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(54) **INTRACARDIAC ECHOCARDIOGRAPHY
IMAGE RECONSTRUCTION IN
COMBINATION WITH POSITION TRACKING
SYSTEM**

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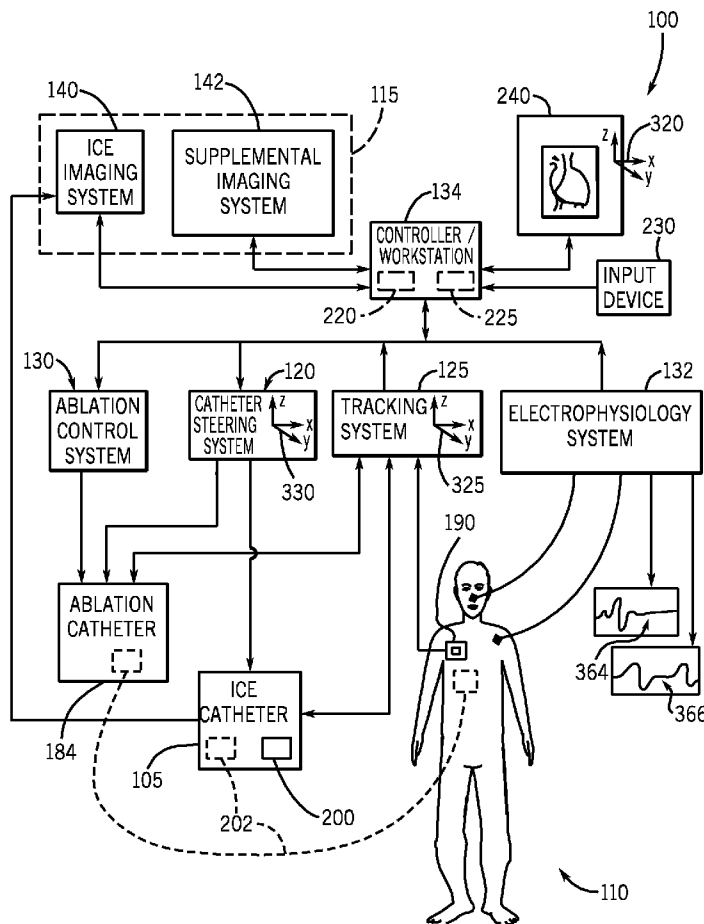
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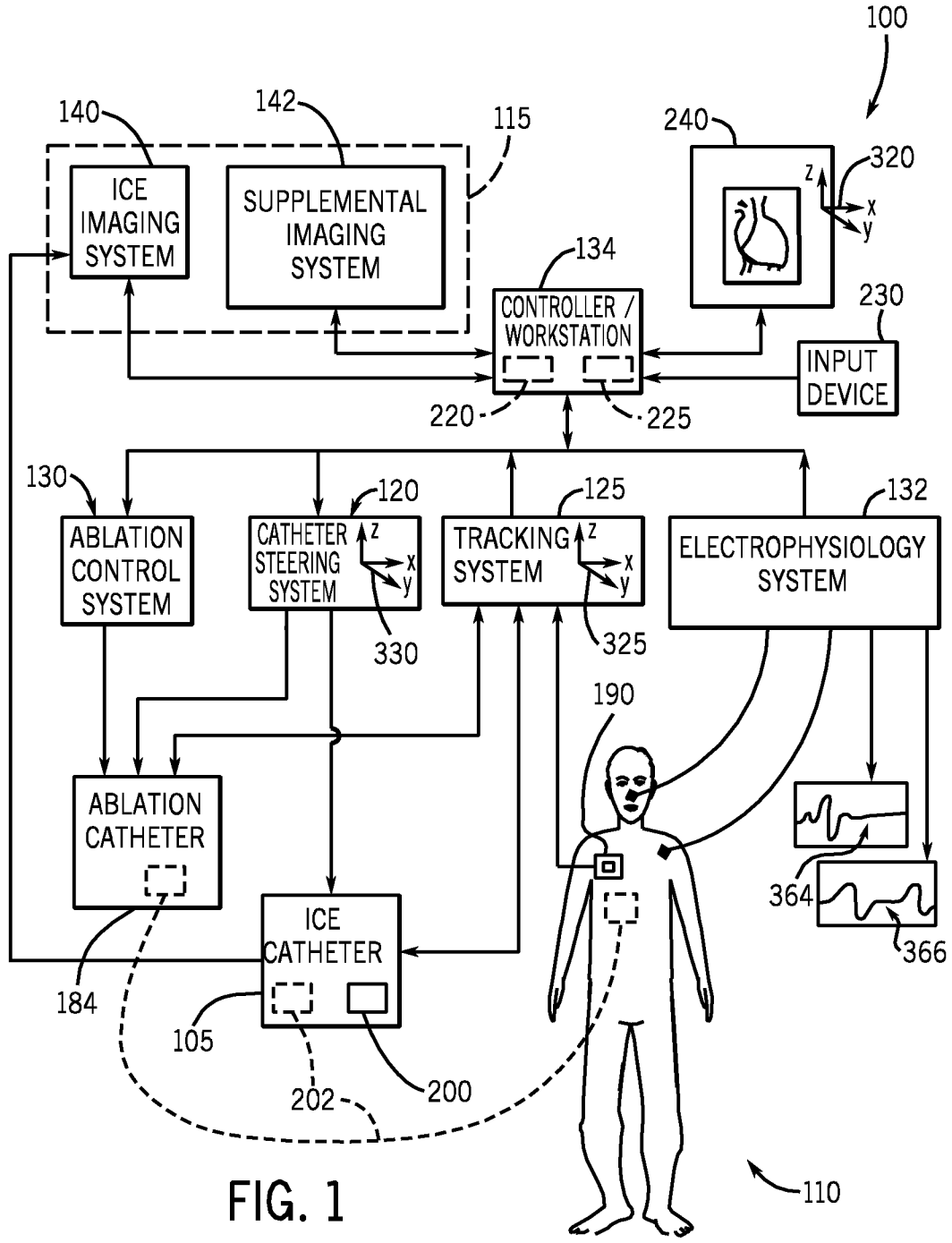
Related U.S. Application Data

(63) Continuation of application No. 12/060,714, filed on
Apr. 1, 2008, now Pat. No. 8,428,690.

(57) **ABSTRACT**

A system and method to display a four-dimensional (4D) model of an imaged anatomy is provided. The system comprises a controller, and an imaging system including an imaging probe in communication with the controller. The imaging probe can acquire generally real-time, 3D image data relative to a direction of image acquisition along an imaging plane. The system also includes a tracking system in communication with the controller. The tracking system includes at least one tracking element integrated with the imaging probe. The system is operable to process the generally real-time, 3D image data acquired by the imaging probe relative to generally real-time tracking information acquired by the tracking system so as to display the 4D model of the imaged anatomy.





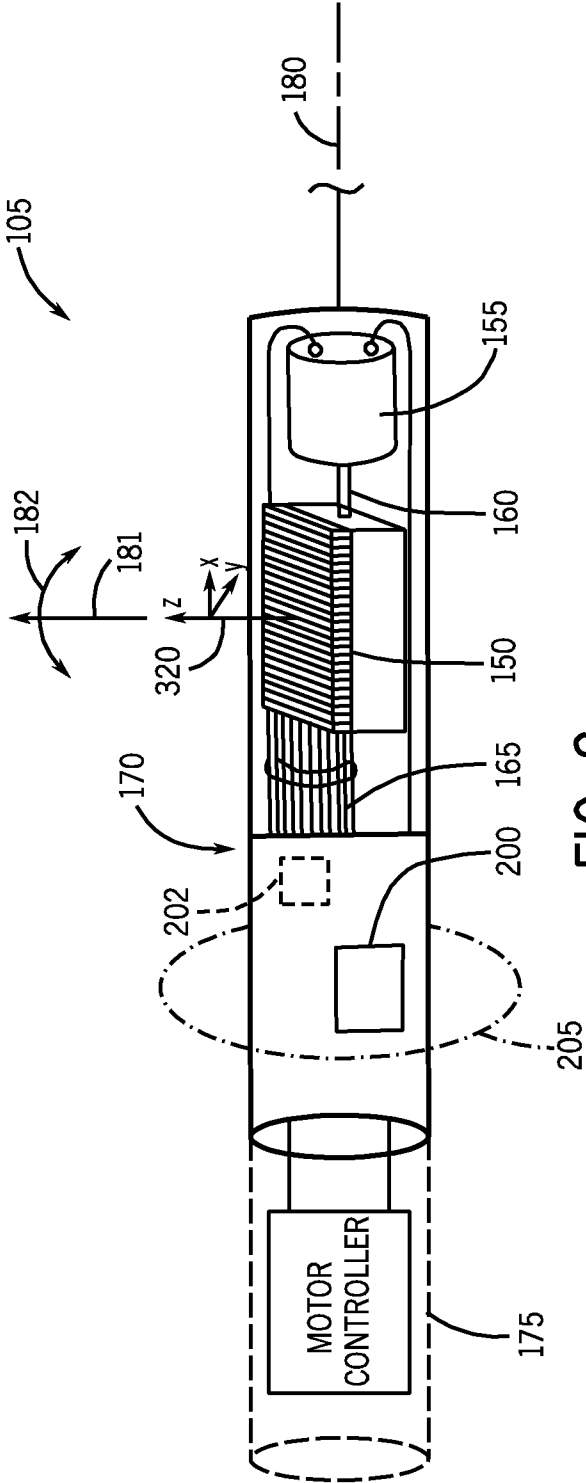


FIG. 2

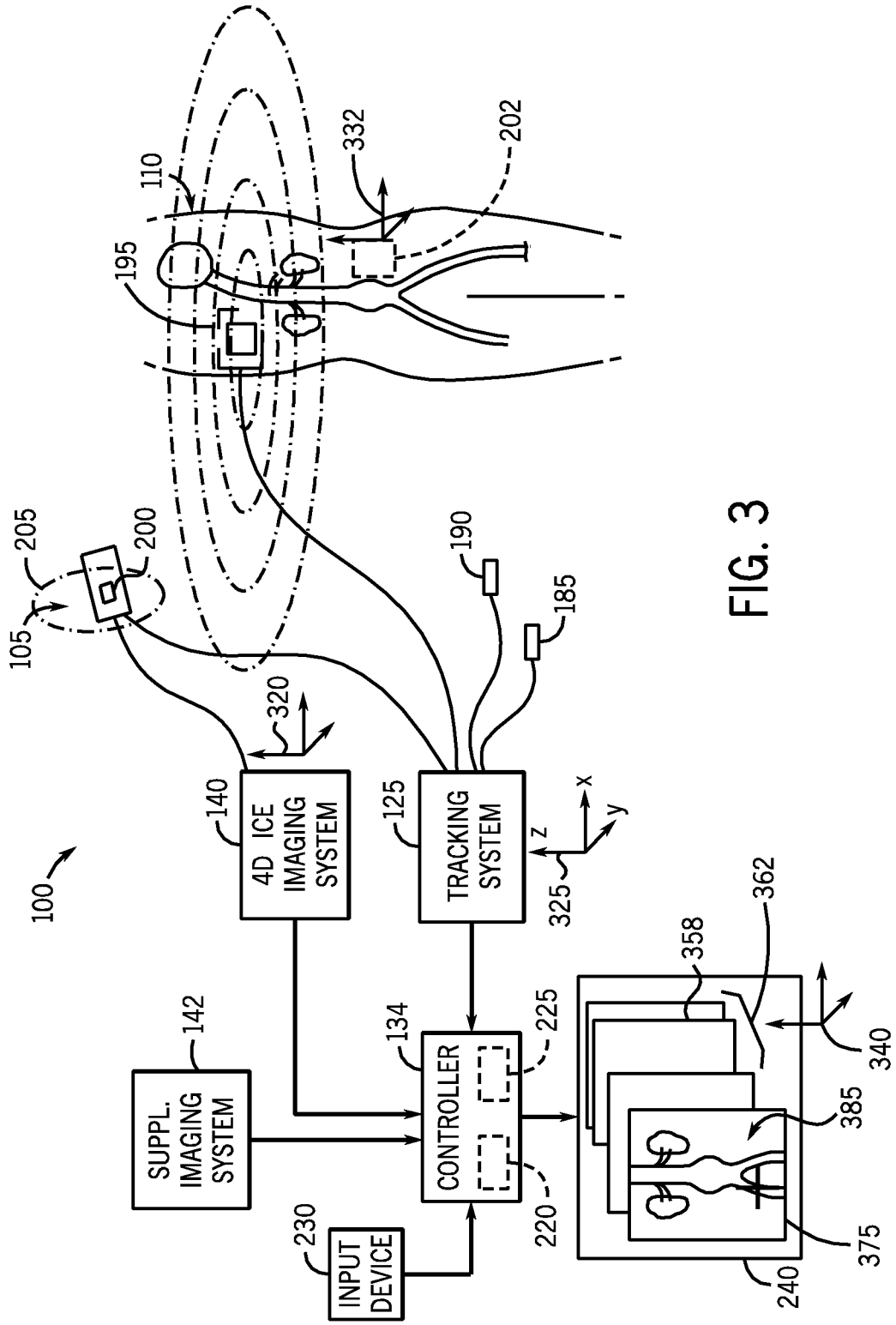


FIG. 3

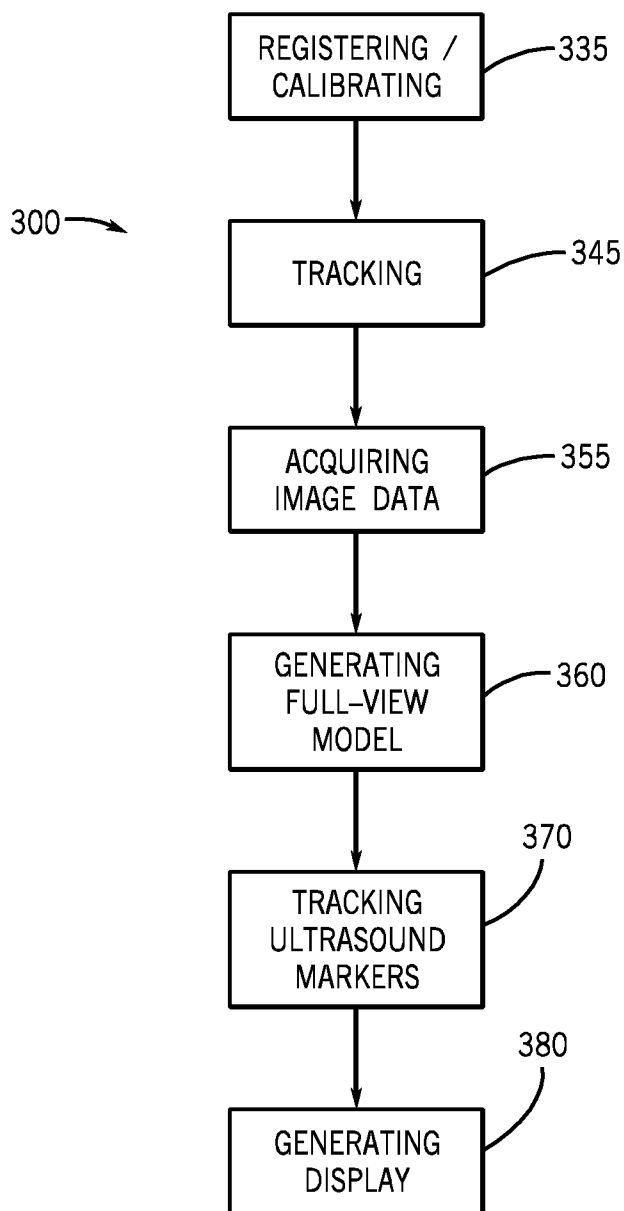


FIG. 4

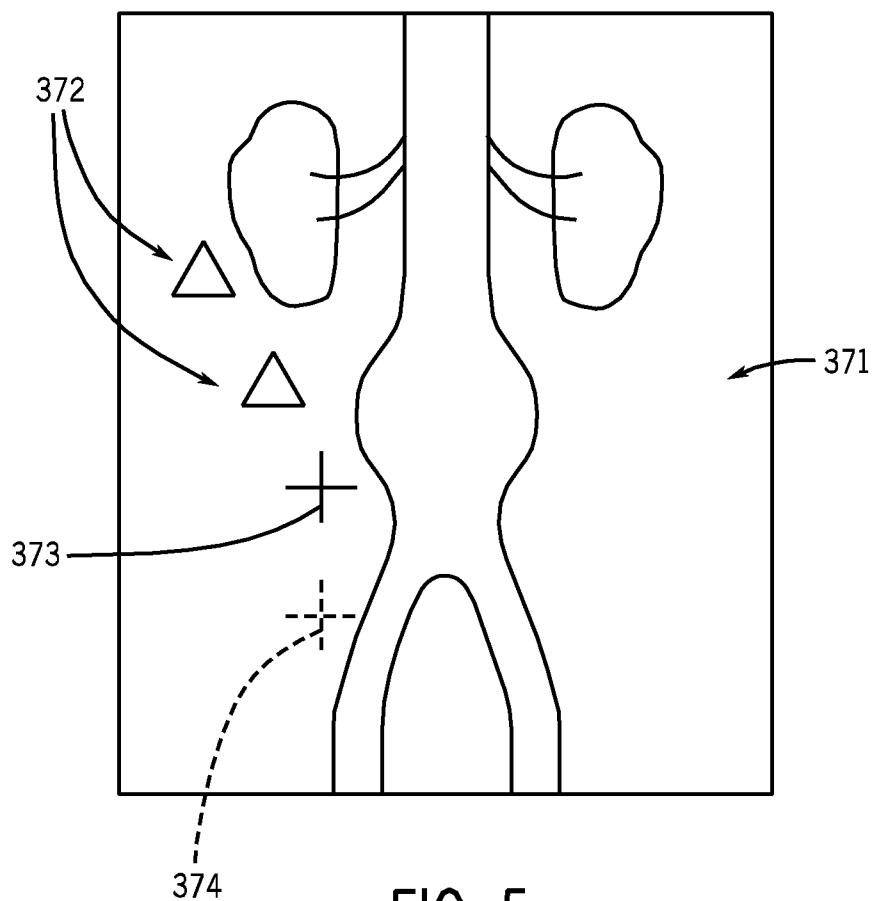


FIG. 5

**INTRACARDIAC ECHOCARDIOGRAPHY
IMAGE RECONSTRUCTION IN
COMBINATION WITH POSITION TRACKING
SYSTEM**

**CROSS REFERENCE TO RELATED
APPLICATIONS**

[0001] This application is a continuation application and claims priority to and the benefit of U.S. patent application Ser. No. 12/060,714, filed Apr. 1, 2008, and entitled "INTRACARDIAC ECHOCARDIOGRAPHY IMAGE RECONSTRUCTION IN COMBINATION WITH POSITION TRACKING SYSTEM", which claims the benefit of U.S. Provisional Application No. 60/938,442, filed on May 16, 2007, and entitled "4D INTRACARDIAC ECHOCARDIOGRAPHY RECONSTRUCTION WITH ASSISTANCE OF EM POSITION TRACKER" all of which are hereby incorporated by reference as if fully set forth herein.

BACKGROUND

[0002] The subject matter herein generally relates to medical imaging, and more specifically, to a system and method to navigate a tool through an imaged subject.

[0003] Image-guided surgery is a developing technology that generally provides a surgeon with a virtual roadmap into a patient's anatomy. This virtual roadmap allows the surgeon to reduce the size of entry or incision into the patient, which can minimize pain and trauma to the patient and result in shorter hospital stays. Examples of image-guided procedures include laparoscopic surgery, thoracoscopic surgery, endoscopic surgery, etc. Types of medical imaging systems, for example, computerized tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), ultrasound (US), radiological machines, etc., can be useful in providing static image guiding assistance to medical procedures. The above-described imaging systems can provide two-dimensional or three-dimensional images that can be displayed to provide a surgeon or clinician with an illustrative map to guide a tool (e.g., a catheter) through an area of interest of a patient's body.

[0004] When performing a medical procedure, it is desired to calibrate or align the acquired image data of the imaged subject with the tracked tool so as to navigate through the imaged subject. Yet, the sensors to track the tool and the detectors to acquire the image data may not be precisely located due to manufacturing variation. One example of application of image-guided surgery is to perform an intervention procedure to treat cardiac disorders or arrhythmias. Heart rhythm disorders or cardiac arrhythmias are a major cause of mortality and morbidity. Atrial fibrillation is one of the most common sustained cardiac arrhythmia encountered in clinical practice. Cardiac electrophysiology has evolved into a clinical tool to diagnose these cardiac arrhythmias. As will be appreciated, during electrophysiological studies, probes, such as catheters, are positioned inside the anatomy, such as the heart, and electrical recordings are made from the different chambers of the heart.

[0005] A certain conventional image-guided surgery technique used in interventional procedures includes inserting a probe, such as an imaging catheter, into a vein, such as the femoral vein. The catheter is operable to acquire image data to monitor or treat the patient. Precise guidance of the imaging catheter from the point of entry and through the vascular

structure of the patient to a desired anatomical location is progressively becoming more important. Current techniques typically employ fluoroscopic imaging to monitor and guide the imaging catheter within the vascular structure of the patient.

BRIEF SUMMARY

[0006] A technical effect of the embodiments of the system and method described herein includes increasing the field of view of image data acquisition employed to generate three- or four-dimensional reconstruction of images to guide an interventional surgery procedure. In general, as a surgeon moves the medical instrument with respect to the patient's anatomy, virtual images of the instrument or object are displayed simultaneously relative to real-time acquired image data represented in the model of the patient's anatomy. Another technical effect of the system and method described herein of tracking includes readily tracking the spatial relationship of the medical instruments or objects traveling through an operating space of patient. Yet, another technical effect of the system and method described herein includes reducing manpower, expense, and time to perform interventional procedures, thereby reducing health risks associated with long-term exposure of the subject to radiation.

[0007] According to one embodiment, a system operable to generate a four-dimensional (4D) model of an imaged anatomy, the system comprising a controller and an imaging system including an imaging probe in communication with the controller. The 4D imaging probe is operable to acquire a real-time, 3D image data relative to a direction of image acquisition along an imaging plane. The system further includes a tracking system in communication with the controller. The tracking system includes at least one tracking element integrated with the 4D ultrasound imaging probe. The system is operable to process the real-time, 3D image data acquired by the imaging probe relative to generally real-time tracking information acquired by the tracking system to generate a 4D model of the imaged anatomy.

[0008] According to another embodiment, a method of image acquisition of an imaged anatomy is provided. The method comprises the steps of acquiring a series of partial view 3D image data with a 4D imaging probe defined by an image coordinate system and a time reference; tracking a position of the 4D imaging probe relative to the time reference and a tracking coordinate system; generating a 4D model of the imaged anatomy by merging the series of partial view 3D image data defined relative to the time reference; and displaying the 4D model in superposition with a representation of the tracked position of the imaging probe.

[0009] Systems and methods of varying scope are described herein. In addition to the aspects of the subject matter described in this summary, further aspects of the subject matter will become apparent by reference to the drawings and with reference to the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 illustrates a schematic diagram of an embodiment of a system of the subject matter described herein to perform imaged guided medical procedures on an imaged subject.

[0011] FIG. 2 illustrates a picture of a tool to travel through the imaged subject.

[0012] FIG. 3 illustrates a more detailed schematic diagram of a tracking system in combination with an imaging system as part of the system described in FIG. 1.

[0013] FIG. 4 shows an embodiment of a method of performing an image-guided procedure via the system of FIG. 1.

[0014] FIG. 5 shows an embodiment of an illustration of tracking historical, current, and future locations of diagnostic or therapeutic catheters via the system of FIG. 1 to form a surgical plan.

DETAILED DESCRIPTION

[0015] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments, which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the embodiments, and it is to be understood that other embodiments may be utilized and that logical, mechanical, electrical and other changes may be made without departing from the scope of the embodiments. The following detailed description is, therefore, not to be taken in a limiting sense.

[0016] FIG. 1 generally illustrates an embodiment of a system 100 operable to create a full-view three- or four-dimensional (3D or 4D) image or model from a series of generally real-time, acquired 3D or 4D image data (e.g., ultrasound) relative to tracked position information of an imaging probe (e.g., catheter 105) traveling through the imaged subject 110. Although the following description is in regard to a catheter, the type of probe (e.g., endoscope, laparoscope, etc. or combination thereof) can vary. One embodiment of the system 100 is operable to acquire the series of 3D or 4D ultrasound image data while simultaneously rotating and tracking a position and orientation of the catheter 105 through the imaged subject. From the acquired 3D or 4D ultrasound image data, a technical effect of the system 100 includes creating an illustration of a full-view, 4D model of a region of interest (e.g., a beating heart) so as to guide delivery of an instrument.

[0017] An embodiment of the system 100 generally includes an image acquisition system 115, a steering system 120, a tracking system 125, an ablation system 130, and an electrophysiology system 132 (e.g., a cardiac monitor, respiratory monitor, pulse monitor, etc. or combination thereof), and a controller or workstation 134.

[0018] Still referring to FIG. 1, the image acquisition system 115 is generally operable to generate a three-dimensional, or four-dimensional image model corresponding to an area of interest of the imaged subject 110. Examples of the image acquisition system 115 can include, but are not limited to, computed tomography (CT), magnetic resonance imaging (MRI), x-ray or radiation, positron emission tomography (PET), ultrasound (US), angiographic, fluoroscopic, and the like or combination thereof. The image acquisition system 115 can be operable to generate static images acquired by static imaging detectors (e.g., CT systems, MRI systems, etc.) prior to a medical procedure, or real-time images acquired with real-time imaging detectors (e.g., angiographic systems, fluoroscopic systems, laparoscopic systems, endoscopic systems, etc.) during the medical procedure. Thus, the types of images acquired by the acquisition system 115 can be diagnostic or interventional.

[0019] An embodiment of the image acquisition system 115 includes a real-time, intracardiac echocardiography

(ICE) imaging system 140 that employs ultrasound to acquire image data of the patient's anatomy and to merge acquired image data to generate a three-dimensional model of the patient's anatomy relative to time, generally herein referred to as a four-dimensional (4D) model or image. In accordance with another embodiment, the image acquisition system 115 is operable to fuse or combine acquired image data using above-described ICE imaging system 140 with pre-acquired or intra-operative image data or image models (e.g., two- or three-dimensional reconstructed image models) generated by another type of supplemental imaging system 142 (e.g., CT, MRI, PET, ultrasound, fluoroscopy, x-ray, etc. or combinations thereof).

[0020] FIG. 2 illustrates one embodiment of the catheter 105, herein referred to as an ICE catheter 105. The illustrated embodiment of the ICE catheter 105 includes a transducer array 150, a micromotor 155, a drive shaft or other mechanical connection 160 between the micromotor 155 and the transducer array 150, an interconnect 165, and a catheter housing 170.

[0021] According to the illustrated embodiment in FIG. 2, the micromotor 155 via the drive shaft 160 generally rotates the transducer array 150. The rotational motion of the transducer array 150 is controlled by a motor control 175 of the micromotor 155. The interconnect 165 generally refers to, for example, cables and other connections coupling so as to receive and/or transmit signals between the transducer array 150 with the ICE imaging system (shown in FIG. 1) 105. An embodiment of the interconnect 165 is configured to reduce its respective torque load on the transducer array 150 and the micromotor 155.

[0022] An embodiment of the catheter housing 170 generally encloses the transducer array 150, the micromotor 155, the drive shaft 160, and the interconnect 165. The catheter housing 170 may further enclose the motor control 175 (illustrated in dashed line). The catheter housing is generally of a material, size, and shape adaptable to internal imaging applications and insertion into regions of interest of the imaged subject 110. At least a portion of the catheter housing 170 that intersects the ultrasound imaging volume or scanning direction is comprised of acoustically transparent (e.g., low attenuation and scattering, acoustic impedance near that of the blood and tissue ($Z \sim 1.5M \text{ Rayl}$)) material. An embodiment of the space between the transducer array 150 and the housing 170 is filled with acoustic coupling fluid (e.g., water) having an acoustic impedance and sound velocity near those of blood and tissue (e.g., $Z \sim 1.5M \text{ Rayl}$, $V \sim 1540 \text{ m/sec}$).

[0023] An embodiment of the transducer array 150 is a 64-element one-dimensional array having 0.110 mm azimuth pitch, 2.5 mm elevation, and 6.5 MHz center frequency. The elements of the transducer array 150 are electronically phased in order to acquire a sector image generally parallel to a longitudinal axis 180 of the catheter housing 170. In operation, the micromotor 155 mechanically rotates the transducer array 150 about the longitudinal axis 180. The rotating transducer array 150 captures a plurality of two-dimensional images for transmission to the ICE imaging system 140 (shown in FIG. 1). The ICE imaging system 140 (See FIG. 1) is generally operable to assemble the sequence or succession of acquired 2D images so as to generally produce or generate 3D image or reconstructed models of the imaged subject 110.

[0024] Still referring to FIG. 2, the motor control 175 via the micromotor 155 generally regulates or controls the rate of rotation of the transducer array 150 about the longitudinal

axis **180** of the ICE catheter **105**. For example, the motor control **175** can instruct the micromotor **155** to rotate the transducer array **150** relatively slowly to produce the 3D reconstructed image or model. Also, the motor control **175** can instruct the micromotor **155** to rotate the transducer array **150** relatively faster to produce a real-time, 3D reconstructed image or model, referred to as the 4D reconstructed image or model. The 4D reconstructed image or model can be defined to include the 3D reconstructed image or model correlated relative to a general instant in time or instantaneous time. The motor control **175** is also generally operable to vary the direction of rotation so as to generally create an oscillatory motion of the transducer array **150**. By varying the direction of rotation, the motor control **175** is operable to reduce the torque load associated with the interconnect **165**, thereby enhancing the performance of the transducer array **150** to focus imaging on specific regions within the range of motion of the transducer array **150** about the longitudinal axis **180**.

[0025] Referring back to FIG. 1, an embodiment of the steering system **120** is generally coupled in communication to control maneuvering (including the position or the orientation) of the ICE catheter **105**. The embodiment of the system **100** can include synchronizing the steering system **120** with gated image acquisition by the ICE imaging system **140**. The steering system **120** may be provided with a manual catheter steering function or an automatic catheter steering function or combination thereof. With selection of the manual steering function, a user manually aligns an imaging plane vector **181** (See FIG. 2) relative to a marker at the ICE catheter **105** shown on the 3D ICE reconstructed image or model, as well as directs the ICE catheter **105** to a target anatomical site. With selection of the automatic steering function, the controller **134** and/or steering system **120** or combination thereof estimates a displacement or a rotation angle **182** (See FIG. 2) relative to a reference (e.g., see ICE imaging reference frame discussed later) that is needed to aim the ICE imaging plane vector **181** (See FIG. 2) from the catheter **105**, passes position information of the ICE catheter **105** to the steering system **120**, and automatically drives or positions the ICE catheter **105** to continuously follow the delivery of a second instrument (e.g., an ablation catheter **184** of the ablation system **130**). The reference can vary.

[0026] Referring to FIGS. 1 and 3, the tracking system **125** is generally operable to track or detect the position of the tool or ICE catheter **105** relative to the acquired image data or 3D or 4D reconstructed image or model generated by the image acquisition system **115**, or relative to delivery of a second instrument or tool (e.g., ablation system **130**, electrophysiology system **132**).

[0027] As illustrated in FIG. 3, an embodiment of the tracking system **125** includes an array or series of microsensors or tracking elements **185**, **190**, **195**, **200** connected (e.g., via a hard-wired or wireless connection) to communicate position data to the controller **134** (See FIG. 1). Yet, it should be understood that the number of tracking elements **185**, **190**, **195**, **200** can vary. An embodiment of the system **100** includes intraoperative tracking and guidance in the delivery of the at least one catheter **184** of the ablation system **130** by employing a hybrid electromagnetic and ultrasound positioning technique. The hybrid electromagnetic/ultrasound positioning technique facilitates dynamic tracking by locating tracking elements or dynamic references **185**, **190**, **195**, **200**, alone or in combination with ultrasound markers **202** (e.g., comprised of metallic objects such as brass balls, wire, etc.). The ultrasonic

markers **202** may be active (e.g., illustrated in dashed line located at catheters **105** and **184**) or passive targets (e.g., illustrated in dashed line at imaged anatomy of subject **110**) (See FIG. 1). An embodiment of the ultrasound markers **202** can be located at the ICE catheter **105** and/or ablation catheter **184** (See FIG. 1) so as to be identified or detected in acquired image data by supplemental imaging system **142** and/or the ICE imaging system **140**. The tracking system **125** can be configured to selectively switch between tracking relative to electromagnetic tracking elements **185**, **190**, **195**, **200** or ultrasound markers **202** or simultaneously track both.

[0028] For sake of example and referring to FIG. 3, assume the series of tracking elements **185**, **190**, **195**, **200** includes a combination of transmitters or dynamic references **185** and **190** in communication or coupled (e.g., RF signal, optically, electromagnetically, etc.) with one or more receivers **195** and **200**. The number and type transmitters in combination with receivers can vary. Either the transmitters **185** and **190** or the receivers **195** and **200** can define the reference of the spatial relation of the tracking elements **185**, **190**, **195**, **200** relative to one another. An embodiment of one of the receivers **195** represents a dynamic reference at the imaged anatomy of the subject **110**. An embodiment of the system **100** (See FIG. 1) can be operable to register or calibrate the location (e.g., position and/or orientation) of the tracking elements **185**, **190**, **195**, **200** relative to the acquired imaging data by the image acquisition system **115** (See FIG. 1), and operable to generate a graphic representation suitable to visualize the location of the tracking elements **185**, **190**, **195**, **200** relative to the acquired image data.

[0029] The tracking elements **185**, **190**, **195**, **200** generally enable a surgeon to continually track the position and orientation of the catheters **105** or **184** (See FIG. 1) during surgery. The tracking elements **185**, **190**, **195**, **200** may be passively powered, powered by an external power source, or powered by an internal battery. One embodiment of one or more of the tracking elements or microsensors **185**, **190**, **195**, **200** include electromagnetic (EM) field generators having microcoils operable to generate a magnetic field, and one or more of the tracking elements **185**, **190**, **195**, **200** include an EM field sensor operable to detect an EM field. For example, assume tracking elements **185** and **190** include an EM field sensor operable such that when positioned into proximity within the EM field generated by the other tracking elements **195** or **200** is operable to calculate or measure the position and orientation of the tracking elements **195** or **200** in real-time (e.g., continuously), or vice versa, calculate the position and orientation of the tracking elements **185** or **190**.

[0030] For example, tracking elements **185** and **190** can include EM field generators attached to the subject **110** and operable to generate an EM field, and assume that tracking element **195** or **200** includes an EM sensor or array operable in combination with the EM generators **185** and **190** to generate tracking data of the tracking elements **185**, **190** attached to the patient **110** relative to the microsensor **195** or **200** in real-time (e.g., continuously). According to one embodiment of the series of tracking elements **185**, **190**, **195**, **200**, one is an EM field receiver and a remainder are EM field generators. The EM field receiver may include an array having at least one coil or at least one coil pair and electronics for digitizing magnetic field measurements detected by the receiver array. It should, however, be understood that according to alternate embodiments, the number and combination of EM field receivers and EM field generators can vary.

[0031] The field measurements generated or tracked by the tracking elements **185, 190, 195, 200** can be used to calculate the position and orientation of one another and attached instruments (e.g., catheters **105** or **184** (See FIG. 1)) according to any suitable method or technique. In one embodiment, the field measurements tracked by the combination of tracking elements **185, 190, 195, 200** can be digitized into signals for transmission (e.g., wireless, or wired) to the tracking system **125** or controller **134**. The controller **134** is generally operable to register the position and orientation information of the one or more tracking elements **185, 190, 195, 200** relative to the acquired imaging data from ICE imaging system **140** or other supplemental imaging system **142**. Thereby, the system **100** is operable to visualize or illustrate the location of the one or more tracking elements **185, 190, 195, 200** or attached catheters **105** or **184** (See FIG. 1) relative to pre-acquired image data or real-time image data acquired by the image acquisition system **115** (See FIG. 1).

[0032] Referring now to FIGS. 2 and 3, an embodiment of the tracking system **125** includes the tracking element **200** located at the ICE catheter **105**. The tracking element **200** is in communication with the receiver **195**. This embodiment of the tracking element **200** includes a transmitter that comprises a series of coils that define the orientation or alignment of the ICE catheter **105** about the rotational axis (generally aligned along the longitudinal axis **180**) of the ICE catheter **105**. The tracking element **200** can be located integrally with the ICE catheter **105** and can be generally operable to generate or transmit a magnetic field **205** to be detected by the receiver **195** of the tracking system **125**. In response to passing through the magnetic field **205**, the receiver **195** generates a signal representative of a spatial relation and orientation of the receiver **195** or other reference relative to the transmitter **200**. Yet, it should be understood that the type or mode of coupling, link or communication (e.g., RF signal, infrared light, magnetic field, electrical potential, etc.) operable to measure the spatial relation varies. The spatial relation and orientation of the tracking element **200** is mechanically pre-defined or measured in relation relative to a feature (e.g., a tip) of the ICE catheter **105**. Thereby, the tracking system **125** is operable to track the position and orientation of the ICE catheter **105** navigating through the imaged subject **110**.

[0033] Alternatively, the tracking elements **185, 190, or 200** can include a plurality of coils (e.g., Helmholtz coils) operable to generate a magnetic gradient field to be detected by the receiver **195** of the tracking system **125** and which defines an orientation of the ICE catheter **105**. An embodiment of the receiver **195** includes at least one conductive loop operable to generate an electric signal indicative of spatial relation and orientation relative to the magnetic field generated by the tracking elements **185, 190** and **200**.

[0034] Referring back to FIG. 1, an embodiment of the ablation system **130** includes the ablation catheter **184** that is operable to work in combination with the ICE catheter **105** of the ICE imaging system **140** to deliver ablation energy to ablate or end electrical activity of tissue of the imaged subject **110**. An embodiment of the ICE catheter **105** can include or be integrated with the ablation catheter **184** or be independent thereof. An embodiment of the ablation catheter **184** can include one of the tracking elements **185, 190** of the tracking system **125** described above to track or guide intra-operative delivery of ablation energy to the imaged subject **110**. Alternatively or in addition, the ablation catheter **184** can include ultrasound markers **202** operable to be detected from the

acquired ultrasound image data generated by the ICE imaging system **140**. The ablation system **130** is generally operable to manage the ablation energy delivery to an ablation catheter **184** relative to the acquired image data and tracked position data.

[0035] Still referring to FIG. 1, an embodiment of an electrophysiological system(s) **132** is connected in communication with the ICE imaging system **140**, and is generally operable to track or monitor or acquire data of the cardiac cycle or respiratory cycle of imaged subject **110**. Data acquisition can be correlated to the gated acquisition or otherwise acquired image data, or correlated relative to generated 3D or 4D models created by the image acquisition system **115**.

[0036] An embodiment of the controller or workstation computer **134** can be generally connected in communication with and controls the image acquisition system **115** (e.g., the ICE imaging system **140** or supplemental imaging system **142**), the steering system **120**, the tracking system **125**, the ablation system **130**, and the electrophysiology system **132** so as to enable each to be in synchronization with one another and to enable the data acquired therefrom to produce or generate a full-view 3D or 4D ICE model of the imaged anatomy.

[0037] An embodiment of the controller **134** includes a processor **220** in communication with a memory **225**. The processor **220** can be arranged independent of or integrated with the memory **225**. Although the processor **220** and memory **225** are described located at the controller **134**, it should be understood that the processor **220** or memory **225** or portion thereof can be located at the image acquisition system **115**, the steering system **120**, the tracking system **125**, the ablation system **130** or the electrophysiology system **132** or combination thereof.

[0038] The processor **220** is generally operable to execute the program instructions representative of acts or steps described herein and stored in the memory **225**. The processor **220** can also be capable of receiving input data or information or communicating output data. Examples of the processor **220** can include a central processing unit of a desktop computer, a microprocessor, a microcontroller, or programmable logic controller (PLC), or the like or combination thereof.

[0039] An embodiment of the memory **225** generally comprises one or more computer-readable media operable to store a plurality of computer-readable program instructions for execution by the processor **220**. The memory **225** can also be operable to store data generated or received by the controller **134**. By way of example, such media may comprise RAM, ROM, PROM, EPROM, EEPROM, Flash, CD-ROM, DVD, or other known computer-readable media or combinations thereof which can be used to carry or store desired program code in the form of instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. When information is transferred or provided over a network or another communications connection (either hardwired, wireless, or a combination of hardwired or wireless) to a machine or remote computer, the remote computer properly views the connection as a computer-readable medium. Thus, any such a connection is properly termed a computer-readable medium.

[0040] As shown in FIG. 1, the controller **134** further includes or is in communication with an input device **230** and an output device **240**. The input device **230** can be generally operable to receive and communicate information or data from a user to the controller **210**. The input device **230** can

include a mouse device, pointer, keyboard, touch screen, microphone, or other like device or combination thereof capable of receiving a user directive. The output device 240 is generally operable to illustrate output data for viewing by the user. An embodiment of the output device 240 can be operable to simultaneously illustrate or fuse static or real-time image data generated by the image acquisition system 115 (e.g., the ICE imaging system 140 or supplemental imaging system 142) with tracking data generated by the tracking system 125. The output device 240 is capable of illustrating two-dimensional, three-dimensional, and/or four-dimensional image data or combinations thereof through shading, coloring, and/or the like. Examples of the output device 240 include a cathode ray monitor, a liquid crystal display (LCD) monitor, a touch-screen monitor, a plasma monitor, or the like or combination thereof.

[0041] Having provided a description of the general construction of the system 100, the following is a description of a method 300 (see FIG. 4) of operation of the system 100 in relation to the imaged subject 110. Although an exemplary embodiment of the method 300 is discussed below, it should be understood that one or more acts or steps comprising the method 300 could be omitted or added. It should also be understood that one or more of the acts can be performed simultaneously or at least substantially simultaneously, and the sequence of the acts can vary. Furthermore, it is embodied that at least several of the following steps or acts can be represented as a series of computer-readable program instructions to be stored in the memory 225 of the controller 210 for execution by the processor 220 or one or more of the image acquisition system 115, the steering system 120, the tracking system 125, or the ablation system 130 or the remote computer station connected thereto via a network (wireless or wired).

[0042] Referring now to FIGS. 1 and 3 and for sake of example, assume that the spatial relation and orientation of the image data acquired by the transducer array 150 of the ICE imaging system 140 is defined by an image coordinate system 320 referenced in predetermined spatial relation and orientation relative to the transducer array 150 (See FIG. 2) at the ICE catheter 105. The image coordinate system 320 generally defines the spatial relation of voxels or pixels of image data relative to one another in the generated image frames or models generated by the ICE imaging system 140 in three-dimensions relative to time (i.e., four-dimensional model). Also, for sake of example, assume the tracking system 125 utilizes a tracking coordinate system 325 to define tracking spatial relation and orientation and movement of the tracking elements 185, 190, 195, and 200 or respective catheters 105 and 184 relative to one another and to time. For example, the tracking coordinate system 325 references the orientation and spatial relation of the tracking element 200 at the ICE catheter 105 relative to one of the receiver or references 185, 190, 195 of the tracking system 125. Also, for sake of example, assume the steering system 130 utilizes a mechanical or steering coordinate system 330 to define maneuvering and orientation of either or both of the catheters 105 and 184 relative to one another. The tracking system 125 may further employ an ultrasonic coordinate system 332 defined by ultrasonic markers 202. Although these coordinate systems 320 and 325 and 330 can be described as Cartesian x-y-z coordinate systems, the type of coordinate systems 320, 325, 330, 332 (e.g., polar, etc.) can vary. In addition, the location and orientation of the coordinate systems 320, 325, 330, 332 can vary.

[0043] The controller 134 via the tracking system 125 is operable to track movement of the ICE catheter 105 in accordance with known mathematical algorithms programmed as program instructions of software for execution by the processor 220 of the controller 134 or by the tracking system 125. An exemplary navigation software is INSTATRAK® as manufactured by the GENERAL ELECTRIC® Corporation, NAVIVISION® as manufactured by SIEMENS®, and BRAINLAB®.

[0044] Referring back to FIG. 1, having described registration of the ICE imaging system 140 with the tracking system 125, the step of registering can further extend to registering the ICE imaging system 140 and tracking system 125 relative to other components of the system 100, including the steering system 120, ablation system 130, or the electrophysiological system(s) (e.g., cardiac monitoring system, respiratory monitoring system, etc.) 132, generally similar to the method of registering described above directed to the ICE imaging system 140 with the tracking system 125.

[0045] Referring to FIGS. 1 through 4, the method 300 includes a step 335 of registering and/or calibrating the image acquisition system 115 (including the ICE imaging system 140), the steering system 120, the tracking system 125, and the ablation system 130 with one another. An embodiment of the step 335 of calibrating and registering includes registering both an ICE imaging reference frame or ICE imaging catheter coordinate system (referred to later as “ice”) 320 relative to the mechanical reference frame or coordinate system 330 of the steering system (referred to later as “mcs”) 130, and additionally registering the previous coordinate systems 320, 330 relative to the electromagnetic microsensor or dynamic reference sensor frame or coordinate system (referred to later as “scs”) 325. The above described registering events or coordinate transformations can be denoted as T(ice->scs) and T(mcs->scs), respectively.

[0046] An embodiment of the registering and/or calibrating step 335 includes the step of rigidly attaching at least one dynamic reference microsensor or tracking element 185, 190, 195 or 200 (See FIG. 2) at the imaged anatomy. An example of this step includes integrating the dynamic reference microsensor at the distal end of a (steerable) catheter (e.g., dynamic reference catheter) 105 (See FIG. 2), and delivering and anchoring the at least one dynamic reference tracking element 185, 190, 195, or 200 (See FIG. 2) at the imaged organ, e.g. the heart. According to another embodiment, the dynamic reference can be independent and separate of the catheter 105.

[0047] The dynamic reference microsensor 185, 190, 195, or 200 establishes a so-called world coordinate system (world reference frame—dynamic reference microsensor) (wcs) 340 (See FIG. 3) that enables the system 100 to compensate for the respiratory and/or cardiac motion of the imaged organ in the display of the acquired generally real-time, 3D ultrasound image data or pre-operative or intra-operative image data acquired by the supplemental imaging system 142. According to another example, the dynamic reference microsensor can be rigidly attached externally of the imaged subject 110, e.g. the patient’s chest such that the system 100 can compensate for motion of the imaged organ via synchronizing image acquisition relative to the respiratory and/or cardiac cycle of the imaged subject 110 tracked by the electrophysiology system 132. The coordinate transformation from the tracking coordinate system 325 to the world coordinate system 340 can be denoted T(scs->wcs).

[0048] The embodiment of the method 300 further includes a step 345 of tracking (e.g., via the tracking system) a position or location of the at least one catheter 105 or 184 relative to the acquired image data. According to one embodiment of the method 300, at least one instrument catheter 105 or 184 is integrated with a plurality of hybrid electromagnetic position microsensors 185, 190, 195, 200 and ultrasonic markers 202. The electromagnetic microsensors 185, 190, 195, 200 and ultrasonic markers 202 can both be located and rigidly mounted on the at least one instrument catheter 105 or 184. A computer image-processing program is operable to detect and mark positions of the ultrasonic markers 202 relative to the generated 3D or 4D ICE image model.

[0049] The controller 134 can be generally operable to align positions of the ultrasonic markers 202 with the tracking coordinate reference frame or coordinate system 325. This registration information may be used for the alignment (calibration) between the tracking reference frame or coordinate system 325 and the ultrasonic marker reference frame or coordinate system 332 relative to the ICE imaging reference frame or coordinate system 320. This information may also be used for detecting the presence of electromagnetic distortion or tracking inaccuracy.

[0050] An embodiment of the method 300 further includes a step 355 of acquiring image data (e.g., scan) of the anatomy of interest of the imaged subject 110. An embodiment of the step of acquiring image data includes generating a series of partial-views 358 of 3D or 4D image data from real-time image data acquired while rotating the ICE catheter 105 around the longitudinal axis 180 (See FIG. 2) that extends through the center of the ICE catheter 105. Image acquisition with the catheter 105 can include more general motion in addition to rotation of the transducer array 150 about axis 180. The motor 155 can provide some range of rotation of the transducer array 150 to generate a 4D model 112 with an enhanced field of view. To image an entire “anatomy of interest” (e.g. an entire chamber of the heart), the imaging catheter 105 can be deflected, advanced, or retracted in addition to rotation of the transducer array 150.

[0051] deflect, advance, or retract the catheter, in addition to simple rotation.

[0052] An embodiment of the image acquisition step 355 includes calculating positions or degree of rotation of the ICE catheter 105 about the longitudinal axis 180. The image acquisition step 355 can further include synchronizing or gating a sequence of image acquisition relative to tracking data acquired by the hybrid tracking system 125 (e.g., tracking a location (e.g., position and/or orientation) relative to the acquired image data). In addition, the image acquisition step 355 can further include synchronizing or gating a sequence of image acquisition relative to measuring cardiac and respiratory signals by the electrophysiology system 132.

[0053] According to one embodiment of the image acquisition step 355, the ablation catheter 184 can be detected or is visible in the acquired image data by the ICE imaging system 140. By “scribbling” the anatomical surface of the anatomy of interest with the at least one instrument catheter 184 relative to acquired tracking data of the location of the catheters 105 or 184, the anatomical boundary may be enhanced to result in a more accurate surface model for image registration and surgical planning.

[0054] Referring to FIGS. 1 through 4, an embodiment of the method 300 further includes a step 360 of generating or reconstructing a full-view 3D or 4D model 362 from the

sequence of generated partial-view 3D or 4D image views 358 relative to the world coordinate frame 340 established by the dynamic reference or tracking element 185, 190, 195, or 200. The 4D ICE imaging system 140, the tracking system 125, the steering system 120, the cardiac and respiratory monitoring system 132, and the 4D ICE imaging catheter 105 are generally involved in acquisition and reconstructing the full view 4D ICE model for the anatomy of the imaged subject 110. The step 360 can include merging the series of partial 3D or 4D image views or views 358 (See FIG. 3) relative to acquired electrophysiology data (e.g., cardiac cycle, respiratory cycle) acquired by the electrophysiology system 132. The step 360 can further include generating a display of the generated 3D or 4D model 362 (See FIG. 3) synchronized relative to electrophysiology signals 364, 366 (see FIG. 1).

[0055] An embodiment of the method 300 can further include a step 370 of acquiring or measuring location data of the ultrasonic markers 202 described above by detecting or identifying the voxels illustrative thereof in the acquired, real-time 3D or 4D ultrasound image data via the ICE imaging system 140. An embodiment of the ultrasonic markers 202 can be configured to identify each of a series of tools or catheters 105 or 184 delivered through an imaged subject 110. An embodiment of the pattern of the tracking elements 185, 190, 195, 200 and/or ultrasonic markers 202 may be uniquely defined for different types of instrument catheters 105 or 184 for identification purposes. Dependent on the uniquely defined tracking elements 185, 190, 195, 200 and/or ultrasonic markers 202, the image acquisition system 115, tracking system 125 or controller 134 or combination thereof can be operable to uniquely identify location and orientation of each of the tools or catheters 105 and 184. An embodiment of the system 100 is operable to extract the location of voxels from the acquired image data correlated to the imaging of the ultrasonic markers 202. In this way, the location of the ultrasonic markers 202 may be tracked with respect to the ICE catheter 105 or ablation catheter 184, or vice versa.

[0056] An embodiment of the system 100 includes a software having image processing programs operable to extract the locations of the ultrasonic markers 202 from the acquired generally real-time, 3D or 4D ultrasound image data (e.g., partial views 358), an electromagnetic distortion detection program using information from the 3D or 4D ultrasound image data, and the tracking program with instructions to execute steps of the hybrid tracking technique described above. According to one embodiment, the system 100 processes acquired 3D or 4D ICE image data to extract voxel positions of the ultrasonic markers 202 relative to the ablation catheter 184. The system 100 also processes the acquired 3D or 4D ultrasound image data to generate a surface model of the imaged anatomy. The system 100 is also operable to calculate the vector 181 generally representative of a central direction of a field of view of the ICE imaging system 140.

[0057] Referring to FIGS. 1 through 5, according to another embodiment, the system 100 includes a graphic user interface (GUI) 371 operable to facilitate image data acquisition and reconstruction of the 3D or 4D ICE model 362, including display of a generally real-time 3D or 4D ICE image model 362 created from the acquired anatomical data; to display detected/identified locations or representations thereof of at least one instrument catheter 105 or 184 relative to the illustrated, real-time 3D or 4D ICE image model 362; to display the vector 181 showing the general central direction of a field of view of the 3D or 4D ICE image model 362; to receive an

input of a selection of a target anatomical site relative to the 3D or 4D ICE image model 362; to display a distance between the tip of the catheter 105 or 184 relative to an anatomical surface of the 3D or 4D ICE image model 362; to display a path of delivery of the catheter 105 or 184 relative to a target anatomical site illustrated at the 3D or 4D ICE image model 362; to display synchronization of image data acquisition to create the 3D or 4D ICE image model 362 relative to the signal of the tracked cardiac or respiratory cycle; and to receive input indicative of a selection between a manual and automatic steering function of the ICE catheter 105.

[0058] According to one embodiment, the system 100 automatically conducts a 4D scan of the anatomy of interest of the imaged subject 110. The controller 134 can calculate or estimate a number of the ICE scans needed to generate the full-view 4D model reconstruction. Based on the field of view (FOV) of the ultrasound transducer array 150 and a tracked starting position of the ICE catheter 105, the system 100 is operable to calculate a set of orientations (e.g. $T(mcs.p1 \rightarrow scs)T(scs \rightarrow wcs)$, $T(mcs.p2 \rightarrow scs)T(scs \rightarrow wcs)$, $T(mcs.pn \rightarrow scs)T(scs \rightarrow wcs)$ where p1, p2, and pn are different catheter orientations) of the ultrasound imaging plane 181 to conduct a full-view 4D scan in the dynamic reference sensor frame 340. The controller 134 can also communicate signals representative of instructions to the steering system 130 that direct automatic maneuvering and rotating of the ICE catheter 105 to a series of imaging positions, e.g., $T(mcs.p1 \rightarrow scs)T(scs \rightarrow wcs)$, $T(mcs.p2 \rightarrow scs)T(scs \rightarrow wcs)$, . . . , and $T(mcs.pn \rightarrow scs)T(scs \rightarrow wcs)$.

[0059] According to another embodiment, the ICE catheter 105 of the ICE imaging system 140 executes the full-view 3D or 4D ICE scan of the imaged anatomy according to received input instructions directed to manually drive the ICE catheter 105 into a series of imaging positions, as well as received input instructions directed to manually activate each event of image acquisition. Referring to FIG. 5, an embodiment of the GUI 371 facilitates the 3D or 4D ICE image acquisition via displaying representations 372 of a history of each position of the ICE catheter 105 or ablation catheter 184 at events of image acquisition, displaying a representation 373 of a current position of the ICE catheter 105, and displaying a representation 374 of a next or future position or location of an image acquisition event by the ICE catheter 105.

[0060] The 3D or 4D ICE image and catheter position acquisitions can be triggered at the preset cardiac and respiratory phase, e.g. t1, t2, . . . , tn. At a given catheter orientation (pi), the system 100 is operable to acquire and transform a series of ultrasound images relative to the world coordinate frame 340, represented by $[T(ice.pi \rightarrow scs)T(scs \rightarrow wcs)].t1$, $[T(ice.pi \rightarrow scs)T(scs \rightarrow wcs)].t2$, . . . , and $[T(mcs.pi \rightarrow scs)T(ice \rightarrow wcs)].tn$.

[0061] Alternatively, the 3D or 4D ICE image acquisition may be conducted at a dynamic or variable rate optimized according to the imaged volume, desired ultrasound image quality, etc. With each acquired ultrasound image volume (or plane or beam), the system 100 records a current cardiac and respiratory phase (ti), and the current catheter or image position (pi).

[0062] Upon the completion of the full-view 3D or 4D scan, the system 100 can reconstruct the generated series of partial views 358 of 3D or 4D ultrasound image data at different catheter orientations and different cardiac cycle time or phase. By transforming or registering the partial views 358 of the acquired 3D or 4D ICE image data relative to the world

coordinate frame 340 (see FIG. 3), the system 100 can calculate the following transformations: $[T(ice.p1 \rightarrow scs)T(scs \rightarrow wcs)].t1$, $[T(ice.p1 \rightarrow scs)T(scs \rightarrow wcs)].t2$, . . . , $[T(ice.p2 \rightarrow scs)T(scs \rightarrow wcs)].t1$, . . . , and $[T(ice.pn \rightarrow scs)T(scs \rightarrow wcs)].tn$.

[0063] To generate the full-view 3D or 4D ICE model 362, an embodiment of the system 100 can group the partial views 358 of 3D or 4D ultrasound image data according the cardiac timing sequence, e.g. $[T(ice.p1 \rightarrow scs)T(scs \rightarrow wcs)].t1$, $[T(ice.p2 \rightarrow scs)T(scs \rightarrow wcs)].t1$, . . . , and $[T(ice.pn \rightarrow scs)T(scs \rightarrow wcs)].t1$ at cardiac phase t1. A number of image processing techniques such as image smoothing, filtering, or averaging can be used to merge the series of partial views 358 to a full-view 3D or 4D ICE model 362 $[T(ice.3D \rightarrow wcs)].t1$ for the t1 cardiac phase or the respiratory phase.

[0064] The controller 134 is operable to repeat the above-described image reconstruction process to create a full-view 3D or 4D ICE model of the anatomic structure, denoted as $[T(ice.3D \rightarrow wcs)].t1$, $[T(ice.3D \rightarrow wcs)].t2$, . . . , and $[T(ice.3D \rightarrow wcs)].tn$, for the rest of the cardiac phases or respiratory phases.

[0065] According to one embodiment of the system 100 and method 300 described herein, the controller 134 can control operation of the steering system 120, the tracking system 125, the ablation system 130, and the electrophysiology monitoring system 132, the ICE imaging system 140 and/or any supplemental imaging system 142. Via the controller 134, the system 100 is operable to process the acquired image data relative to the acquired real-time tracking information from the hybrid tracking system 125 and the cardiac and respiratory cycle information from the electrophysiology system 132. The system 100 is further operable to generate full-view 3D or 4D ICE model of the imaged anatomy, register the acquired partial views 358 of the real-time 3D or 4D ICE image data with the generated full-view 3D or 4D model 362 or other pre-operative or intra-operative real-time non-ICE images 375 (e.g., MRI, CT, PET, etc.), and control the steering system 120 in maneuvering the ICE catheter 105 or ablation catheter 184 relative to the direction of the 3D or 4D ICE imaging plane 181 (or vice versa) (See FIG. 2).

[0066] Referring to FIGS. 1 through 5, the method 300 further includes a step 380 of generating a display 385 of the partial views 358 (See FIG. 3) of the general real-time 3D or 4D ICE image data superimposed or combined relative to one or more of the following: the full-view 4D ICE model 362 (See FIG. 3); one or more of an MRI, CT, PET, or other pre- or intra-operative images 375; representations 372, 373, 374 (See FIG. 5) of the generally real-time tracked positions of the ICE catheter 105 or therapy catheter 184 (See FIG. 1); the cardiac and/or respiratory cycle data 364, 366 (See FIG. 1) synchronized with a time of acquisition of the partial views 358 of the 3D or 4D ICE image data and positions of either catheter 105 or 184; a preoperative surgical plan, including identifying and illustrating the surgical or ablation targets according to preoperative or intraoperative images 375 (e.g., EP information superimposed on the full-view 3D or 4D model 362) (See FIG. 3); selection between manual and automatic catheter steering functions; and generating a display of the one or more locations of the surgical site on the full-view 3D or 4D ICE model 362 during delivery of the surgical treatment.

[0067] A technical effect of the embodiments of the system 100 and method 300 described above is to provide an image reconstruction algorithm that provides a full-view 4D image

model of anatomic structure, fast registration of the acquired partial views **358** of the 3D or 4D ICE image data relative to other preoperative and intraoperative images **375**, capability to create the surgical plan that comprises graphic representations of historical locations, current locations, and future locations of image acquisition **372, 373, 374** (See FIG. 5), and intra-operative guidance to maneuver various devices, for example the diagnostic or therapeutic catheters **105** or **184**. The system **100** and method **300** also provide an integrated solution to create a full-view 3D or 4D ICE model **362** from the series of real-time partial 3D or 4D views **358** and catheter position information.

[0068] Another technical effect of the above-described system **100** and method **300** described above is an ability to register the 3D or 4D ICE imaging system **140** with the tracking system **125** or another type or supplemental imaging system **142** via execution of computer-readable program instructions stored and executable at the controller **134**. As described above, the controller **134** is operable to perform registration of the coordinate systems **320, 325, 330, 332, 340** relative to one another.

[0069] Another technical effect of the system **100** and method **300** described above is an ability to combine image data and models generated by the ICE imaging system **140** with a location of the ICE catheter **105** or ablation catheter **184** being tracked by tracking system **125**, all in combination with imaged data or models generated by another imaging system **142**, with an ability to compensate for deficiencies in the imaged data acquired with the ICE imaging system **140**. Accordingly, the system **100** and method **300** enhance tracking and guidance of the position and orientation of the catheter **105** or transducer array **150** navigating through the imaged subject **110**. The system **100** and method **300** also synchronize tracking and guidance of movement and orientation of the ICE catheter **105** or ablation catheter **184** associated with the ablation system **130**, with each other as well as with electrophysiological signals (e.g., respiratory cycle, cardiac cycle, etc.) as tracked by the electrophysiological system (s) **132**.

[0070] Technical effects of integrating the 4D ICE imaging system **140** with the tracking system **125** includes, inter alia, enhancement of the field of the view of the 4D ICE imaging catheter **105**, acceleration of the 4D ICE registration process with other pre-operative and intra-operative images, and enhancement of pre-operative surgical planning and intra-operative instrument catheter guidance.

[0071] Embodiments of the subject matter described herein include method steps which can be implemented in one embodiment by a program product including machine-executable instructions, such as program code, for example in the form of program modules executed by machines in networked environments. Generally, program modules include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Machine-executable instructions, associated data structures, and program modules represent examples of computer program code for executing steps of the methods disclosed herein. The particular sequence of such computer- or processor-executable instructions or associated data structures represent examples of corresponding acts for implementing the functions described in such steps.

[0072] Embodiments of the subject matter described herein may be practiced in a networked environment using logical connections to one or more remote computers having proces-

sors. Logical connections may include a local area network (LAN) and a wide area network (WAN) that are presented here by way of example and not limitation. Such networking environments are commonplace in office-wide or enterprise-wide computer networks, intranets and the Internet and may use a wide variety of different communication protocols. Those skilled in the art will appreciate that such network computing environments will typically encompass many types of computer system configurations, including personal computers, hand-held devices, multi-processor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, and the like. Embodiments of the subject matter described herein may also be practiced in distributed computing environments where tasks are performed by local and remote processing devices that are linked (either by hardwired links, wireless links, or by a combination of hardwired or wireless links) through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

[0073] This written description uses examples to disclose the subject matter, including the best mode, and also to enable any person skilled in the art to make and use the subject matter described herein. Accordingly, the foregoing description has been presented for purposes of illustration and description, and is not intended to be exhaustive or to limit the subject matter to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the subject matter described herein. The patentable scope of the subject matter is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

We claim:

1. A system operable to display a four-dimensional (4D) model of an imaged anatomy, comprising:

a controller;

an imaging system including an imaging probe in communication with the controller, the imaging probe operable to acquire generally real-time, three-dimensional (3D) image data relative to a direction of image acquisition along an imaging plane;

and

a tracking system in communication with the controller, the tracking system including

at least one tracking element integrated with the imaging probe,

wherein the system is operable to process the real-time, 3D image data acquired by the imaging probe relative to generally real-time tracking information acquired by the tracking system so as to display a 4D model of the imaged anatomy.

2. The system of claim **1**, wherein the imaging probe includes a 4D imaging catheter operable to acquire a series of partial view, generally real-time, 3D ultrasound image data of the imaged anatomy, wherein the imaging system is further operable to generate the 4D model of the imaged anatomy from the acquired 3D ultrasound image data, and wherein the system registers newly acquired real-time, 3D ultrasonic image data so as to display in superposition relative to the generated 4D model.

- 3. The system of claim 2, further comprising:
 an electrophysiology system in communication with the controller, the electrophysiology system operable to acquire a cardiac cycle and a respiratory cycle information in synchronization with a time of acquisition of image data by the 4D imaging system; and
 a display that simultaneously includes illustration of:
 the newly acquired, generally real-time, 3D ultrasound image data superimposed relative to the 4D model,
 the position of the 4D imaging catheter, and
 a cardiac and a respiratory cycle information illustrated at a time of acquisition in synchronization relative to the time of acquisition of the newly acquired, generally real-time, 3D ultrasonic image data.
- 4. The system of claim 3, wherein the tracking system includes a dynamic reference comprising tracking element located at the imaged anatomy.
- 5. The system of claim 4, wherein a spatial relation and an orientation of the generally real-time, 3D ultrasound image data is defined by an image coordinate system referenced in predetermined spatial relation and orientation relative to the 4D imaging catheter, wherein the spatial relation of the at least one tracking element integrated at the 4D imaging catheter relative to the dynamic reference is defined by a tracking coordinate system.
- 6. The system of claim 5, wherein the generally real-time 3D ultrasound image data acquired by the 4D imaging catheter is comprised of a series of partial-view 3D ultrasound image data acquired while rotating the imaging catheter about a longitudinal axis that extends through a center of the 4D imaging catheter.
- 7. The system of claim 5, further comprising an ablation system having an ablation catheter in communication with the controller, the ablation catheter and the 4D imaging catheter both maneuvered by a steering system, wherein maneuvering of the 4D imaging catheter and the ablation catheter by the steering system is defined relative to a mechanical coordinate system registered in relation to the image coordinate system and the tracking coordinate system.
- 8. The system of claim 3, wherein the controller calculates a degree of rotation of a motor to drive movement of the 4D imaging catheter about the longitudinal axis in synchronization relative to time of image acquisition of 3D ultrasound image data, as well as relative to tracking data acquired by the tracking system and acquisition of the cardiac and respiratory cycle information acquired by the electrophysiology system.
- 9. The system of claim 3, wherein the controller merges the acquired, generally real-time partial 3D views of image data according to a sequence of the cardiac or respiratory cycle information to generate the 4D model.
- 10. The system of claim 2, wherein the controller is operable to calculate a number of image acquisition scans per-

- formed by the 4D imaging catheter about the longitudinal axis estimated to generate the 4D model of the imaged anatomy.
- 11. A method of image acquisition of an imaged anatomy, the method comprising the steps of:
 acquiring a series of partial view 3D image data with a 4D imaging probe, defined by an image coordinate system and a time reference;
 tracking a position of the 4D imaging probe relative to the time reference and a tracking coordinate system;
 generating a 4D model of the imaged anatomy by merging the series of partial view 3D image data defined by the position of the 4D imaging probe relative the tracking coordinate system and relative to the time reference; and
 displaying the 4D model.
- 12. The method of claim 11, further comprising the step of: steering movement of the imaging probe and an ablation catheter relative to the tracking data acquired by the tracking system and relative to the 4D model synchronized in generally real-time relative to the time reference.
- 13. The method of claim 12, wherein the step of displaying includes superposing the 4D model with one of a pre-operative or intra-operative image data not acquired with the 4D imaging probe.
- 14. The method of claim 11, wherein the imaging probe includes a 4D imaging catheter operable to acquire a series of generally real-time, partial view, 3D ultrasound image data, wherein the step of displaying includes simultaneously illustrating the acquired generally real-time, 3D ultrasound image data superimposed relative to the 4D model and the position of the 4D imaging catheter.
- 15. The method of claim 14, further comprising the step of registering the acquired series of partial-view 3D ultrasonic image data, the 4D model, and the tracked position of the 4D imaging catheter relative to a dynamic reference sensor located at the imaged anatomy.
- 16. The method of claim 14, wherein the step of acquiring the series of generally real-time, partial-view 3D ultrasound image data includes rotating the 4D imaging catheter about a longitudinal axis that extends through a center of the 4D imaging catheter.
- 17. The method of claim 16, wherein the acquiring step includes calculating a degree of rotation for a motor to drive movement of the 4D imaging catheter about the longitudinal axis.
- 18. The method of claim 17, the method further comprising the step of calculating a number of image acquisition scans performed while rotating the 4D imaging catheter about the longitudinal axis so as to generate the 4D model of the imaged anatomy.

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