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AUTOMATED TOOL FOR VEIN SHAVING IN ANATOMICAL MAP

Abstract

An automated technique for revising an electro-anatomical map generated using a catheter having a plurality of electrodes. A first electro-anatomical map that includes an anatomical structure having a mapped volume with a substantially tubular shape is displayed, and one or more points along medial axis of the mapped volume are estimated. At a first cross-section of the mapped volume, a first best-fitting ellipse is determined. A generalized cylindrical volume is calculated between the first cross-section and a second cross-section in accordance with at least the first best-fitting ellipse. Data points from the mapped volume that are outside of the generalized cylindrical volume are removed and a revised map is displayed.

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Background/Summary

FIELD OF INVENTION

[0001] The present invention is related to anatomical mapping. More particularly, the present invention relates to improving the visualization of anatomical structures such as veins in an electro-anatomical map.

BACKGROUND

[0002] Some clinical procedures employ techniques for the analysis of a computerized anatomical map of an organ. For example, in electrophysiology (EP) procedures such as catheter-based radio frequency (RF) ablation for pulmonary vein isolation (a first line of treatment for atrial fibrillation (AF)), an anatomical map of a heart chamber is generated and used. Fast anatomical mapping (FAM) is one algorithm for building such an anatomical map from electrical signals captured by a catheter on a myocardium. The anatomical map is used to guide a physician to desired ablation sites. As part of the building of the anatomical map (e.g., an aspect of generating the anatomical map of the FAM), a technician can modify the volume of the FAM by performing a manual, time consuming process of shaving. Shaving occurs for a variety of reasons, including, e.g., to present a more anatomically accurate representation and/or to resolve visual artifacts in the map.

[0003] With existing mapping techniques, artifacts of the mapping process can cause anatomical structures such as veins to appear narrow in one portion of the vein and larger in a neighboring portion of the vein. Such a visualization can imply that a pulmonary vein stenosis is present at the site where the vein is narrow. In order to remove such artifacts, manual shaving of the map is typically performed by an operator. When addressing an artifact such as that described above (implying a pulmonary vein stenosis), voxels are manually removed (shaved) from the volume of the vein until the vein has a more constant volume. An automated solution to this manual shaving process is needed.

SUMMARY

[0004] An automated technique for revising an electro-anatomical map (e.g., a FAM) is provided. The map is generated using a catheter having a plurality of electrodes. As the catheter moves within the body during a medical procedure, the map is generated based on data points acquired using the electrodes, and is subsequently revised. Initially, a first electro-anatomical map that includes an anatomical structure having a mapped volume with a substantially tubular shape is displayed on a user interface. At a first cross-section of the mapped volume, a first best-fitting ellipse is determined based on data points associated with the first cross-section of the mapped volume. A first point along a medial axis of the mapped volume is estimated in accordance with a center of the first best-fitting ellipse. A second point along the medial axis on a second cross-section of the mapped volume is estimated; the first-cross section being different from the second cross-section. A generalized cylindrical volume spanning between the first cross-section and the second cross-section is calculated in accordance with at least the first best-fitting ellipse. Data points from the mapped volume that are outside of the generalized cylindrical volume are removed. A second electro-anatomical map having an updated version of the anatomical structure generated without the removed data points is displayed on the user interface.

[0005] In some examples, a plurality of points defining the medial axis are determined. In some of these examples, the first cross-section is normal to the medial axis and the second point is estimated by selecting one of the plurality of points defining the medial axis.

[0006] In some examples, further points along the medial axis on further cross-sections of the mapped volume are estimated and the generalized cylindrical volume spans the first cross-section, the second cross-section and the further cross-sections.

[0007] In some examples, the anatomical structure is a vein associated with a heart muscle, data

points associated with the first cross-section of the mapped volume correspond to ablation tags, and data points associated with the second cross-section and each of the further cross-sections of the mapped volume do not correspond to ablation tags.

[0008] In some examples, more than two best-fitting ellipses are determined based on data points associated with other cross-sections of the mapped volume, and the generalized cylindrical volume is calculated accordance with more than two-best fitting ellipses.

[0009] In some examples, the first best-fitting ellipse is a circle, and the substantially tubular shape is a ruled surface or generalized cylinder. In other embodiments, a best-fitting spline is used.

[0010] According to one or more embodiments, the exemplary embodiments above can be implemented as methods, apparatuses, systems, and/or computer program products.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings, wherein like reference numerals in the figures indicate like elements, and wherein:

[0012] FIG. 1 depicts an example catheter-based electrophysiology mapping and ablation system according to one or more embodiments;

[0013] FIG. 2 is a block diagram of an example system for remotely monitoring and communicating biometric data according to one or more embodiments;

[0014] FIG. 3 is a system diagram of an example computing environment in communication with a network according to one or more embodiments;

[0015] FIG. 4 is a block diagram of an example device in which one or more features of the disclosure can be implemented according to one or more embodiments;

[0016] FIG. 5A depicts an electro-anatomical map of the heart prior to performing an anatomy fit for ablation tags, according to an example;

[0017] FIG. 5B depicts an electro-anatomical map of the heart after performance of an anatomy fit for ablation tags, according to an example;

[0018] FIG. 6 depicts an electro-anatomical map of the heart along with its medial axis, according to an example;

[0019] FIG. 7 depicts an electro-anatomical map of a pulmonary vein showing its medial axis and several best-filling ellipses positioned along the medial axis, according to an example;

[0020] FIG. 8 depicts several ellipses for generating a tubular shape along the medial axis of the pulmonary vein of FIG. 7, according to an example;

[0021] FIG. 9 depicts a tubular shape that is used for removing data points from the map, according to an example;

[0022] FIG. 10 depicts a side-by-side comparison of the map of FIG. 5B and an updated version of that map which has been revised in accordance with the techniques described herein, according to an example;

[0023] FIG. 11 depicts an electro-anatomical map of the heart, according to a further example; and

[0024] FIG. 12 depicts a method according to one or more embodiments.

DETAILED DESCRIPTION

[0025] Disclosed herein is a method and/or system for anatomical mapping. The method and/or system includes a processor executable code or software that is necessarily rooted in process operations by, and in processing hardware of, medical device equipment performing and using the anatomical mapping. For ease of explanation, the anatomical map is described herein with respect to mapping a heart. However, any anatomical structure, body part, organ, or portion thereof can be a target for mapping using the techniques described herein.

[0026] According to one or more embodiments, the methods and systems disclosed herein generate anatomical maps of the heart that include an endocardial surface of a left atrium (LA). A map can be one three-dimensional (3D) model or a combination of multiple 3D models. The methods and systems can generate and edit the maps of the heart and provide real-time or post-processed maps during or in connection with an EP procedure (e.g., an ablation procedure). By way of example, the methods and systems can revise an anatomical map using the techniques disclosed herein, thereby improving the operations and outcomes of the anatomical mapping.

[0027] Reference is made to FIG. 1 showing an example system (e.g., medical device equipment and/or catheter-based electrophysiology mapping and ablation system), shown as system **10**, in which one or more features of the subject matter herein can be implemented according to one or more embodiments. All or part of the system **100** can be used to collect information (e.g., biometric data) and/or used to implement the map revision techniques as described herein. In some examples, such techniques are implemented using a processor executable code or software that is stored on a memory of the system **10** and that is necessarily rooted in process operations by, and in processing hardware of, the system **10**.

[0028] FIG. 1 illustrates a recorder **11**, a heart **12**, a catheter **14**, a model or anatomical map **20**, an electrogram **21**, a spline **22**, a patient **23**, a physician **24** (which is representative of any medical professional, technician, clinician, operator, clinical support specialist, clinical account specialist, healthcare personnel, etc.), a location pad **25**, one or more electrodes **26**, a display device **27**, a distal tip **28**, a sensor **29**, a coil **32**, a patient interface unit (PIU) **30**, electrode skin patches **38**, an ablation energy generator **50**, and a workstation **55**. Note further each element and/or item of the system **10** is representative of one or more of that element and/or that item. The example system **10** shown in FIG. 1 implements the embodiments disclosed herein. The disclosed embodiments can similarly be applied using other system components and settings. Additionally, the system **10** can include additional components, for example elements for sensing electrical activity, wired or wireless connectors, processing and display devices, or other components.

[0029] The system **10** includes multiple catheters **14**, which are percutaneously inserted by the physician **24** through the patient's vascular system into a chamber or vascular structure of the heart **12**. Typically, a delivery sheath catheter is inserted into the left or right atrium near a desired location in the heart **12**. Thereafter, a plurality of catheters can be inserted into the delivery sheath catheter to arrive at the desired location. The plurality of catheters **14** may include catheters dedicated for sensing Intracardiac Electrogram (IEGM) signals, catheters dedicated for ablating, and/or catheters dedicated for both sensing and ablating. The example catheter **14** that is configured for sensing IEGM is illustrated herein. The physician **24** brings the distal tip **28** of the catheter **14** into contact with a heart wall for sensing a target site in the heart **12**. For ablation, the physician **24** would similarly bring a distal end of an ablation catheter to a target site for ablating.

[0030] The catheter **14** is an exemplary catheter that includes at least one and preferably multiple electrodes **26** optionally distributed over a plurality of splines **22** at the distal tip **28** and configured to sense the IEGM signals. The catheter **14** may additionally include the sensor **29** embedded in or near the distal tip **28** for tracking position and orientation of the distal tip **28**. Optionally and preferably, the position sensor **29** is a magnetic based position sensor including three magnetic coils for sensing 3D position and orientation. According to one or more embodiments, shape and parameters of the catheter **14** vary based on whether the catheter **14** is used for diagnostic or ablation purposes, the type of arrhythmia, patient anatomy, and other factors, which affects catheter maneuverability (e.g., an ability to touch without bending the surface and the tracked parts of the catheter **14**). The shape and parameters of the catheter **14** also impact the accuracy of anatomical maps. Large spherical single-shot catheters, which can ablate a pulmonary vein within seconds, have become popular but require guidance from fluoroscopy, CT/MRI, or additional mapping catheters.

[0031] The sensor **29** (e.g., a position or a magnetic based position sensor) may be operated

together with the location pad **25** including a plurality of magnetic coils **32** configured to generate magnetic fields in a predefined working volume. Real time position of the distal tip **28** of the catheter **14** may be tracked based on magnetic fields generated with the location pad **25** and sensed by the sensor **29**. Details of the magnetic based position sensing technology are described in U.S. Pat. Nos. 5,539,199; 5,443,489; 5,558,091; 6,172,499; 6,239,724; 6,332,089; 6,484,118; 6,618,612; 6,690,963; 6,788,967; 6,892,091.

[0032] The system **10** includes one or more electrode patches **38** positioned for skin contact on the patient **23** to establish location reference for the location pad **25** as well as impedance-based tracking of the electrodes **26**. For impedance-based tracking, electrical current is directed toward the electrodes **26** and sensed at the patches **38** (e.g., electrode skin patches) so that the location of each electrode can be triangulated via the patches **38**. Details of the impedance-based location tracking technology are described in U.S. Pat. Nos. 7,536,218; 7,756,576; 7,848,787; 7,869,865; and 8,456,182, which are incorporated herein by reference.

[0033] The recorder **11** displays the electrograms **21** captured with the electrodes **18** (e.g., body surface electrocardiogram (ECG) electrodes) and intracardiac electrograms (IEGM) captured with the electrodes **26** of the catheter **14**. The recorder **11** may include pacing capability for pacing the heart rhythm and/or may be electrically connected to a standalone pacer.

[0034] The system **10** may include the ablation energy generator **50** that is adapted to conduct ablative energy to the one or more of electrodes **26** at the distal tip **28** of the catheter **14** configured for ablating. Energy produced by the ablation energy generator **50** may include, but is not limited to, radiofrequency (RF) energy or pulsed-field ablation (PFA) energy, including monopolar or bipolar high-voltage DC pulses as may be used to effect irreversible electroporation (IRE), or combinations thereof.

[0035] The PIU **30** is an interface configured to establish electrical communication between catheters, electrophysiological equipment, power supply and the workstation **55** for controlling operation of the system **10**. Electrophysiological equipment of the system **10** may include for example, multiple catheters **14**, the location pad **25**, the body surface ECG electrodes **18**, the electrode patches **38**, the ablation energy generator **50**, and the recorder **11**. Optionally and preferably, the PIU **30** additionally includes processing capability for implementing real-time computations of location of the catheters and for performing ECG calculations.

[0036] The workstation **55** includes memory, a processor unit with memory or storage with appropriate operating software loaded therein, and user interface capability. The workstation **55** may provide multiple functions, optionally including modeling the endocardial anatomy in three-dimensions (3D) and rendering the model or anatomical map **20** (e.g., a visualization) for display on the display device **27**, displaying on the display device **27** activation sequences (or other data) compiled from recorded electrograms **21** in representative visual indicia or imagery superimposed on the rendered anatomical map **20**, displaying real-time location and orientation of multiple catheters within the heart chamber, and displaying on the display device **27** sites of interest for example places where ablation energy has been applied. One commercial product embodying elements of the system **10** is available as the CARTO™ 3 System, available from Biosense Webster, Inc., 31A Technology Drive, Irvine, CA 92618. Note that modeling the endocardial anatomy in 3D can include generating a surface thereof as a triangular mesh.

[0037] For instance, the system **10** can be part of a surgical system (e.g., CARTO® system sold by Biosense Webster) that is configured to obtain biometric data (e.g., anatomical and electrical measurements of a patient's organ, for example the heart **12** and as described herein) and perform a cardiac ablation procedure. More particularly, treatments for cardiac conditions for example cardiac arrhythmia often require obtaining a detailed mapping of cardiac tissue, chambers, veins, arteries and/or electrical pathways. For example, a prerequisite for performing a catheter ablation successfully is that the cause of the cardiac arrhythmia is accurately located in a chamber of the heart **12**. Such locating may be done via an electrophysiological investigation during which

electrical potentials are detected and spatially resolved with a mapping catheter (e.g., the catheter **14**) introduced into the chamber of the heart **12**. This electrophysiological investigation, the so-called electro-anatomical mapping, thus provides 3D mapping data which can be displayed on the display device **27**. In many cases, the mapping function and a treatment function (e.g., ablation) are provided by a single catheter or group of catheters such that the mapping catheter also operates as a treatment catheter at the same time.

[0038] FIG. **2** is a block diagram of an example system **100** for remotely monitoring and communicating biometric data (e.g., patient biometrics). In the example illustrated in FIG. **2**, the system **100** includes a patient biometric monitoring and processing apparatus **102** associated with a patient **104**, a local computing device **106**, a remote computing system **108**, a first network **110**, a patient biometric sensor **112**, a processor **114**, a user input (UI) sensor **116**, a memory **118**, a second network **120**, and a transmitter-receiver (i.e., transceiver) **122**.

[0039] According to one or more embodiments, the patient biometric monitoring and processing apparatus **102** may be an apparatus that is internal to the patient's body (e.g., subcutaneously implantable), for example the catheter **14** of FIG. **1**. The patient biometric monitoring and processing apparatus **102** may be inserted into a patient via any applicable manner including orally injecting, surgical insertion via a vein or artery, an endoscopic procedure, or a laparoscopic procedure.

[0040] According to one or more embodiments, the patient biometric monitoring and processing apparatus **102** may be an apparatus that is external to the patient, for example the electrode patches **38** of FIG. **1**. For example, as described in more detail below, the patient biometric monitoring and processing apparatus **102** may include an attachable patch (e.g., that attaches to a patient's skin). The monitoring and processing apparatus **102** may also include a catheter with one or more electrodes, a probe, a blood pressure cuff, a weight scale, a bracelet or smart watch biometric tracker, a glucose monitor, a continuous positive airway pressure (CPAP) machine or virtually any device which may provide an input concerning the health or biometrics of the patient.

[0041] According to one or more embodiments, the patient biometric monitoring and processing apparatus **102** may include both components that are internal to the patient and components that are external to the patient.

[0042] A single patient biometric monitoring and processing apparatus **102** is shown in FIG. **2**. Example systems may, however, include a plurality of patient biometric monitoring and processing apparatuses. A patient biometric monitoring and processing apparatus may be in communication with one or more other patient biometric monitoring and processing apparatuses. Additionally or alternatively, a patient biometric monitoring and processing apparatus may be in communication with the network **110**.

[0043] One or more patient biometric monitoring and processing apparatuses **102** may acquire biometric data (e.g., patient biometrics, for example electrical signals, blood pressure, temperature, blood glucose level, or other biometric data) and receive at least a portion of the biometric data representing the acquired patient biometrics and additional information associated with the acquired patient biometrics from one or more other patient biometric monitoring and processing apparatuses **102**. The additional information may be, for example, diagnosis information and/or additional information obtained from an additional device, for example a wearable device. Each of the patient biometric monitoring and processing apparatus **102** may process data, including its own biometric data as well as data received from one or more other patient biometric monitoring and processing apparatuses **102**.

[0044] Biometric data (e.g., patient biometrics, patient data, or patient biometric data) can include one or more of local activation times (LATs), electrical activity, topology, bipolar mapping, reference activity, ventricle activity, dominant frequency, impedance, or other data. The LAT can be a point in time of a threshold activity corresponding to a local activation, calculated based on a normalized initial starting point. Electrical activity can be any applicable electrical signals that can

be measured based on one or more thresholds and can be sensed and/or augmented based on signal to noise ratios and/or other filters. A topology can correspond to the physical structure of a body part or a portion of a body part and can correspond to changes in the physical structure relative to different parts of the body part or relative to different body parts. A dominant frequency can be a frequency or a range of frequency that is prevalent at a portion of a body part and can be different in different portions of the same body part. For example, the dominant frequency of a PV of a heart can be different than the dominant frequency of the right atrium of the same heart. Impedance can be the resistance measurement at a given area of a body part.

[0045] Examples of biometric data include, but are not limited to, patient identification data, intracardiac electrocardiogram (IC ECG) data, bipolar intracardiac reference signals, anatomical and electrical measurements, trajectory information, body surface (BS) ECG data, historical data, brain biometrics, blood pressure data, ultrasound signals, radio signals, audio signals, two- or three-dimensional image data, blood glucose data, and temperature data. The biometrics data can be used, generally, to monitor, diagnosis, and treat any number of various diseases, for example cardiovascular diseases (e.g., arrhythmias, cardiomyopathy, and coronary artery disease) and autoimmune diseases (e.g., type I and type II diabetes). Note that BS ECG data can include data and signals collected from electrodes on a surface of a patient, IC ECG data can include data and signals collected from electrodes within the patient, and ablation data can include data and signals collected from tissue that has been ablated. Further, BS ECG data, IC ECG data, and ablation data, along with catheter electrode position data, can be derived from one or more procedure recordings.

[0046] In FIG. 2, the network **110** is an example of a short-range network (e.g., local area network (LAN), or personal area network (PAN)). Information may be sent, via the network **110**, between the patient biometric monitoring and processing apparatus **102** and the local computing device **106** using any one of various short-range wireless communication protocols, for example Bluetooth, Wi-Fi, Zigbee, Z-Wave, near field communications (NFC), ultraband, or infrared (IR).

[0047] The network **120** may be a wired network, a wireless network or include one or more wired and wireless networks. For example, the network **120** may be a long-range network (e.g., wide area network (WAN), the internet, or a cellular network). Information may be sent, via the network **120** using any one of various long-range wireless communication protocols (e.g., TCP/IP, HTTP, 3G, 4G/LTE, or 5G/New Radio).

[0048] The patient biometric monitoring and processing apparatus **102** may include the patient biometric sensor **112**, the processor **114**, the UI sensor **116**, the memory **118**, and the transceiver **122**. The patient biometric monitoring and processing apparatus **102** may continually or periodically monitor, store, process and communicate, via the network **110**, any number of various biometric data. Examples of biometric data include electrical signals (e.g., ECG signals and brain biometrics), blood pressure data, blood glucose data, and temperature data. The biometric data may be monitored and communicated for treatment across any number of various diseases, for example cardiovascular diseases (e.g., arrhythmias, cardiomyopathy, and coronary artery disease) and autoimmune diseases (e.g., type I and type II diabetes).

[0049] The patient biometric sensor **112** may include, for example, one or more sensors configured to sense a type of biometric data. For example, the patient biometric sensor **112** may include an electrode configured to acquire electrical signals (e.g., heart signals, brain signals or other bioelectrical signals), a temperature sensor, a blood pressure sensor, a blood glucose sensor, a blood oxygen sensor, a pH sensor, an accelerometer and a microphone.

[0050] As described in more detail below, the patient biometric monitoring and processing apparatus **102** may be an ECG monitor for monitoring ECG signals of a heart (e.g., the heart **12**). The patient biometric sensor **112** of the ECG monitor may include one or more electrodes for acquiring ECG signals. The ECG signals may be used for treatment of various cardiovascular diseases, as well as anatomical mapping.

[0051] The transceiver **122** may include a separate transmitter and receiver. Alternatively, the

transceiver **122** may include a transmitter and receiver integrated into a single device.

[0052] The processor **114** may be configured to store biometric data in the memory **118** acquired by the patient biometric sensor **112** and to communicate the biometric data across the network **110** via a transmitter of the transceiver **122**. Data from one or more other patient biometric monitoring and processing apparatus **102** may also be received by a receiver of the transceiver **122**, as described in more detail herein. By way of example, the automated map revision techniques described herein are implemented as a processor executable code or software that can be stored on the memory **118** (as shown) and executed by the processor **114**. By way of further example, the automated map revision techniques are implemented as code stored and executed on the local computing device **106** and/or the remote computing system **108**. Thus, the operation of the automated map revision techniques is necessarily rooted in process operations by, and in processing hardware of, the system **100**.

[0053] According to one or more embodiments, system **100** operates to generate on a display (e.g., display device **27**) an initial visualization (e.g., a first electro-anatomical map) during an ablation procedure. The initial visualization is generated from data points sensed by a catheter positioned in a patent, and includes an anatomical structure (e.g., a vein) having a mapped volume with a substantially tubular shape. Applying the techniques described in connection with FIGS. 5-12 below, system **100** determines, at a first cross-section of the mapped volume, a first best-fitting ellipse based on data points associated with the first cross-section. A first point along a medial axis of the mapped volume is estimated in accordance with (e.g., from) a center of the first best-fitting ellipse. A second point along the medial axis on a second cross-section of the mapped volume is estimated; the first-cross section being different from the second cross-section. A generalized cylindrical volume that spans between the first cross-section and the second cross-section is calculated in accordance with at least the first best-fitting ellipse. System **100** removes data points from the mapped volume that are outside of the generalized cylindrical volume. A second electro-anatomical map having an updated version of the anatomical structure generated without the removed data points is displayed (e.g., on display device **27**) as part of a user interface.

[0054] In some examples, the anatomical structure is a vein associated with a heart muscle, data points associated with the first cross-section of the mapped volume correspond to ablation tags, and data points associated with the second cross-section and additional cross-sections of the mapped volume do not correspond to ablation tags.

[0055] In some examples, a plurality of points defining the medial axis are determined. In some of these examples, the first cross-section is normal to the medial axis and the second point is estimated by selecting one of the plurality of points defining the medial axis.

[0056] According to one or more embodiments, the patient biometric monitoring and processing apparatus **102** includes UI sensor **116** that may be, for example, a piezoelectric sensor or a capacitive sensor configured to receive a user input, for example a tapping or touching. For example, the UI sensor **116** may be controlled to implement a capacitive coupling, in response to tapping or touching a surface of the patient biometric monitoring and processing apparatus **102** by the patient **104**. Gesture recognition may be implemented via any one of various capacitive types, for example resistive capacitive, surface capacitive, projected capacitive, surface acoustic wave, piezoelectric and infrared touching. Capacitive sensors may be disposed at a small area or over a length of the surface such that the tapping or touching of the surface activates the monitoring device.

[0057] As described in more detail below, the processor **114** may be configured to respond selectively to different tapping patterns of the capacitive sensor (e.g., a single tap or a double tap), which may be the UI sensor **116**, such that different tasks of the patch (e.g., acquisition, storing, or transmission of data) may be activated based on the detected pattern. In some embodiments, audible feedback may be given to the user from the patient biometric monitoring and processing apparatus **102** when a gesture is detected.

[0058] The local computing device **106** of the system **100** is in communication with the patient biometric monitoring and processing apparatus **102** and may be configured to act as a gateway to the remote computing system **108** through the second network **120**. The local computing device **106** may be, for example, a, smart phone, smartwatch, tablet or other portable smart device configured to communicate with other devices via the network **120**. Alternatively, the local computing device **106** may be a stationary or standalone device, for example a stationary base station including, for example, modem and/or router capability, a desktop or laptop computer using an executable program to communicate information between the patient biometric monitoring and processing apparatus **102** and the remote computing system **108** via the PC's radio module, or a USB dongle. Biometric data may be communicated between the local computing device **106** and the patient biometric monitoring and processing apparatus **102** using a short-range wireless technology standard (e.g., Bluetooth, Wi-Fi, ZigBee, Z-wave and other short-range wireless standards) via the short-range wireless network **110**, for example a local area network (LAN) (e.g., a personal area network (PAN)). In some embodiments, the local computing device **106** may also be configured to display the acquired patient electrical signals and information associated with the acquired patient electrical signals, as described in more detail herein.

[0059] In some embodiments, the remote computing system **108** may be configured to receive at least one of the monitored patient biometrics and information associated with the monitored patient via network **120**, which is a long-range network. For example, if the local computing device **106** is a mobile phone, network **120** may be a wireless cellular network, and information may be communicated between the local computing device **106** and the remote computing system **108** via a wireless technology standard, for example any of the wireless technologies mentioned above. As described in more detail below, the remote computing system **108** may be configured to provide (e.g., visually display and/or aurally provide) the at least one of the patient biometrics and the associated information to the physician **24**.

[0060] FIG. **3** is a system diagram of an example of a computing environment **200** in communication with network **120**. In some instances, the computing environment **200** is incorporated in a public cloud computing platform (e.g., Amazon Web Services or Microsoft Azure), a hybrid cloud computing platform (e.g., HP Enterprise OneSphere) or a private cloud computing platform.

[0061] As shown in FIG. **3**, computing environment **200** includes a computer system **210**, which is one example of the workstation **55** of FIG. **1**, the local computing device **106** of FIG. **2**, and/or the remote computing system **108** of FIG. **2** upon which embodiments described herein may be implemented. By way of example, the tenting detection and correction techniques described herein are implemented as a processor executable code or software that can be stored on the system memory **231** (as shown) and executed by processors **220**, and rooted in process operations by, and in processing hardware of, the computing environment **200**.

[0062] The computer system **210** may, via processors **220**, which may include one or more processors, perform various functions. The functions may include analyzing monitored biometric data and the associated information and, according to physician-determined or algorithm driven thresholds and parameters, providing (e.g., via display **266**) alerts, additional information or instructions. The functions may include the operation of the tenting error and correction techniques as described herein. As described in more detail herein, the computer system **210** may be used to provide (e.g., via display **266**) the physician **24** of FIG. **1** with a dashboard of patient information, such that such information may enable the physician **24** to identify and prioritize patients having more critical needs than others.

[0063] As shown in FIG. **3**, the computer system **210** may include a communication mechanism, for example a bus **221** or other communication mechanism for communicating information within the computer system **210**. The computer system **210** further includes one or more processors **220** coupled with the bus **221** for processing the information. The processors **220** may include one or

more CPUs, GPUs, or any other processor known in the art.

[0064] The computer system **210** also includes a system memory **230** coupled to the bus **221** for storing information and instructions to be executed by processors **220**. The system memory **230** may include computer readable storage media in the form of volatile and/or nonvolatile memory, for example read only system memory (ROM) **231** and/or random-access memory (RAM) **232**. The system memory RAM **232** may include other dynamic storage device(s) (e.g., dynamic RAM, static RAM, and synchronous DRAM). The system memory ROM **231** may include other static storage device(s) (e.g., programmable ROM, erasable PROM, and electrically erasable PROM). In addition, the system memory **230** may be used for storing temporary variables or other intermediate information during the execution of instructions by the processors **220**. A basic input/output system **233** (BIOS) may contain routines to transfer information between elements within computer system **210**, for example during start-up, that may be stored in system memory ROM **231**. RAM **232** may comprise data and/or program modules that are immediately accessible to and/or presently being operated on by the processors **220**. System memory **230** may additionally include, for example, operating system **234**, application programs **235**, other program modules **236** and program data **237**.

[0065] The illustrated computer system **210** also includes a disk controller **240** coupled to the bus **221** to control one or more storage devices for storing information and instructions, for example a magnetic hard disk **241** and a removable media drive **242** (e.g., floppy disk drive, compact disc drive, tape drive, and/or solid-state drive). The storage devices may be added to the computer system **210** using an appropriate device interface (e.g., a small computer system interface (SCSI), integrated device electronics (IDE), Universal Serial Bus (USB), or FireWire).

[0066] The computer system **210** may also include a display controller **265** coupled to the bus **221** to control a monitor or display **266**, for example a cathode ray tube (CRT) or liquid crystal display (LCD), for displaying information to a computer user. The illustrated computer system **210** includes a user input interface **260** and one or more input devices, for example a keyboard **262** and a pointing device **261**, for interacting with a computer user and providing information to the processor **220**. The pointing device **261**, for example, may be a mouse, a trackball, or a pointing stick for communicating direction information and command selections to the processor **220** and for controlling cursor movement on the display **266**. The display **266** may provide a touch screen interface that may allow input to supplement or replace the communication of direction information and command selections by the pointing device **261** and/or keyboard **262**.

[0067] The computer system **210** may perform a portion or each of the functions and methods described herein in response to the processors **220** executing one or more sequences of one or more instructions contained in a memory, for example, the system memory **230**. Such instructions may be read into the system memory **230** from another computer readable medium, for example, a hard disk **241** or a removable media drive **242**. The hard disk **241** may contain one or more data stores and data files used by embodiments described herein. Data store contents and data files may be encrypted to improve security. The processors **220** may also be employed in a multi-processing arrangement to execute the one or more sequences of instructions contained in system memory **230**. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions. Thus, embodiments are not limited to any specific combination of hardware circuitry and software.

[0068] As stated above, the computer system **210** may include at least one computer readable medium or memory for holding instructions programmed according to embodiments described herein (e.g., embodiments of the tenting error detection and correction techniques) and for containing data structures, tables, records, or other data described herein. The term computer readable medium as used herein refers to any non-transitory, tangible medium that participates in providing instructions to the processor **220** for execution. A computer readable medium may take many forms including, but not limited to, non-volatile media, volatile media, and transmission

media. Non-limiting examples of non-volatile media include optical disks, solid state drives, magnetic disks, and magneto-optical disks, for example hard disk **241** or removable media drive **242**. Non-limiting examples of volatile media include dynamic memory, for example system memory **230**. Non-limiting examples of transmission media include coaxial cables, copper wire, and fiber optics, including the wires that make up the bus **221**. Transmission media may also take the form of acoustic or light waves, for example those generated during radio wave and infrared data communications.

[0069] The computing environment **200** may further include the computer system **210** operating in a networked environment using logical connections to local computing device **106** and one or more other devices, for example a personal computer (laptop or desktop), mobile devices (e.g., patient mobile devices), a server, a router, a network PC, a peer device or other common network node, and typically includes many or all of the elements described above relative to computer system **210**. When used in a networking environment, computer system **210** may include modem **272** for establishing communications over a network **120**, for example the Internet. Modem **272** may be connected to system bus **221** via network interface **270**, or via another appropriate mechanism.

[0070] Network **120**, as shown in FIGS. **2** and **3**, may be any network or system generally known in the art, including the Internet, an intranet, a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), a direct connection or series of connections, a cellular telephone network, or any other network or medium capable of facilitating communication between computer system **210** and other computers (e.g., local computing device **106**).

[0071] FIG. **4** is a block diagram of an example device **400** in which one or more features of the disclosure can be implemented. The device **400** may be local computing device **106**, for example. The device **400** can include, for example, a computer, a gaming device, a handheld device, a set-top box, a television, a mobile phone, or a tablet computer. The device **400** includes a processor **402**, a memory **404**, a storage device **406**, one or more input devices **408**, and one or more output devices **410**. The device **400** can also optionally include an input driver **412** and an output driver **414**. It is understood that the device **400** can include additional components not shown in FIG. **4** including an artificial intelligence accelerator.

[0072] In various alternatives, the processor **402** includes a central processing unit (CPU), a graphics processing unit (GPU), a CPU and GPU located on the same die, or one or more processor cores, wherein each processor core can be a CPU or a GPU. In various alternatives, the memory **404** is located on the same die as the processor **402**, or is located separately from the processor **402**. The memory **404** includes a volatile or non-volatile memory, for example, random access memory (RAM), dynamic RAM, or a cache. By way of example, the map revision techniques described herein are implemented as a processor executable code or software that can be stored on the memory **404** (as shown) and executed by processor **402**, and rooted in process operations by, and in processing hardware of, the example device **400**.

[0073] The storage device **406** includes a fixed or removable storage means, for example, a hard disk drive, a solid-state drive, an optical disk, or a flash drive. The input devices **408** include, without limitation, a keyboard, a keypad, a touch screen, a touch pad, a detector, a microphone, an accelerometer, a gyroscope, a biometric scanner, or a network connection (e.g., a wireless local area network card for transmission and/or reception of wireless IEEE 802 signals). The output devices **410** include, without limitation, a display device, a speaker, a printer, a haptic feedback device, one or more lights, an antenna, or a network connection (e.g., a wireless local area network card for transmission and/or reception of wireless IEEE 802 signals).

[0074] The input driver **412** communicates with the processor **402** and the input devices **408**, and permits the processor **402** to receive input from the input devices **408**. The output driver **414** communicates with the processor **402** and the output devices **410**, and permits the processor **402** to send output to the output devices **410**. It is noted that the input driver **412** and the output driver **414** are optional components, and that the device **400** will operate in the same manner if the input driver

412 and the output driver **414** are not present. The output driver **414** includes an accelerated processing device (“APD”) **416** which communicates to a display device as represented by the output devices **410**. The APD **416** accepts compute commands and graphics rendering commands from processor **402**, processes those compute and graphics rendering commands, and provides pixel output to display device for display. As described in further detail below, the APD **416** includes one or more parallel processing units to perform computations in accordance with a single-instruction-multiple-data (“SIMD”) paradigm. Thus, although various functionality is described herein as being performed by or in conjunction with the APD **416**, in various alternatives, the functionality described as being performed by the APD **416** is additionally or alternatively performed by other computing devices having similar capabilities that are not driven by a host processor (e.g., processor **402**) and provides graphical output to a display device. For example, it is contemplated that any processing system that performs processing tasks in accordance with a SIMD paradigm may perform the functionality described herein. Alternatively, it is contemplated that computing systems that do not perform processing tasks in accordance with a SIMD paradigm perform the functionality described herein.

[0075] FIG. 5A depicts an electro-anatomical map of heart **500** prior to performing an anatomy fit for ablation tags, according to an example. Heart **500** includes a pulmonary vein **502**, which extends along a length **504a**. Vein **502** has a substantially tubular shape along length **504a**. In FIG. 5A, the substantially tubular shape of vein **502** has a cross-sectional size that exhibits a variation along length **504a** consistent with a normal (healthy) vein. The electro-anatomical map also includes a plurality of tags **501**. One example of a tag **501** is an ablation tag, which objectively identifies and annotates a site on the electro-anatomical map whenever predefined criteria such as catheter stability, time, contact force, or impedance drop are fulfilled. One example of an ablation tag is provided by The CARTO VISITAG™ system sold by Biosense Webster. In an embodiment of that system, the system calculates an index known as the Ablation Tag Index, which is a numerical value reflecting the quality and effectiveness of the ablation at a specific location. This index helps the electrophysiologist assess whether sufficient tissue has been treated to achieve the desired therapeutic effect. This system is often integrated with a 3D mapping system, which allows the electrophysiologist to visualize the cardiac anatomy in three dimensions. This integration helps guide the catheter to the targeted areas and provides a comprehensive view of the ablation procedure. In FIG. 5A, ablation tags **501** are shown on the map, and correspond to the locations of ablation sites.

[0076] In some examples, during a medical procedure such as a cardiac ablation, a fast anatomical map (FAM) (shown for example in FIGS. 5A and 5B) is generated and used for providing a 3D map of heart **500**. The points used to generate the FAM are collected without regards to the respiration of the heart, or other conditions such as the pushing of the catheter against a tissue wall. The fact that such points are used to generate the FAM can result in the FAM being too large. In other examples, vein **502** may lack accuracy on the FAM due to a lack of data points. FIG. 5B depicts an electro-anatomical map of the heart with additional ablation tags **501a**. Ablation tags **501a** pass under vein **502** and continue around the surface of the heart.

[0077] In some examples, a technique is performed to conform or fit the FAM (which as mentioned above can be oversized or inaccurate) to the anatomy defined by ablation tags **501a**. In some cases, this occurs when the physician is ablating, the catheter is in contact with the tissue, but the ablating electrodes are not visualized on the surface (as the surface is oversized). In response, a technician shaves the FAM to ensure that the ablation tag is placed on the surface and not inside the surface. This process requires “fitting” the anatomy in such a way that the ablation tags are placed correctly on the surface. During this fitting, the location information of the ablation tags **501**, **501a** is considered more accurate and is therefore weighted more heavily at the locations of the ablation tags than other data used to generate the FAM. In the example of FIG. 5B, the anatomy fit results in a visual artifact that causes the underside of vein **502** to appear pinched at the location identified by

arrow **505**, where vein **502** meets the heart chamber. This “pinching” artifact results when the anatomy fit causes the portions of the heart shown on the map proximate the ablation tags to shrink without shrinking or adjusting remaining portions of the FAM, and causes vein **502** to erroneously to take on an appearance consistent with stenosis. As explained below, the techniques described herein provide a solution for removing this artifact from the FAM by conforming the remainder of vein **502** (not proximate ablation tags **501a**) in a manner consistent with the shrinkage of vein **502** proximate tags **501a**, so that vein **502** no longer appears to suffer from stenosis. The techniques described herein are not limited to correction of artifacts resembling stenosis, but apply more generally to the processing of FAMs which include data points of varying levels of accuracy.

[0078] FIG. **6** depicts an electro-anatomical map of the heart along with its medial axis, according to an example. In contrast to FIG. **5B** where only ablation tags on the front surface of the heart were shown, in FIG. **6**, ablation tags **501a** on the front surface are shown using a solid dot, while ablation tags **501b** on the back surface of the heart are shown with a dot in silhouette. A medial axis **601** of heart **500**, together with a medial axis **601a** of vein **502**, are also shown. In some examples, system **100** determines and displays medial axes **601**, **601a** during an ablation procedure. A medial axis, sometimes referred to as the skeleton or centerline, is a geometric concept used in computational geometry and represents a set of points within a shape where there is more than one point equidistant to the boundary of the shape. The medial axis is often considered to represent the core or central part of a shape. In medical imaging, for example, the medial axis can be used to represent the central structure of an organ such as heart **500**. While in the example of FIG. **6**, the entirety of medial axis **601** is shown as being determined by system **100**, in other examples (e.g., the example of FIG. **11**) only one or more points on the medial axis are estimated. It will be understood that the references herein to “estimating” a point on the medial axis include both selection of a point on a previously calculated medial axis, as well as other techniques wherein one or more points along the medial axis are estimated.

[0079] Referring still to FIG. **6**, as part of the technique for removing the “pinching” artifact identified with arrow **505** from the map, system **100** calculates at least one best-fitting ellipse **602**, which passes through and lies in a plane perpendicular to medial axis **601a** within vein **502**. In some examples, best-fitting ellipse **602** is an ellipse that is determined to be the most appropriate or optimal representation of the set of data points represented by ablation tags on the surface of vein **502** in the plane of the ellipse. Fitting an ellipse to these points involves finding the ellipse that minimizes some measure of the difference between the ellipse and the data points on the surface of vein **502** in the plane of the ellipse. There are various methods for fitting an ellipse to a set of points, and the techniques described herein are not limited to a specific method for determining a best-fitting ellipse. A common approach for determining a best-fitting ellipse that is applicable to the techniques described herein is the least squares method, where the sum of the squared distances between the data points on the surface of vein **502** in the plane of the ellipse is minimized. It will be understood that a best-fitting circle is a specific case of an ellipse where the two foci coincide at the center, resulting in zero eccentricity. While the description set forth herein uses best-fitting ellipses for conforming the FAM (and, e.g., vein **502**) to the size information provided by ablation tags **501a**, use of other best-fitting shapes including best-fitting circles and best fitting closed-splines are within the scope of this disclosure. A best-fitting closed-spline refers to a spline curve that has been adjusted or fitted to a set of data points in such a way that it minimizes some measure of the difference between the spline and the given data.

[0080] In some examples, after a best-fitting ellipse is determined based on the collected data points, the size of the best-fitting ellipse is compared to minimum and/or maximum thresholds. In one example, these thresholds correspond to the minimum and maximum vein sizes associated with a typical vein size for a person having a profile similar to that of the patient. In these examples, if the best fitting ellipse is less than minimum threshold and/or greater than the maximum threshold, the best-fitting ellipse calculated based on the collected data points is not used for further

calculations. In some such examples, an ellipse equal in size to the minimum threshold is substituted in the case where the best-fitting ellipse calculated from the collected data points is less than the minimum; and/or an ellipse equal in size to the maximum threshold is substituted in the case where the best-fitting ellipse calculated from the collected data points is more than the maximum.

[0081] In the embodiment of FIG. 6, data points corresponding to ablation tags are not available at locations other than the area proximate the right-most best-fitting ellipse **602**. In such circumstances, system **100** may lack the data points required to separately calculate further best-fitting ellipses along the medial axis. Instead of calculating such further best-fitting ellipses, in the embodiment of FIG. 6 copies of the right-most ellipse are projected along the medial axis at an angle normal thereto, as shown.

[0082] FIG. 7 depicts an electro-anatomical map of pulmonary vein **502** showing its medial axis **601a** according to an alternative embodiment where system **100** separately calculates additional best-fitting ellipses **603-605**, each of which passes through and lies in a plane perpendicular to medial axis **601a** within vein **502**. In the example shown, best fitting ellipse **602a** is located proximate the location of ablation tags **501a**, **501b** (not shown), which, as described above, correspond more closely to the actual size of the vein than other points on the FAM. Best-fitting ellipses **603-605** are calculated based on available data (e.g., further ablation tags corresponding to vein **502**) positioned at different cross-sections of the mapped volume of vein **502** normal to the medial axis **601a**. In one example, the length of the major axis and the length of the minor axis of each of best-fitting ellipses **603-605** is reduced so as to correspond or be equal to the length of the major axis and the length of the minor axis, respectively, of best-fitting ellipse **602**. In another embodiment, information indicative of the size of the vein is derived from a pre-acquired image such as a CT or MRI and used for adjusting or shrinking ellipses **603-605**. In a further embodiment, information of the size of the vein is estimated from the size of other veins (e.g., 2-3 other veins) depicted in the electro-anatomical map, and this estimate is used for adjusting or shrinking ellipses **602-605**. In a still further embodiment, information indicative of the amount of shaving that will be required for a vein is estimated based on the amount of shaving required for other veins, and this estimate is used for adjusting or shrinking ellipses **602-605**. While in the example shown, four best-fitting ellipses are used along the length of vein **502**, any suitable number of best-fitting ellipses can be used for implementing the techniques described herein. After best-fitting ellipses **603-605** are each reduced to a size that more closely corresponds to that of best-fitting ellipse **602**, a revised volume for vein **502** is determined by the mapping system, as explained more fully below.

[0083] FIG. 8 depicts an example of a technique for removing the “pinching” artifact similar to that of FIG. 6, except copies **602b-602d** of the right-most best-fitting ellipse **602** are projected along the medial axis at an angle normal thereto. After copies **602b-d** are projected along the medial axis, a revised volume for vein **502** is determined by the mapping system, as explained more fully below. While in the example shown, four copies of ellipse **602a** are used along the length of vein **502**, any suitable number of copies can be used for implementing the techniques described herein.

[0084] After calculation of the ellipses described in connection with the examples of FIGS. 6-8, a revised volume for vein **502** is determined by the mapping system. In the example of FIG. 9, system **100** calculates a new volume **901** (corresponding to a revised surface of vein **502**) by interpolating between the boundaries of copies **602a-d** of ellipse **601a** along medial axis **601a**. For purposes of the techniques described herein, volume **901** is considered to be a generalized cylinder or ruled surface that extends along medial axis **601a** like a pipe or tube; however, because volume **901** corresponds to a vein, it will not correspond in shape to a perfect or regular cylinder. Following calculation of volume **901**, the voxels in the FAM between original volume **902** and new volume **901** are removed, and an updated version of vein **502** (without the artifact described above) is displayed. While in the example described above, the voxels between original volume **902** and new volume **901** are removed in an automated manner in a single step (e.g., actuated by a single-click of

an operator via a user interface), it will be understood that removal of these voxels can be performed in multiple steps using an automated shaving procedure where voxels from volume **902** are shaved in layers until new volume **901** is reached. In some examples, this step-wise procedure is accomplished by an operator shaving successive layers from original volume **902** via a user interface on display **27**.

[0085] While in the example of FIG. **9**, the volume **901** is calculated based on four copies of one best-fitting ellipse, it will be understood that in other examples such as that shown in FIG. **7**, additional separately calculated best-fitting ellipses are used for the calculation of volume **901**. In some examples, two or more best fitting ellipses are used. In some examples, the number of best-fitting ellipses used for calculating tubular volume **901** involves a compromise between accuracy and efficiency. In these examples, the computational time required to compute each best-fitting ellipse is balanced against the increased accuracy of volume **901** associated with each additional best-fitting ellipse, and an optimum number of best-fitting ellipses is chosen based on these considerations.

[0086] FIG. **10** depicts a side-by-side comparison of the map of FIG. **5B** (left) and an updated version of that map (right) which has been revised in accordance with the techniques described herein, according to an example. In the example of FIG. **5B**, the anatomy fit resulted in a visual artifact that caused vein **502** to appear pinched at the location identified by arrow **505**, where vein **502** meets the heart chamber. The map shown on the right in FIG. **10** has been revised in accordance with the techniques described above such that the remaining portions of vein **502** along length **504c** have been shrunk to more closely correspond in size to the portion of the vein proximate area **505**. In the revised map, vein **502** appears as healthy, and no longer resembles one suffering from stenosis.

[0087] While, in the above example, the techniques for revising the FAM are described in connection with vein **502**, the techniques described herein are not limited to veins, and can be applied to other anatomical structures in the heart or elsewhere in the human body.

[0088] FIG. **11** depicts an electro-anatomical map of the heart, according to a further example. While in the examples of FIGS. **6-8**, sufficient data points to define all or most of medial axis **601a** were calculated, in the example of FIG. **11** the medial axis as a whole is not calculated. Rather, in the example of FIG. **11**, a limited number of data points (e.g., one or more data points) are estimated as being along the medial axis. In the example of FIG. **11**, best-fitting ellipse **602** is calculated to be the most appropriate or optimal representation of the set of data points represented by ablation tags on the surface of vein **502** in the plane of the ellipse, as described above. System **100** calculates a center point **901** of ellipse **602**, and a radius **902** of ellipse **602**. In one embodiment, system **100** estimates that center point **901** lies along the medial axis (not shown) of vein **502**. System **100** projects a distance corresponding to line **903** in a direction normal the plane of ellipse **602** to estimate a further data point **904** along the medial axis. System **100** identifies point **906** by projecting from point **904** along line **905** a distance corresponding to the length of radius **902**. Line **905** is normal to line **903**. System **100** identifies a point **907** on the map surface closest to point **906**, and uses point **907** to calculate closed curve **908** which estimates the surface of vein **502** at a cross-section passing through point **904**. Techniques for calculating closed curve **908** are disclosed in connection with the discussion of, e.g., FIG. **3** of U.S. Pat. No. 11,461,895, owned by the assignee of the present application. The contents of U.S. Pat. No. 11,461,895 is incorporated by reference in its entirety. While in FIG. **11**, only a single closed curve is shown, it will be understood that in other examples system **100** calculates multiple additional closed curves along vein **502** by repeating the process described above, until multiple closed curves are determined along the length of the vein.

[0089] Continuing with the example of FIG. **11**, system **100** calculates a new volume (corresponding to a revised surface of vein **502**) by interpolating between the boundaries of ellipse **602** and each successive closed curve calculated long vein **502**. This process is similar to that

described in connection with FIG. 9, except that closed curves are substituted for one or more of the ellipses shown in FIG. 9. The new volume corresponds to a generalized cylinder or ruled surface that extends along the vein like a pipe or tube. Following calculation of the new volume, the voxels in the FAM between original volume and new volume are removed, and an updated version of vein **502** is displayed. The voxels between original volume and the new volume **901** are removed either in an automated manner in a single step (e.g., actuated by a single-click of an operator via a user interface), or in multiple steps using an automated shaving procedure where voxels from volume the old volume are shaved in layers until new volume is reached. In some examples, this step-wise procedure is accomplished by an operator shaving successive layers from original volume via a user interface on display **27**.

[0090] Turning now to FIG. **12**, a method **1200** is illustrated according to one or more exemplary embodiments. The method **1200** is an example set of operations rooted in and executed by the workstation **55** of FIG. **1**, the local computing device **106** of FIG. **2**, the remote computing system **108** of FIG. **2**, and/or the example device **400** of FIG. **4**. The method **1200** shows an example of how system **100** generates and presents maps of an anatomical structure (e.g., one or more 3D models) on a user interface, and revises such maps in accordance with the techniques set forth herein, for example during an EP procedure (e.g., an ablation procedure).

[0091] The method **1200** begins at block **1201**, where a first electro-anatomical map that includes an anatomical structure having a mapped volume with a substantially tubular shape is displayed on a user interface. In one example, the first electro-anatomical map corresponds to the map shown in FIG. **5B**, the anatomical structure having a mapped volume with a substantially tubular shape corresponds to vein **502** shown in FIG. **5B**, and the user interface corresponds to a user interface displayed on display device **27** (shown in FIG. **1**). In this example, the anatomical map depicts a 3D rendering of a heart, and includes features such as one or more ablation tags.

[0092] At block **1202**, at a first cross-section of the mapped volume, a first best-fitting ellipse (or other best-fitting shape) is determined based on data points associated with the first cross-section of the mapped volume. In one example, the first best-fitting ellipse corresponds to ellipse **602** (in FIG. **7**).

[0093] At block **1203**, at least one point along a medial axis (e.g., axis **601a**) of the mapped volume (e.g., vein **502**) is estimated. While in the example of FIG. **6**, the entirety of medial axis **601** is shown as being determined (or estimated) by system **100**, in other examples (e.g., the example of FIG. **11**) only one or more points on the medial axis are estimated. It will be understood that the references herein to “estimating” point(s) on the medial axis include both selection of a point on a previously calculated (estimated) medial axis, as well as other techniques (e.g., the techniques of FIG. **11**) wherein one or more points along the medial axis are estimated.

[0094] In block **1204**, at a second cross-section of the mapped volume, a second point along the medial axis on the second cross-section is estimated. In some examples, a copy of the first best-fitting ellipse is positioned at the second cross-section. In some such examples, further copies of the first best-fitting ellipse are positioned at further cross-sections along the vein in a direction normal to the estimated medial axis. In other examples, a second best-fitting ellipse is separately calculated and positioned at the second cross-section. In one example, the second best-fitting ellipse is initially calculated based on the original volume **902** of vein **502** and then revised (or, e.g., shrunk) to more closely correspond in size to the first best-fitting ellipse. In some such examples, further best-fitting ellipses (separately calculated) are positioned at further cross-sections along the vein in a direction normal to the estimated medial axis. In other embodiments, a combination of copies of the first-best fitting ellipse and other separately calculated best-fitting ellipses are position along the vein. As mentioned above, other best-fitting shapes are within the scope of the techniques described herein.

[0095] In block **1205**, a generalized cylindrical volume is calculated along the estimated medial axis and spanning between the first cross-section and the second cross-section in accordance with

the first best-fitting ellipse. In one example, the generalized cylindrical volume corresponds to volume **901** (in FIG. **9**) and is determined by interpolating between the boundaries of the copies of the first best-fitting ellipses, or between first and second best-fitting ellipses along the estimated medial axis. In some embodiments, where a plurality of best-fitting ellipses are determined along the length of vein **502**, the volume is determined in block **1205** by interpolating between the boundaries of multiple best-fitting ellipses along the estimated medial axis. In block **1206**, data points (or in some cases, voxels) that are outside of the volume are removed. In some examples, this step includes removing all voxels between new volume **901** and original volume **902**, as shown in FIG. **9**, and is performed in a single step or multiple steps by an operator during a medical procedure. In block **1207**, a second electro-anatomical map (e.g., the map shown on the right side of FIG. **10**) having an updated version of the anatomical structure generated without the removed data points is displayed on the user interface.

[0096] In some examples, the techniques in FIG. **12** are applied to a vein associated with a heart muscle and the data points associated with the first cross-section of the mapped volume correspond to ablation tags. In some such examples, at one or more of a plurality of additional cross-sections of the mapped volume normal to and along a length of the medial axis, the data points associated with the cross-section do not correspond to ablation tags. In some examples, the first best-fitting ellipse is a circle, and the substantially tubular shape is a substantially cylindrical shape. In some embodiments, the electro-anatomical map is a fast anatomical map that is generated during a cardiac ablation procedure.

[0097] The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the blocks may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

[0098] Although features and elements are described above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. In addition, the methods described herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. A computer readable medium, as used herein, is not to be construed as being transitory signals per se, for example radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

[0099] Examples of computer-readable media include electrical signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a register, cache memory, semiconductor memory devices, magnetic media (e.g., internal hard disks and removable disks), magneto-optical media, optical media (e.g., compact disks (CD) and digital versatile disks (DVDs)), a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), and a memory stick. A processor in association with software may be used to implement a radio frequency transceiver for

use in a terminal, base station, or any host computer.

[0100] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one more other features, integers, steps, operations, element components, and/or groups thereof.

[0101] The descriptions of the various embodiments herein have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

Claims

1. A method for revising an electro-anatomical map generated using a catheter positioned in a human body, the catheter having a plurality of electrodes, wherein the map is generated from data points acquired using the electrodes as the catheter moves within the body during a medical procedure, the method comprising: displaying a first electro-anatomical map that includes an anatomical structure having a mapped volume with a substantially tubular shape; at a first cross-section of the mapped volume, determining a first best-fitting ellipse based on data points associated with the first cross-section of the mapped volume; estimating a first point along a medial axis of the mapped volume in accordance with a center of the first-best fitting ellipse; estimating a second point along the medial axis on a second cross-section of the mapped volume; the first-cross section being different from the second cross-section; calculating a generalized cylindrical volume spanning between the first cross-section and the second cross-section in accordance with at least the first best-fitting ellipse; removing data points from the mapped volume that are outside of the generalized cylindrical volume; and displaying a second electro-anatomical map having an updated version of the anatomical structure generated without the removed data points.
2. The method of claim 1, further comprising determining a plurality of points defining the medial axis, wherein the first cross-section is normal to the medial axis and the step of estimating the second point comprises selecting one of the plurality of points.
3. The method of claim 1, wherein the anatomical structure is a vein associated with a heart muscle.
4. The method of claim 1, wherein the data points associated with the first cross-section of the mapped volume correspond to ablation tags.
5. The method of claim 4, further comprising: estimating further points along the medial axis on further cross-sections of the mapped volume; and wherein the generalized cylindrical volume spans the first cross-section, the second cross-section and the further cross-sections.
6. The method of claim 4, wherein data points associated with the second cross-section and each of the further cross-sections of the mapped volume do not correspond to ablation tags.
7. The method of claim 6, wherein the generalized cylindrical volume is a substantially cylindrical shape.
8. The method of claim 1, wherein the electro-anatomical map is a fast anatomical map.
9. A system for revising an electro-anatomical map generated using a catheter positioned in a human body, the catheter having a plurality of electrodes, wherein the map is generated from data points acquired using the electrodes as the catheter moves within the body during a medical procedure, the system comprising: a memory that stores the electro-anatomical map; a processor

coupled to the memory; and a user-interface coupled to the processor; wherein the processor is configured to perform operations including: display, on the user-interface, a first electro-anatomical map that includes an anatomical structure having a mapped volume with a substantially tubular shape; at a first cross-section of the mapped volume, determine a first best-fitting ellipse based on data points associated with the first cross-section of the mapped volume; estimate a first point along a medial axis of the mapped volume in accordance with a center of the first best-fitting ellipse; estimate a second point along the medial axis on a second cross-section of the mapped volume; the first-cross section being different from the second cross-section; calculate a generalized cylindrical volume spanning between the first cross-section and the second cross-section in accordance with at least the first best-fitting ellipse; remove data points from the mapped volume that are outside of the generalized cylindrical volume; and display, on the user-interface, a second electro-anatomical map having an updated version of the anatomical structure generated without the removed data points.

10. The system of claim 9, further comprising determining a plurality of points defining the medial axis, wherein the first cross-section is normal to the medial axis and the step of estimating the second point comprises selecting one of the plurality of points.

11. The system of claim 9, wherein the anatomical structure is a vein associated with a heart muscle.

12. The system of claim 10, wherein the data points associated with the first cross-section of the mapped volume correspond to ablation tags.

13. The system of claim 12, wherein the processor is further configured to: estimate further points along the medial axis on further cross-sections of the mapped volume; and wherein the generalized cylindrical volume spans the first cross-section, the second cross-section and the further cross-sections.

14. The system of claim 12, wherein the data points associated with the second cross-section and each further cross-section of the mapped volume do not correspond to ablation tags.

15. The system of claim 14, wherein the generalized cylindrical volume is a substantially cylindrical shape.

16. The system of claim 10, wherein the electro-anatomical map is a fast anatomical map.

17. A non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to perform operations comprising: displaying a first electro-anatomical map that includes an anatomical structure having a mapped volume with a substantially tubular shape; at a first cross-section of the mapped volume, determining a first best-fitting ellipse based on data points associated with the first cross-section of the mapped volume; estimating a first point along a medial axis of the mapped volume in accordance with a center of the first best-fitting ellipse; estimating a second data point along the medial axis on a second cross-section of the mapped volume; the first-cross section being different from the second cross-section; calculating a generalized cylindrical volume along the medial axis and spanning between the first cross-section and the second cross-section in accordance with at least the first best-fitting ellipse; removing data points from the mapped volume that are outside of the generalized cylindrical volume; and displaying a second electro-anatomical map having an updated version of the anatomical structure generated without the removed data points.

18. The non-transitory computer readable medium of claim **18**, wherein the operations further comprise: determining a plurality of points defining the medial axis, wherein the first cross-section is normal to the medial axis and estimating the second point comprises selecting one of the plurality of points.

19. The non-transitory computer-readable medium of claim 17, wherein the anatomical structure is a vein associated with a heart muscle.

20. The non-transitory computer-readable medium of claim 19, wherein the data points associated with the first cross-section of the mapped volume correspond to ablation tags.

