensing signal being indicative of the position of the ultrasound unit.

17. The system as defined in claim **14**, wherein the ultrasound unit is a transthoracic echo probe or a transesophageal echo probe.

18. The system as defined in claim **14**, wherein the ultrasound signal represents an ultrasound image and wherein the cardiac structure calculation unit is adapted to detect the cardiac structure in the ultrasound image and to calculate the position of the cardiac structure based on the cardiac structure detected in the ultrasound image.

19. A method for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being, the method comprising:

determining positions of the plurality of surface electrodes, wherein a vest as defined in claim **14** is worn by the living being and comprises the plurality of surface electrodes, wherein spatial relations between an optical shape sensing fiber of the vest and the surface electrodes are provided by a spatial relation providing unit, and wherein the positions of the surface electrodes are calculated depending on a three-dimensional shape of the optical shape sensing fiber as indicated by an optical shape sensing signal provided by the optical shape sensing fiber and the provided spatial relation by a surface electrodes positions calculation unit,

determining a position of a cardiac structure of the living being, wherein the position of the cardiac structure is determined based on a) an ultrasound signal received from an ultrasound unit equipped with an optical shape sensing sensor, wherein the ultrasound signal is indicative of the position of the cardiac structure, and b) an optical shape sensing signal received from the optical shape sensing sensor of the ultrasound unit, wherein the optical shape sensing signal is indicative of the position of the ultrasound unit, by an cardiac structure position calculation unit, determining the electrical activity map at the cardiac structure based on the electrical signals measured on the outer surface of the living being, the determined positions of the plurality of electrodes and the determined position of the cardiac structure by an electrical activity map determination unit.

20. A computer program for providing an electrical activity map of the heart of a living being by means of electrical signals from the heart acquired by a plurality of surface electrodes being arranged on an outer surface of the living being, the computer program comprising program code means for causing a system as defined in claim **14**.

* * * * *

专利名称(译)	用于使用光学形状感测来提供电活动图的系统		
公开(公告)号	US20140148677A1	公开(公告)日	2014-05-29
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摘要(译)

本发明涉及一种系统（1），用于借助于由多个表面电极（9）获取的电信号提供心脏的电活动图。表面电极位置确定单元（4,6,13）通过光学形状感测定位确定多个表面电极的位置。光学形状感测元件可以包括棒（4），或者可选地，嵌入在包括表面电极的背心中的光学形状感测纤维。可以使用超声来确定心脏结构的位置。电活动图确定单元（16）基于测量的电信号，所确定的多个电极的位置以及心脏结构的位置，特别是心外膜表面的位置，确定心脏结构处的电活动图。由于光学形状感测用于确定多个表面电极的位置而不是例如X射线，因此可以确定电活动图，而不必施加x射线辐射剂量。

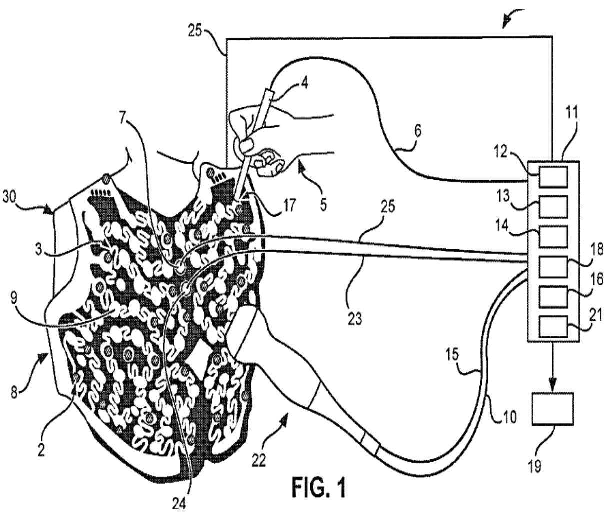

FIG. 1