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(54) **COMPENSATION OF MOTION IN A MOVING ORGAN USING AN INTERNAL POSITION REFERENCE SENSOR**

BEWEGUNGSKOMPENSATION IN EINEM BEWEGTEN ORGAN MITHILFE EINES INTERNEN POSITIONSREFERENZSENSORS

COMPENSATION DE MOUVEMENT DANS UN ORGANE EN MOUVEMENT À L’AIDE D’UN CAPTEUR DE RÉFÉRENCE DE POSITION INTERNE

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of United States non-provisional application no. 12/650,932, filed 31 December 2009.

BACKGROUND OF THE INVENTION

a. Field of the Invention

[0002] The instant invention relates generally to medical imaging and navigation and more particularly to a system for compensation of motion in a moving organ using an internal reference sensor.

b. Background Art

[0003] US 2001/0031919 A1 relates to medical diagnostic and surgery systems and methods for threedimensional medical images and navigation, wherein the location and orientation of reference points are used to align the coordinate system of three-dimensional images with the coordinate system of a surgical tool.

[0004] Systems and methods for obtaining and displaying two-dimensional and three-dimensional images are known in the art, for example, as seen by reference to U.S. Patent No. 7,386,339 entitled "MEDICAL IMAGING AND NAVIGATION SYSTEM" to Strommer et al. Strommer et al. disclose a medical imaging and navigation system that has a capability for constructing and displaying three-dimensional images of moving organs, synchronously with the actual movement of these organs and synchronously with an invasive surgical tool, such as a catheter. The system includes a medical positioning system (MPS) for ascertaining the location and orientation of multiple MPS sensors, a two-dimensional imaging system having an image detector for obtaining two-dimensional images of the moving organ and a superimposing processor. The MPS system includes a sensor mounted on the surgical tool and a sensor attached to the body of the patient for a positional reference ("Patient Reference Sensor", or PRS). The system acquires a plurality of two-dimensional images (and respective location/orientation data and organ timing data, *e.g.,* ECG signal) and records the sets of positions and orientation of all sensors. The system reconstructs a three-dimensional image from the combination of 2-D images and sensor data. When a physician inserts the surgical tool into the body of the patient, the system also detects the location and orientation of the MPS sensor that is mounted on the tool. The superimposing processor super-imposes a representation of the surgical tool on the currently displayed two-dimensional and three-dimensional images, which may be played back in accordance with real-time ECG data.

[0005] The PRS is provided so that the sensors associated with the surgical tools remain in a co-registered coordinate system to the X-ray imager at all times. The system detects movements of the patient using the PRS (e.g., patient body movements and respiration induced movements). The movements (as sensed by the PRS) are used to shift the coordinate system relative to the coordinate system in which the two-dimensional images were acquired. Therefore, in Strommer et al., the projection of real-time location information on previously recorded 2-D or 3-D images is both ECG synchronized and respiration compensated. However, in some situations, there is little or no correlation between the external motion compensation signals being used *(i.e.,* the ECG signal and the PRS readings) and the internal motion of a region of interest. For example only, in the case of atrial fibrillation, the ECG signal may not effectively serve as a predictor or correlation input for the motion of the atria.

[0006] There is therefore a need for a system for compensation for the motion of a moving organ that minimizes or eliminates one or more of the problems set forth above.

BRIEF SUMMARY OF THE INVENTION

[0007] One advantage of the methods and apparatus described, depicted and claimed herein relates to the ability to accurately compensate for the motion of a moving region of interest in a patient's body *(e.g.,* a moving organ such as the heart), such as may be needed when superimposing a representation of a catheter tip on an image acquired at a time different than a time when the position of the catheter tip was acquired.

[0008] This disclosure is directed to a method and apparatus for displaying a moving region of interest (ROI) located within a body. One example of a method that is not part of the invention as claimed involves tracking the motion of the ROI over time and generating a motion compensation function. Next, determining a position and orientation (P&O) of an invasive medical device, such as, for example, a catheter. The next step involves correcting the determined P&O using the motion compensation function to thereby compensate for the motion of the ROI between a first time at which an image of the ROI was acquired and a second time (different than the first time) at which the P&O was determined. The next step involves superimposing a representation of the medical device onto the image in accordance with the corrected P&O.

[0009] In a preferred example of a method that is not part of the invention as claimed, tracking the motion of the region of interest involves associating a first localization sensor with the moving region of interest such that the sensor moves with the region of interest. Through this step, the localization system (e.g., a medical position system (MPS) in one embodiment) can acquire a first series of P&O readings, which readings define not only the motion of the sensor but also the motion of the region of interest. The method further involves acquiring a second series of P&O readings from a second localization sensor associated with the medical device. When the correlation between the first and second series of P&O readings exceeds a threshold, the system is enabled to perform motion compensation since the same motion of the region of interest can be assumed to influence the motion of the medical device. In one embodiment, the motion compensation function may comprise a time-varying vector displacement. Thus, for a given spatial position, for a given time, the function defines a vector displacement (and potentially rotation) by which the P&O of the medical device will need to be corrected so as to match its corresponding value at a time when the image was taken.

[0010] In still further examples of methods that are not part of the invention as claimed, a plurality of localization sensors are deployed, where the compensation function is a weighted summation of the individual displacement vectors respectively attributed to the movements detected by the plurality of localization sensors. A weighting factor associated with each input may correspond to the correlation level observed for that input relative to the motion of the medical device.

[0011] These and other benefits, features, and capabilities are provided according to the structures, systems, and methods depicted, described and claimed herein. The invention is defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

Figure 1 is a schematic and block diagram view of a system incorporating an embodiment for compensation of motion in a moving organ using an internal position reference sensor.

Figure 2 is a diagrammatic view of the system of Figure 1, in a fluoroscopy-based imaging embodiment.

Figures 3A-3C are plan views showing the motion of a moving organ and the corresponding motion of an internal position reference sensor.

Figure 4 is a schematic and block diagram view of one exemplary embodiment of a medical positioning system (MPS) as shown in block form in Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Referring now to the drawings wherein like reference numerals are used to identify identical components in the various views, Figure 1 is a diagrammatic view of a system 10 in which aspects of the invention may be embodied. It should be understood that while embodiments of the invention will be described in connection with a magnetic field-based positioning system deployed in connection with a fluoroscopy-based imaging system, such an embodiment is exemplary only and not limiting in nature.

[0014] Before proceeding to a detailed description keyed to the drawings, a general overview concerning motion compensation will be set forth. As a starting point, there is a desire to reduce a patient's exposure to x-rays, such as may be used in fluoroscopy. It is therefore desirable to be able to use, and reuse to the greatest extent possible, an image (or a sequence of images defining a cine loop) of a region of interest acquired in the past. This will reduce the need for continuous exposure or subsequent additional exposures for the purpose of acquiring updated imaging. Navigation of a medical instrument using the previously-acquired image or cine-loop is made possible by ascertaining the position and orientation (P&O) of the instrument and then superimposing a projection of that instrument's P&O onto the image. A problem arises over time, however, because both the patient as well as his or her internal organs can move (e.g., beating heart), changing positions relative to the time at which the image was taken. Absent compensation for these varying types of motion, the P&O readings reflecting the real time position of the medical instrument would be inaccurately represented on the image *(i.e.,* the representation could be superimposed in the "wrong" location on the image). U.S. Patent No. 7,386,339 referred to in the Background discloses motion compensation for patient movements and respiration-induced movements by providing a patient reference sensor (PRS). By interpreting P&O readings that track the motion of a catheter relative to the P&O readings of the PRS, a certain type of motion compensation can be achieved. In other words, the movements detected by the PRS shift the coordinate system relative to the coordinate system in which the two dimensional images were acquired. However, as also described in the Background, the PRS P&O readings may have little or no correlation to the movements of an internal moving organ.

[0015] With continued reference to Figure 1, the system 10 as depicted includes a main control 12 having various input/output mechanisms 14, a main display 16, an image database 18, a localization system such as a medical positioning system (MPS) system 20, an ECG monitor 22, a plurality of MPS position reference sensors designated 24_1, 24_2 and 24_3, and an MPS-enabled medical device 26 (which itself includes a position reference sensor). The MPS-enabled device 26 may be any interventional device or delivery tool. For example, the device 26 may include guidewires, stylets, cannulation catheters, EP catheters and the like.

[0016] The main control 12, in a computer-implemented embodiment, is programmed to perform a plurality of functions, including those shown in block form in Figure 1: a motion compensation function 28, a position and orientation (P&O) correction function 30 and an image super-imposing function 32. The main control 12 is configured generally to generate data to be displayed (e.g., single image or sequence of images) corresponding to a moving region of interest (ROI) located within the body of a patient. The control 12 is specifically configured (by way of function blocks 28, 30 and 32) to accurately superimpose a representation of a tracked, MPS-enabled medical device 26 on a previously acquired image (or sequence) for display on the display 16, compensated for the motion of a moving region of interest. The input/output mechanisms 14 may comprise conventional apparatus for interfacing with a computer-based control, for example, a keyboard, a mouse, a tablet or the like. The display 16 may also comprise conventional apparatus.

[0017] The image database 18 is configured to store image information of relating to the patient's body, including the moving region of interest, and which may comprise (1) one or more two-dimensional still images acquired at respective, individual times in the past; (2) a plurality of related two-dimensional images obtained in real-time from an image acquisition device (e.g., fluoroscopic images from an x-ray imaging apparatus, such as that shown in exemplary fashion in Figure 2) wherein the image database acts as a buffer (live fluoroscopy); and/or (3) a sequence of related two-dimensional images defining a cine-loop (CL) wherein each image in the sequence has at least an ECG timing parameter associated therewith adequate to allow playback of the sequence in accordance with acquired real-time ECG signals obtained from the ECG monitor 22. It should be understood that the two-dimensional images may be acquired through any imaging modality, now known or hereafter developed, for example X-ray, ultra-sound, computerized tomography, nuclear magnetic resonance or the like.

[0018] The MPS system 20 is configured to acquire positioning (localization) data (*i.e.,* position and orientation-P&O) of one or more MPS sensors. The P&O may be expressed as a position *(i.e.,* a coordinate in three axes X, Y and Z) and orientation *(i.e.,* an azimuth and elevation) of the magnetic field sensor in the magnetic field relative to a magnetic field generator(s)/transmitter(s).

[0019] The internal MPS position reference sensor 24_1 is associated with a moving region of interest (ROI) in the body, which may be a moving organ, and more specifically may be the heart and/or chambers or portions thereof (e.g., atria). The internal position reference sensor 24_1 is associated with the ROI in such a way that it will move together with the moving ROI, and thus fairly indicate the motion of the region of interest. Generally, associating the sensor 24_1 with the region of interest (ROI) may be done in any one or more ways: (1) placing the sensor 24_1, or an interventional device like a catheter carrying the sensor 24_1, in an anatomical area where it is held by the anatomy itself, for example, a catheter that has been maneuvered in a tubular organ like the coronary sinus; (2) fixing the sensor 24_1, or an interventional device like a catheter carrying the sensor, to the anatomy in the region of interest using a fixation mechanism, active or passive, for the duration of the procedure; (3) holding the sensor 24_1, or an interventional device like a catheter carrying the sensor, in steady contact with the anatomy in the region of interest; and (4) placing sensor 24_1 (or interventional device carrying the sensor) in a non-MPS-enabled device that is in turn affixed to the anatomy in the region of interest. As to approach (2), where the region of interest is the heart, an example may include placing the sensor 24_1 epicardially in the surface of the heart. As to approach (3), an example may include associating the sensor 24_1 with a catheter that is maneuvered into steady contact with the heart interior. As to approach (4), an example may include placing an MPS-enabled guidewire (having the sensor 24_1) in the lumen of a pacing lead that is in turn affixed to the tissue of a heart chamber.

[0020] One or more additional, optional internal position sensors may be provided, for example, as shown by sensor 24_2. The additional one or more sensors 24_2 may be associated with either or both of the (1) the moving region of interest; or (2) the medical device 26. The additional sensors 24_2, are configured to provide additional data points (P&O readings) with respect to either the moving region of interest or medical device, as the case may be, thereby providing addition information concerning their respective motions over time.

[0021] The patient reference sensor (PRS) 24_3 is configured to provide a stable, positional reference of the patient's body so as to allow motion compensation for gross patient body movements and/or respiration-induced movements, as described above. The PRS 24_3 may be attached to the patient's manubrium sternum, a stable place on the chest, or other location that is relatively positionally stable.

[0022] In a magnetic field-based embodiment, the P&O may be based on capturing and processing the signals received from the magnetic field sensor while in the presence of a controlled low-strength AC magnetic field. Accordingly, the internal sensors may each comprise one or more magnetic field detection coil(s), and it should be understood that variations as to the number of coils, their geometries, spatial relationships, the existence or absence of cores and the like are possible. From an electromagnetic perspective - all sensors are created equal: voltage is induced on a coil residing in a changing magnetic field, as contemplated here. The sensors 24 are thus configured to detect one or more characteristics of the magnetic field(s) in which they are disposed and generate an indicative signal, which is further processed to obtain the P&O thereof. For one example of a sensor, see U.S. Patent No. 7,197,354 entitled SYSTEM FOR DETERMINING THE POSITION AND ORIENTATION OF A CATHETER issued to Sobe.

[0023] The electro-cardiogram (ECG) monitor 22 is configured to continuously detect an electrical timing signal of the heart organ through the use of a plurality of ECG electrodes (not shown), which may be externally-affixed to the outside of a patient's body. The timing signal generally corresponds to the particular phase of the cardiac cycle, among other things. The ECG signal may be used by the main control 12 for ECG synchronized playback of a previously captured sequences of images (cine loop). The ECG monitor 22 and ECG-electrodes may comprise conventional components.

[0024] Figure 2 is a diagrammatic view of an embodiment which includes a self-contained imaging capability, along with motion compensation. More specifically, the system 10 is shown as being incorporated into an fluoroscopic imaging system 34, which may include commercially available fluoroscopic imaging components *(i.e.,* "Catheter Lab"). The MPS system 20, in a magnetic field-based embodiment, includes a magnetic transmitter assembly (MTA) 36 and a magnetic processing core 38 for determining position and orientation (P&O) readings. The MTA 36 is configured to generate the magnetic field(s) in and around the patient's chest cavity, in a predefined three-dimensional space designated a motion box 40 in Figure 2. The MPS sensors 24; (where i=1, 2, ..., n) as described above are configured to sense one or more characteristics of the magnetic field(s) and when the sensors are in the motion box 40, each generate a respective signal that is provided to the magnetic processing core 38. The processing core 38 is responsive to these detected signals and is configured to calculate respective three-dimensional position and orientation (P&O) readings for each MPS sensor 24_i in the motion box 40. Thus, the MPS system 20 enables real-time tracking of each sensor 24_i in three-dimensional space. In the illustrated embodiment, the positional relationship between the image coordinate system and the MPS coordinate system may be calculated based on a known optical-magnetic calibration of the system (e.g., established during setup), since the positioning system and imaging system may be considered fixed relative to each other in such an embodiment. However, for other embodiments using other imaging modalities, including embodiments where the image data is imported from an external source, a registration step may need to be performed initially. One exemplary embodiment of an MPS system 20 will be described in greater detail below in connection with Figure 4.

[0025] The main control 12, as configured by way of super-imposing function block 32, includes the capability of producing (and superimposing) a projection of the real-time location information (P&O) of a medical device on previously recorded x-ray images or in the case of cine-loops (CL), onto each image in the sequence. In addition, with the availability of the ECG signal and a PRS position signal, the main control 12 can replay a cine loop in an ECG synchronized and respiration-induced motion compensated manner. In a specific case of ECG synchronizing playback of a cine loop of the heart, the sequence is replayed in concordance with a real-time ECG signal (cardiac phase) of the patient. The main control 12 may also be configured to include a respiration compensation algorithm configured to learn the motion induced by the patient's respiration, based on P&O readings from the PRS. The main control 12 then calculates a respiration correction factor to apply to P&O measurements that are to be projected onto a sequence of cine-loop images. The PRS position signal allows for motion compensation for any patient's body movements, as the medical device's position *(i.e.,* P&O measurement) may preferably be taken relative to the P&O measurements from the PRS.

[0026] However, as noted above, there are situations where there is very little or no correlation between the internal motion of the region of interest and the external signals *(i.e.,* ECG signals and PRS signal) conventionally used for motion compensation. For example, in the case of atrial fibrillation, the ECG signal cannot serve as a predictor or correlation input for the motion of the atria.

[0027] Accordingly, one or more of the internal *(i.e.,* inside the body) position reference sensors (e.g., sensor 24_1) are located in the vicinity of the region of interest, or are otherwise associated with the region of interest (e.g., affixed) such that the internal MPS reference sensor moves together with the region of interest over time. As the region of interest moves, the MPS system 20 acquire a series of location *(i.e.,* position and orientation) readings from the sensor. The motion compensation function block 28 (Figure 1) determines the motion of the sensor (e.g., sensor 24_1) according to acquired series of P&O readings. The block 28 further determines the motion of the region of interest based on the motion of the sensor, which may have a direct correspondence.

[0028] Figures 3A-3C are schematic diagram views of a region of interest, generally referenced 100, at three different activity states (states of movement), designated 100_1, 100_2 and 100_3. In Figures 3A-3C, an internal MPS position reference sensor 24_1 is placed in the vicinity of the region of interest 100 (*e.g.,* at the orifice of the superior vena cava). In Figures 3A-3C, the region of interest 100 is depicted as a circle for simplicity.

[0029] In Figure 3A, the region of interest 100_1 is at a first activity state. The MPS system 20 detects a first position of the sensor 24_1 at the first activity state. This first position (P&O) is represented as a vector 104_1 relative to an arbitrary origin 102. The arbitrary origin 102 may be, for example, the location of the MTA 36 in the MPS system 102, a location on the motion box 40 or any other known location.

[0030] In Figure 3B, the region of interest 100_2 is at a second activity state, which as shown is contracted relative to the first activity state. The MPS system 20 detects a second position *(i.e.,* position and orientation) 104_2 of the sensor 24_1. Note that the sensor 24_1 moves with the region of interest as it moves.

[0031] In Figure 3C, the region of interest 100_3 is at a third activity state, which as shown is expanded relative to the first activity state. The MPS system 20 detects a third position (P&O) 104_3 of the sensor 24_1.

[0032] The series of detected first, second and third positions 104_1, 104_2 and 104_3 of the sensor 24_1 acquired by the MPS system 20 over time defines not only the motion of the sensor itself but also defines the motion of the region of interest. The motion compensation function block 28 may determine the motion of the region of interest 100 directly in accordance with the motion of the sensor 24_1. This same motion can be assumed to influence the motion of the medical device 26, provided predefined criteria are met.

[0033] The criteria include verifying that an adequate level of correlation exists between the motion of the medical device 26 and the motion of the region of interest 100. One approach to verifying correlation is to compare the respective motions relative to a common time-line. For example, over some time interval, the system 10 may track the motion of the device 26, as indicated by the detected P&O's 106_1, 106_2 and 106_3 shown in Figures 3A-3C, in addition to tracking the motion of the internal position sensor 24_1. The system 10 compares the two motions and when the level of correlation exceeds a predetermined threshold, the correlation level is deemed adequate (predetermined criteria satisfied). In this regard, overall, the kind of correlation that is deemed adequate will vary; however, the ultimate goal is to reduce the amount of error (e.g., as expressed in millimeters). For this purpose (with the end goal in mind), correlation approaches may be determined empirically (e.g., bench testing). It should be further understood that the effect of the correlation threshold on the received error will also depend on the types of motions involved. Accordingly, motion compensation/correction will be performed.

[0034] The system 10 may additionally verify that a minimum level of correlation exists between the motion of the device 26 and the other compensation signals described above *(i.e.,* the ECG signal(s) as well as the PRS signal). If there is only poor correlation between the motion of the device 26 and these compensation signals then compensation will not be performed at all. When motion correlation has been verified, the assumption that the motion of the region of interest will influence the motion of the device 26 can be relied on. After correlation has been verified, the MPS system 20 is then enabled to provide motion compensation.

[0035] *Generate Motion Compensation Function.* The MPS system 20 will generate data adequate to track the motion of a moving region of interest over time (e.g., via the internal sensor 24_1) and allow the compensation function block 28 to generate a time varying motion compensation function. Just as the detected movements of the PRS allows shifting of the coordinate system (as described in US Patent No. 7,386,339), the motion of the internal sensor (e.g., sensor 24_1) provides data adequate to implement a similar compensation function. For example in Figures 3A-3C, the position of the medical device 26 moves as the region of interest contracts (Figure 3B) and expands (Figure 3C). The relative displacement of the medical device 26 relative to the sensor 24_1 (and thus also to the region of interest 100) is shown as vectors 108_1, 108_2 and 108_3. Thus, one indication of the medical device's position is that taken relative to the sensor 24_1.

[0036] The compensation function produced based on the motion of the sensor 24_1 is a time-varying spatial function which accounts for the motion of the region of interest between a first time (at which the image was acquired) and a second time (at which the P&O of the device was measured). Assume that a two-dimensional image was acquired at a time when the region interest was in the first activity state 100_1 (*i.e.,* Figure 3A). In this instance, a measured P&O of the device 26 would not need any motion compensation, at least not any to compensate for the motion of the region of interest. However, when the region of interest moves to the second activity state 100_2, motion compensation is required to accurately project the measured P&O onto an image acquired at a time when the region of interest was at the first activity state (in this example). The compensation function evaluated at the time of the second activity state is a displacement vector that compensates for the motion of the region of interest between the given time (*i.e.,* time of the measured device P&O-the time of the second activity state) and the time of the image (*i.e.,* the time the image was acquired-the time of the first activity state). Likewise, the compensation function evaluated at the time of the third activity state 100_3 is a displacement vector to compensate for motion between the given time (*i.e.,* the time of the measured device P&O--the time of the third activity state) and the time of the image *(i.e.,* the time the image was acquired-the time of the first activity state).

[0037] In sum, for a given spatial position (measured P&O) of the device 26 for a given time, the compensation function will constitute a vector displacement (and potentially rotation) by which the measured P&O of the MPS-enabled device 26 has to be corrected to match a given time in the past *(i.e.,* at which the image was acquired). The displacement vector may be weighted in accordance with a weighting factor, which in turn may be calculated based on the calculated correlation level described above. Motion compensation approaches may be used as disclosed in U.S. 7,386,339 referred to above as well U.S. 7,343,195 (Application No. 09/949,160 filed September 7, 2001) entitled "METHOD AND APPARATUS FOR REAL TIME QUANTITATIVE THREE-DIMENSIONAL IMAGE RECONSTRUCTION OF A MOVING ORGAN AND INTRA-BODY NAVIGATION" to Strommer et al.

[0038] *P&O Correction.* The P&O correction block 30 is configured to correct the P&O reading obtained at the given time using the compensation function. P&O correction function 30 adjusts the measured P&O of the medical device in accordance with the calculated displacement vector (and potentially rotation) described above.

[0039] *Projection.* Finally, a projection of the corrected P&O (three-dimensional) is made onto the two-dimensional image, with a representation of the medical device being superimposed on the image (e.g., may be cross-hairs representing the tip of a catheter or other representation). The resulting image may then be displayed on the display 16. One approach for projecting the corrected P&O onto a 2-D image is a direct consequence of the association of the MPS 3D coordinate system with the X-ray 2D coordinate system, as seen by reference to

U.S. Pat. Pub. 2006/0058647, Application No. 11/233,420 entitled METHOD AND SYSTEM FOR DELIVERING A MEDICAL DEVICE TO A SELECTED POSITION WITHIN A LUMEN, to Strommer et al. Once the coordinate systems are co-registered (a process that may be referred to a magnetic-optical calibration, which may be performed at the installation of the MPS system 20, as noted above), the coordinates of any 3D object (e.g., sensor, landmark or other artifacts) which needs to be displayed on a 2D image are multiplied by a coordinate transformation matrix that computes the corresponding 2D coordinates on the displayed image. This approach is exemplary only and not limiting in nature.

[0040] *Multiple Inputs, Internal Sensors.* In embodiments where the external PRS and/or additional internal position reference sensor inputs are used for motion compensation, the compensation function block 28 implements a composite motion compensation function that is formed by the summation of individual motion compensation contributions, *i.e.,* the individual displacement vectors and (potentially rotations) attributable to each motion/sensor input (provided that correlation requirements are met, as described above). For example, additional sensors may be located on the medical device 26 or other medical devices and/or tools, for example, another MPS sensor disposed on a catheter, guide-wire, etc. The P&O readings from additional internal sensors may reveal other movements or other aspects to the movements of the region of interest and/or the medical device.

[0041] The composite compensation function, for example, may include a number of terms where each term corresponds to an input, *i.e.,* one term being provided with respect to the PRS, another term being provided with respect to the internal sensor 24_1, still another term being provided with respect to an additional sensor 24_2, and so on. In another embodiment, the inputs from the PRS, the ECG signals and the one or more internal MPS reference sensors may be used in combination to provide for robust motion compensation. In these embodiments, the individual inputs are weighted by a respective weighting factor to form a composite motion compensation function. The respective level of correlation is a principal factor according to which each weighting factor is determined. The weighted function can be depicted as weighted vector summation of the compensation function vectors.

[0042] Figure 4 is a schematic and block diagram of one exemplary embodiment of MPS system 20, designated as an MPS system 108, as also seen by reference to U.S. Patent No. 7,386,339, referred to above, and portions of which are reproduced below. It should be understood that variations are possible, for example, as also seen by reference to U.S. Patent No. 6,233,476 entitled MEDICAL POSITIONING SYSTEM. This description is exemplary only and not limiting in nature.

[0043] MPS system 110 includes a location and orientation processor 150, a transmitter interface 152, a plurality of look-up table units 154_1, 154_2 and 154_3, a plurality of digital to analog converters (DAC) 156_1, 156_2 and 156_3, an amplifier 158, a transmitter 160, a plurality of MPS sensors 162_1, 162_2, 162_3 and 162_N, a plurality of analog to digital converters (ADC) 164_1, 164_2, 164_3 and 164_N and a sensor interface 166.

[0044] Transmitter interface 152 is connected to location and orientation processor 150 and to look-up table units 154_1, 154_2 and 154_3. DAC units 156_1, 156_2 and 156_3 are connected to a respective one of look-up table units 154_1, 154_2 and 154_3 and to amplifier 158. Amplifier 158 is further connected to transmitter 160. Transmitter 160 is also marked TX. MPS sensors 162_1, 162_2, 162_3 and 162_N are further marked RX_1, RX_2, RX_3 and RX_N, respectively. Analog to digital converters (ADC) 164_1, 164_2, 164_3 and 164_N are respectively connected to sensors 162_1, 162_2, 162_3 and 162_N and to sensor interface 166. Sensor interface 166 is further connected to location and orientation processor 150.

[0045] Each of look-up table units 154_1, 154_2 and 154_3 produces a cyclic sequence of numbers and provides it to the respective DAC unit 156_1, 156_2 and 156_3, which in turn translates it to a respective analog signal. Each of the analog signals is respective of a different spatial axis. In the present example, look-up table 154_1 and DAC unit 156_1 produce a signal for the X axis, look-up table 154_2 and DAC unit 156_2 produce a signal for the Y axis and look-up table 154_3 and DAC unit 156_3 produce a signal for the Z axis.

[0046] DAC units 156_1, 156_2 and 156_3 provide their respective analog signals to amplifier 158, which amplifies and provides the amplified signals to transmitter 160. Transmitter 160 provides a multiple axis electromagnetic field, which can be detected by MPS sensors 162_1, 162_2, 162_3 and 162_N. Each of MPS sensors 162_1, 162_2, 162_3 and 162_N detects an electromagnetic field, produces a respective electrical analog signal and provides it to the respective ADC unit 164_1, 164_2, 164_3 and 164_N connected thereto. Each of the ADC units 164_1, 164_2, 164_3 and 164_N digitizes the analog signal fed thereto, converts it to a sequence of numbers and provides it to sensor interface 166, which in turn provides it to location and orientation processor 150. Location and orientation processor 150 analyzes the received sequences of numbers, thereby determining the location and orientation of each of the MPS sensors 162_1, 162_2, 162_3 and 162_N. Location and orientation processor 150 further determines distortion events and updates look-up tables 154_1, 154_2 and 154_3, accordingly.

[0047] It should be understood that variations and other uses other than for the described imaging examples are possible. High-fidelity device positioning as provided through the motion compensation embodiments described herein may be used for alternate purposes such as for placing accurate landmarks *(i.e.,* to serve as navigation references of other devices), for co-registration with other modalities (e.g., Ensite NavX, computed tomography (CT)), as well as for determining when or distinguishing between a "real" motion (*i.e.,* like the actual moving of a catheter by the physician) has occurred versus what seems to be motion but is actually an external event, such as patient motion.

[0048] It should be understood that the system 10, particularly main control 12, as described above may include conventional processing apparatus known in the art, capable of executing pre-programmed instructions stored in an associated memory, all performing in accordance with the functionality described herein. It is contemplated that the methods described herein, will be programmed in a preferred example, with the resulting software being stored in an associated memory and where so described, may also constitute the means for performing such methods. Implementation in software, in view of the foregoing enabling description, would require no more than routine application of programming skills by one of ordinary skill in the art. Such a system may further be of the type having both ROM, RAM, a combination of non-volatile and volatile (modifiable) memory so that the software can be stored and yet allow storage and processing of dynamically produced data and/or signals.

[0049] The invention is defined by the appended claims.

Claims

1. An apparatus for displaying a moving region of interest (ROI) located within a body, comprising:

   means for generating a time-varying spatial motion compensation function (28) comprising a vector displacement based on the motion of the region of interest (ROI) for taking account for the motion of the region of interest (ROI);
   a positioning system (20) configured to determine a position of a medical device (26), , said positioning system (20) further including a first localization sensor (24_1) configured to be placed in the vicinity of the moving region of interest such that the sensor moves with the region of interest (ROI), wherein said positioning system (20) is further configured to track both motion of the first localization sensor (24_1) and motion of the medical device (26);
   means for verifying a level of correlation between the motion of the medical device (26) and motion of the first localization sensor (24_1)
   means for correcting the determined position of the medical device (26) in case that a correlation between the tracked motions of the first localization sensor (241) and the medical device (26) exceeds a threshold by using the motion compensation function (28) to form a corrected position to thereby compensate for the motion of the region of interest (ROI) between a first time at which the region of interest is acquired according to an imaging modality and a second time at which the position of the medical device (26) was determined, such that the corrected position of the medical device (26) matches a corresponding position of the medical device at the first time, wherein the first time is prior to the second time, and
   means for superimposing a representation of the medical device on the acquired region of interest in accordance with the corrected position.

2. The apparatus of claim 1 wherein the imaging modality comprises fluoroscopy producing a fluoroscopic image comprising a two-dimensional image and said corrected position comprises a three-dimensional coordinate, said apparatus further comprising means for projecting said corrected position onto said two-dimensional image wherein said representation of the medical device is based on said projection.

3. The apparatus of claim 1 further including means (12) for correcting a subject position using the motion compensation function to thereby compensate for the motion of the region of interest (ROI) between a current time at which the subject position is being corrected and an earlier time, wherein the subject position is one of a target position associated with a virtual landmark associated with a selected location in the region of interest (ROI) and a co-registration position associated with a common location in co-registered imaging modalities.

4. The apparatus of claim 1 wherein said first localization sensor (24_1) comprises a magnetic field sensor configured to provide a position and orientation, and wherein said compensation function further comprises a displacement rotation.

5. The apparatus of claim 1 wherein said first localization sensor (24_1) is configured to be attached externally to the body.

6. The apparatus of claim 1 wherein said positioning system (20) is configured to track said motion of said ROI by acquiring a first series of position readings from said first localization sensor (24_1) over a time interval, associating a second localization sensor (24_2) with the medical device, acquiring a second series of position readings from the second localization sensor over said time interval; determining a correlation factor between the respective motions of the first and second localization sensors, and determining said compensation function based on at least the correlation factor.

7. The apparatus of claim 1 wherein the region of interest comprises an organ, said apparatus further

including means for obtaining a plurality of images of the region of interest to thereby form a sequence of images, wherein each image has associated therewith a respective timing parameter indicative of an activity state of the organ.

8. The apparatus of claim 7 wherein said organ comprises a heart organ, and wherein the respective timing parameters correspond to the electrical activity of the heart.

9. The apparatus of claim 8 further including means for displaying the series of images in accordance with the respectively associated timing parameter at which the images were obtained synchronized with a real-time electro-cardiogram of the heart, and wherein said positioning system, said correcting means, and said superimposing means are respectively configured to repeatedly determine the position of the medical device, correct the position, and superimpose a respective representation of the medical device simultaneously with the displaying of the series of images.

Patentansprüche

1. Vorrichtung zur Anzeige einer sich bewegenden Region (ROI), die von Interesse ist und sich innerhalb eines Körpers befindet, mit:

   einem Mittel zum Erzeugen einer Kompensationsfunktion (28) für zeitveränderliche räumliche Bewegung, die eine Vektorversetzung aufweist, basierend auf der Bewegung der Region (ROI), die von Interesse ist, um die Bewegung der Region (ROI), die von Interesse ist, zu berücksichtigen;
   einem Positionsbestimmungssystem (20), das konfiguriert ist zum Bestimmen einer Position einer medizinischen Vorrichtung (26), wobei das Positionsbestimmungssystem (20) ferner einen ersten Lokalisierungssensor (24_1) aufweist, der konfiguriert ist zur Platzierung in der Umgebung der sich bewegenden Region, die von Interesse ist, derart, dass sich der Sensor mit der Region, die von Interesse ist (ROI), bewegt, wobei das Positionsbestimmungssystem (20) ferner konfiguriert ist zur Verfolgung der Bewegung des ersten Lokalisierungssensors (24_1) und der Bewegung der medizinischen Vorrichtung (26);
   einem Mittel zum Verifizieren eines Korrelationsgrads zwischen der Bewegung der medizinischen Vorrichtung (26) und der Bewegung des ersten Lokalisierungssensors (24_1);
   einem Mittel zum Korrigieren der bestimmten Position der medizinischen Vorrichtung (26) in einem Fall, bei dem eine Korrelation zwischen den verfolgten Bewegungen des ersten Lokalisierungssensors (24_1) und der medizinischen Vorrichtung (26) einen Schwellenwert überschreitet, indem die Bewegungskompensationsfunktion (28) verwendet wird, um eine korrigierte Position zu bilden, um dadurch die Bewegung der Region, die von Interesse ist (ROI), zwischen einem ersten Zeitpunkt, bei dem die Region, die von Interesse ist, gemäß einer Bildgebungsmodalität erfasst wird, und einem zweiten Zeitpunkt, bei dem die Position der medizinischen Vorrichtung (26) bestimmt worden ist, derart zu kompensieren, dass die korrigierte Position der medizinischen Vorrichtung (26) mit einer entsprechenden Position der medizinischen Vorrichtung zum ersten Zeitpunkt übereinstimmt, wobei der erste Zeitpunkt vor dem zweiten Zeitpunkt liegt, und
   einem Mittel zum Überlagern einer Darstellung der medizinischen Vorrichtung auf der erfassten Region, die von Interesse ist, gemäß der korrigierten Position.

2. Vorrichtung nach Anspruch 1, bei der die Bildgebungsmodalität eine Fluoroskopie aufweist, die ein Fluoroskopiebild erzeugt, das ein zweidimensionales Bild aufweist, und die korrigierte Position eine dreidimensionale Koordinate aufweist, wobei die Vorrichtung ferner ein Mittel aufweist zum Projizieren der korrigierten Position auf das zweidimensionale Bild, wobei die Darstellung der medizinischen Vorrichtung auf dieser Projektion basiert.

3. Vorrichtung nach Anspruch 1, ferner mit einem Mittel (12) zum Korrigieren einer Subjektposition unter Verwendung der Bewegungskompensationsfunktion, um dadurch die Bewegung der Region, die von Interesse ist (ROI), zu kompensieren zwischen einem gegenwärtigen Zeitpunkt, bei dem die Subjektposition korrigiert ist, und einem früheren Zeitpunkt, wobei die Subjektposition eine Zielposition ist, die zu einer virtuellen Grenze gehört, die mit einem ausgewählten Ort in der Region, die von Interesse ist (ROI), in Verbindung steht, oder einer Mitregistrierungsposition, die zu einem gemeinsamen Ort in mitregistrierten Bildgebungsmodalitäten gehört.

4. Vorrichtung nach Anspruch 1, bei der der erste Lokalisierungssensor (24_1) einen Magnetfeldsensor aufweist, der konfiguriert ist zum Bereitstellen einer Position und einer Orientierung, und bei der die Kompensationsfunktion ferner eine Rotationsversetzung aufweist.

5. Vorrichtung nach Anspruch 1, bei der der erste Lokalisierungssensor (24_1) konfiguriert ist zur äußeren Anbringung an dem Körper.

6. Vorrichtung nach Anspruch 1, bei der das Positionsbestimmungssystem (20) konfiguriert ist zum Verfolgen der Bewegung der ROI, indem eine erste Serie von Positionswerten von dem ersten Lokalisierungssensor (24_1) über ein Zeitintervall erfasst wird, ein zweiter Lokalisierungssensor (24_2) der medizinischen Vorrichtung zugeordnet wird, eine zweite Serie von Positionswerten von dem zweiten Lokalisierungssensor über das Zeitintervall erfasst wird; eine Korrelationsfaktor zwischen den jeweiligen Bewegungen des ersten und zweiten Lokalisierungssensors bestimmt wird; und die Kompensationsfunktion zumindest basierend auf dem Korrelationsfaktor bestimmt wird.

7. Vorrichtung nach Anspruch 1, bei der die Region, die von Interesse ist, ein Organ aufweist, wobei die Vorrichtung ferner ein Mittel aufweist zum Erlangen einer Mehrzahl von Bildern der Region, die von Interesse ist, um dadurch eine Sequenz von Bildern zu bilden, wobei jedem Bild ein jeweiliger Zeitparameter zugeordnet ist, der für einen Aktivitätszustand des Organs kennzeichnend ist.

8. Vorrichtung nach Anspruch 7, bei der das Organ ein Herzorgan aufweist, und die jeweiligen Zeitparameter der elektrischen Aktivität des Herzens entsprechen.

9. Vorrichtung nach Anspruch 8, ferner mit einem Mittel zum Anzeigen der Serie von Bildern gemäß dem jeweils zugeordneten Zeitparameter, bei dem die Bilder erlangt worden sind, in Synchronisation mit einem Echtzeit-Elektrokardiogramm des Herzens, und bei der das Positionsbestimmungssystem, das Korrekturmittel und das Überlagerungsmittel jeweils konfiguriert sind zum wiederholten Bestimmen der Position der medizinischen Vorrichtung, Korrigieren der Position, und Überlagern einer jeweiligen Darstellung der medizinischen Vorrichtung gleichzeitig mit der Anzeige der Serie von Bildern.

Revendications

1. Appareil destiné à afficher une région d'intérêt (ROI) mobile localisée dans un corps, comprenant :

un moyen pour générer une fonction de compensation de mouvement spatial variant dans le temps (28) comprenant un déplacement vectoriel basé sur le mouvement de la région d'intérêt (ROI) pour prendre en compte le mouvement de la région d'intérêt (ROI) ;
un système de positionnement (20) configuré pour déterminer une position d'un dispositif médical (26), ledit système de positionnement (20) comprenant en outre un premier capteur de localisation (24_1) configuré pour être placé à proximité de la région d'intérêt mobile de telle sorte que le capteur se déplace avec la région d'intérêt (ROI), dans lequel ledit système de positionnement (20) est en outre configuré pour suivre à la fois le mouvement du premier capteur de localisation (24_1) et le mouvement du dispositif médical (26) ;
des moyens pour vérifier un niveau de corrélation entre le mouvement du dispositif médical (26) et le mouvement du premier capteur de localisation (24_1)
des moyens pour corriger la position déterminée du dispositif médical (26) dans le cas où une corrélation entre les mouvements suivis du premier capteur de localisation (241) et du dispositif médical (26) dépasse un seuil en utilisant la fonction de compensation de mouvement (28) pour former une position corrigée afin de compenser ainsi le mouvement de la région d'intérêt (ROI) entre un premier moment auquel la région d'intérêt est acquise selon une modalité d'imagerie et un second moment auquel la position du dispositif médical (26) a été déterminée, de sorte que la position corrigée du dispositif médical (26) corresponde à une position correspondante du dispositif médical au premier moment, dans lequel le premier moment est antérieur au second moment, et
des moyens pour superposer une représentation du dispositif médical sur la région d'intérêt acquise en fonction de la position corrigée.

2. Appareil selon la revendication 1, dans lequel la modalité d'imagerie comprend la fluoroscopie produisant une image fluoroscopique comprenant une image bidimensionnelle et ladite position corrigée comprend une coordonnée tridimensionnelle, ledit appareil comprenant en outre des moyens pour projeter ladite position corrigée sur ladite image bidimensionnelle, dans lequel ladite représentation du dispositif médical est basée sur ladite projection.

3. Appareil selon la revendication 1 comprend en outre un moyen (12) pour corriger une position de sujet en utilisant la fonction de compensation de mouvement pour compenser ainsi le mouvement de la région d'intérêt (ROI) entre un moment actuel auquel la position de sujet est corrigée et un moment antérieur, dans lequel la position de sujet est une d'une position cible associée à un repère virtuel associé à un emplacement sélectionné dans la région d'intérêt (ROI) et une position de co-registre associée à un emplacement commun dans des modalités d'imagerie coregistrées.

4. Appareil selon la revendication 1, dans lequel ledit premier capteur de localisation (24_1) comprend un capteur de champ magnétique configuré pour fournir une position et une orientation, et dans lequel ladite fonction de compensation comprend en outre une rotation de déplacement.

5. Appareil selon la revendication 1 dans lequel ledit premier capteur de localisation (241) est configuré pour être fixé à l'extérieur du corps.

6. Appareil selon la revendication 1, dans lequel ledit système de positionnement (20) est configuré pour suivre ledit mouvement dudit ROI en acquérant une première série de lectures de position à partir dudit premier capteur de localisation (24_1) sur un intervalle de temps, en associant un second capteur de localisation (24_2) au dispositif médical, en acquérant une seconde série de lectures de position à partir du second capteur de localisation sur ledit intervalle de temps ; en déterminant un facteur de corrélation entre les mouvements respectifs des premier et second capteurs de localisation, et en déterminant ladite fonction de compensation sur la base d'au moins le facteur de corrélation.

7. Appareil selon la revendication 1 dans lequel la région d'intérêt comprend un organe, ledit appareil comprenant en outre des moyens pour obtenir une pluralité d'images de la région d'intérêt pour former ainsi une séquence d'images, dans lequel chaque image est associée à un paramètre de temporisation respectif indicatif d'un état d'activité de l'organe.

8. Appareil selon la revendication 7, dans lequel ledit organe comprend un organe cardiaque, et dans lequel les paramètres de temporisation respectifs correspondent à l'activité électrique du cœur.

9. Appareil selon la revendication 8 comprenant en outre des moyens pour afficher la série d'images conformément au paramètre de temporisation respectivement associé auquel les images ont été obtenues de manière synchronisée avec un électrocardiogramme en temps réel du cœur, et dans lequel ledit système de positionnement, lesdits moyens de correction et lesdits moyens de superposition sont respectivement configurés pour déterminer de manière répétée la position du dispositif médical, corriger la position et superposer une représentation respective du dispositif médical simultanément à l'affichage de la série d'images.

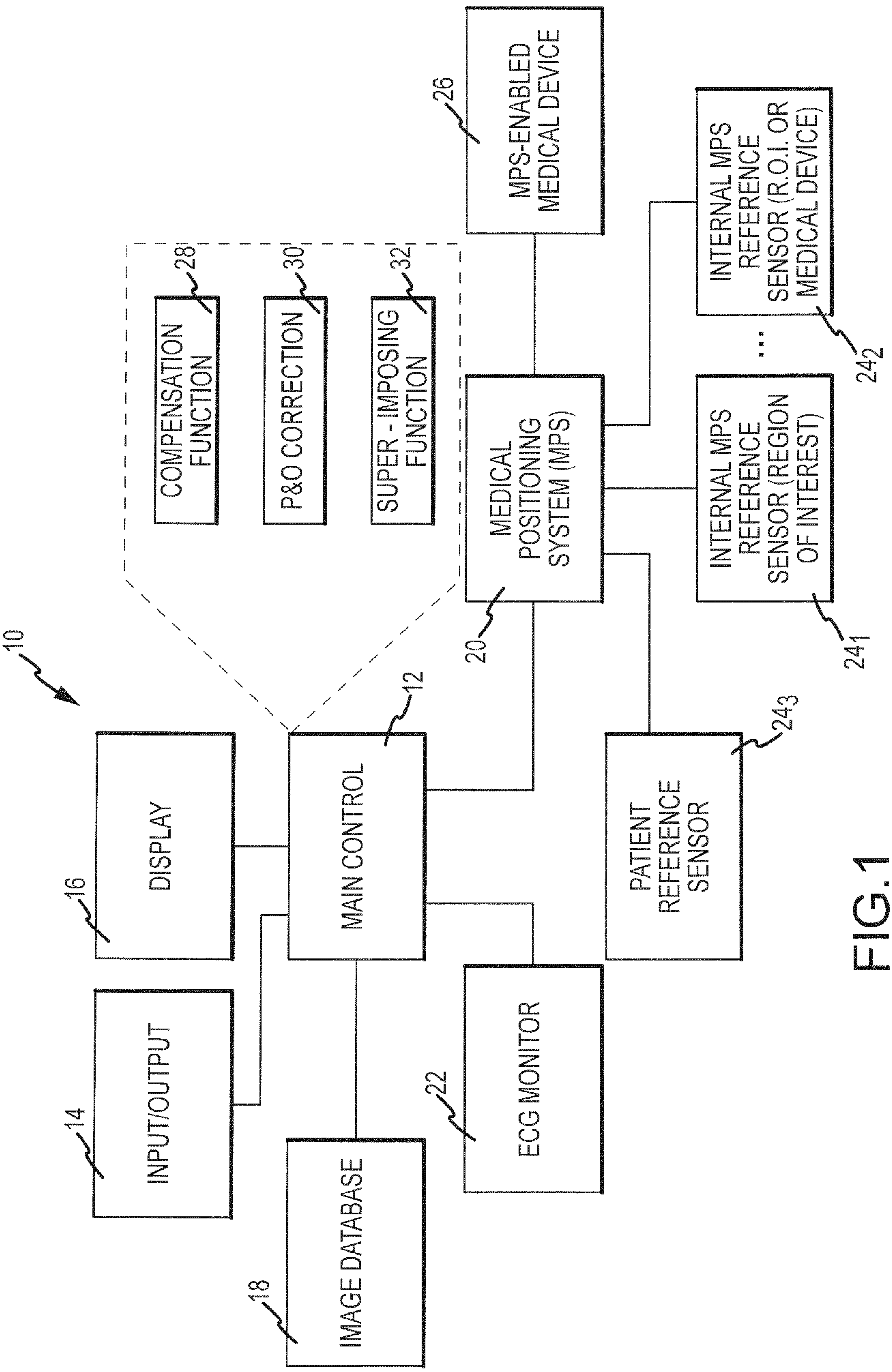
10
DISPLAY
16
INPUT/OUTPUT
14
MAIN CONTROL
12
IMAGE DATABASE
18
ECG MONITOR
22
PATIENT REFERENCE SENSOR
24₃
MEDICAL POSITIONING SYSTEM (MPS)
20
COMPENSATION FUNCTION
28
P&O CORRECTION
30
SUPER - IMPOSING FUNCTION
32
MPS-ENABLED MEDICAL DEVICE
26
INTERNAL MPS REFERENCE SENSOR (REGION OF INTEREST)
24₁
INTERNAL MPS REFERENCE SENSOR (R.O.I. OR MEDICAL DEVICE)
24₂
...

FIG.1

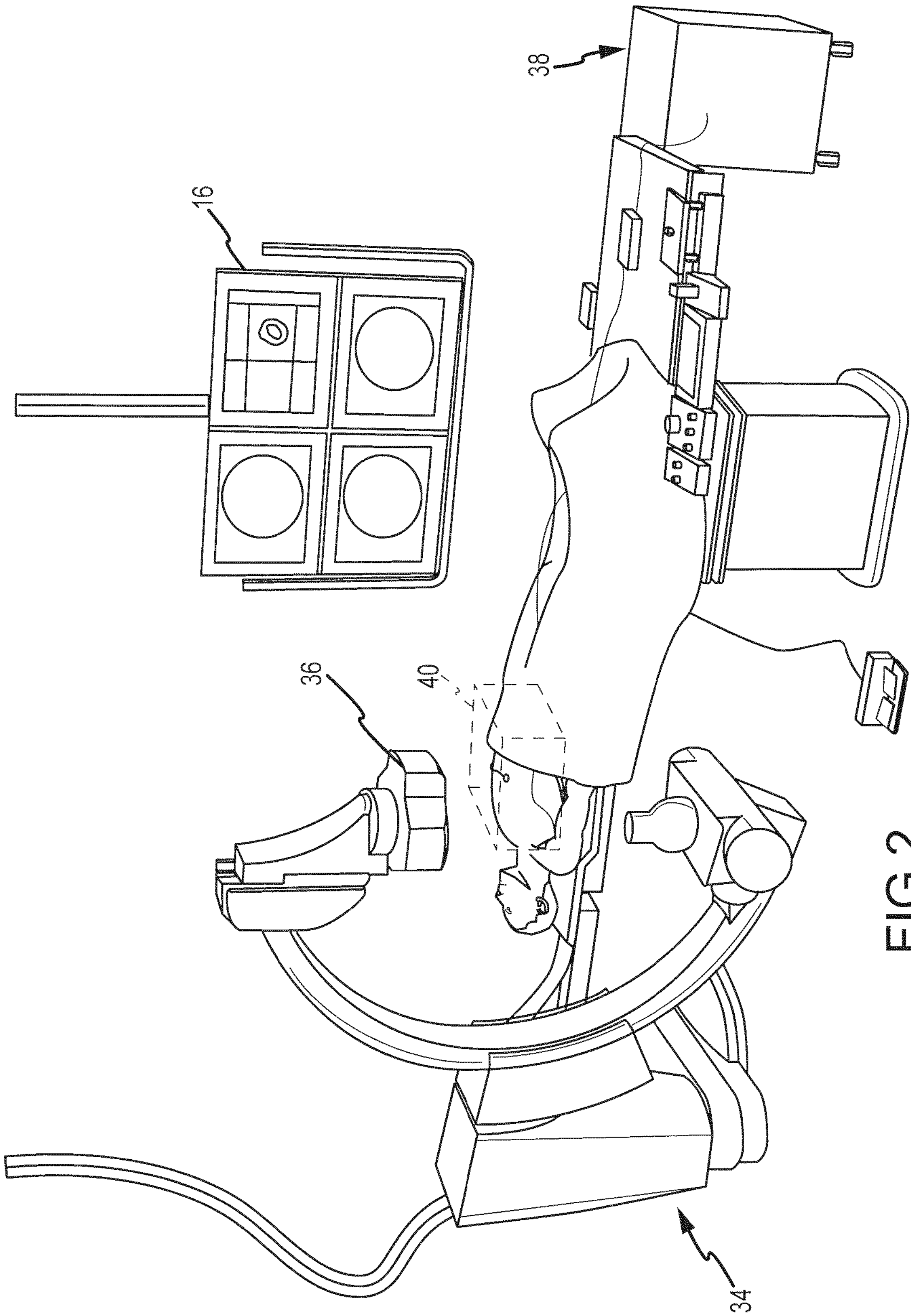

FIG.2

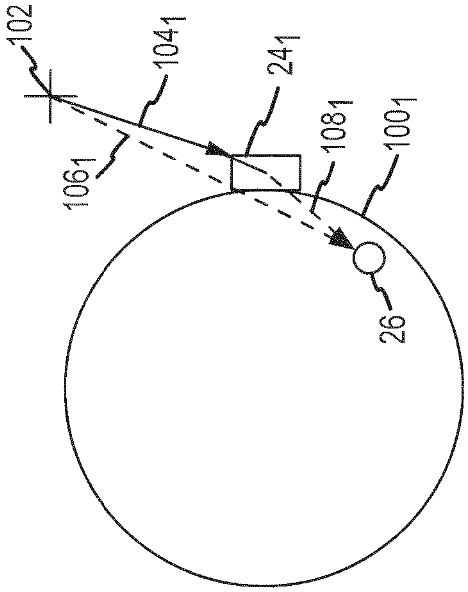

FIG.3A

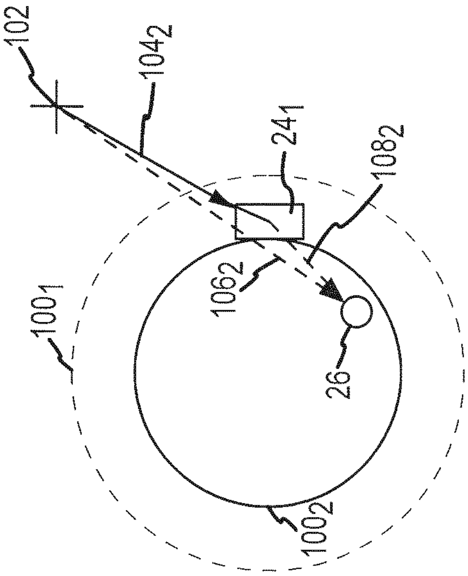

FIG.3B

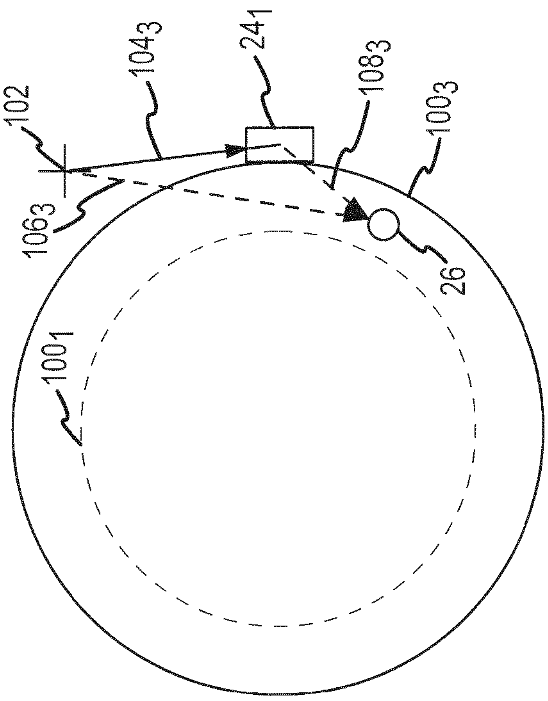

FIG.3C

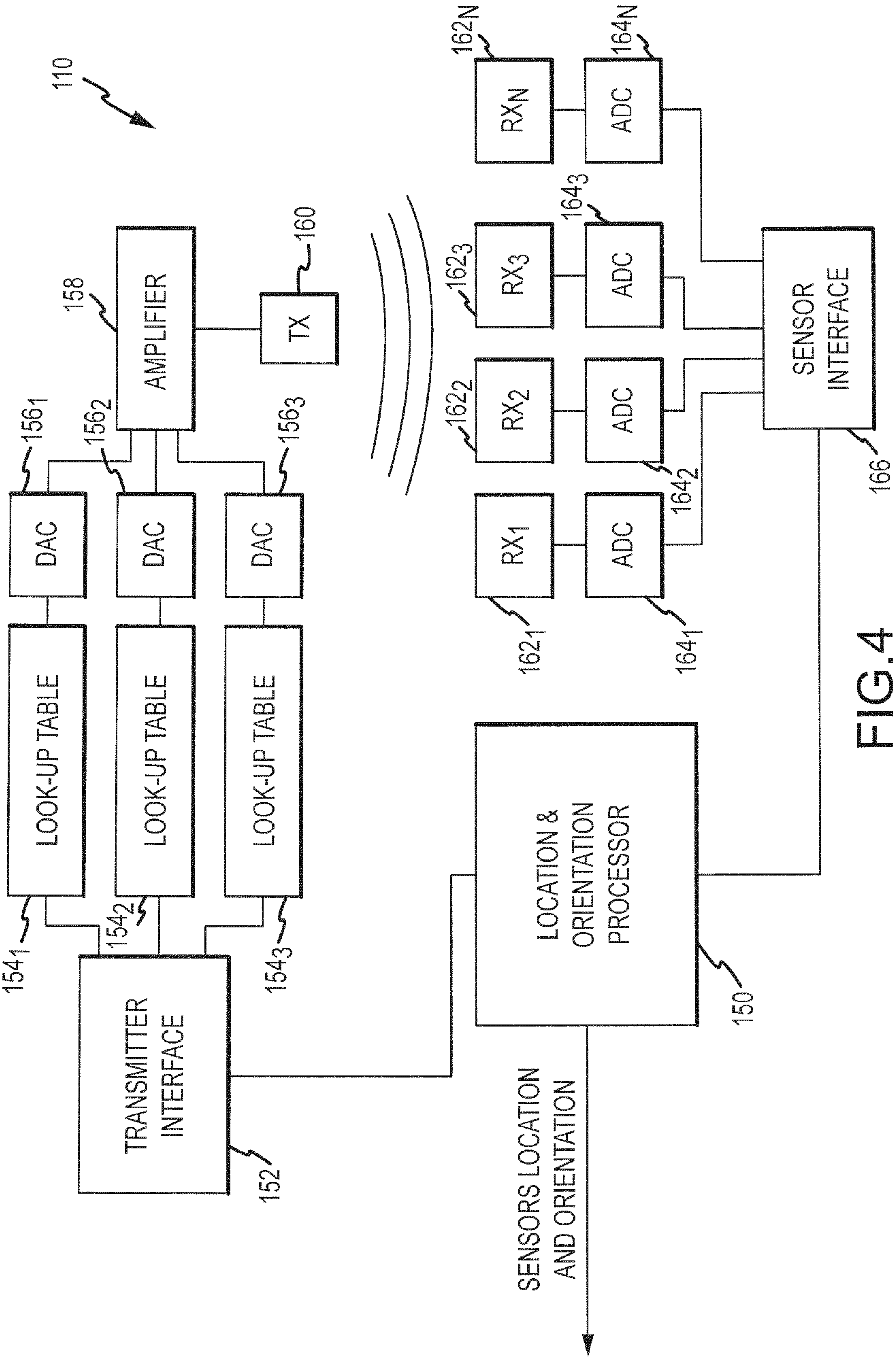
110
TRANSMITTER INTERFACE
152
LOOK-UP TABLE
154_1
LOOK-UP TABLE
154_2
LOOK-UP TABLE
154_3
DAC
156_1
DAC
156_2
DAC
156_3
AMPLIFIER
158
TX
160
RX_1
162_1
RX_2
162_2
RX_3
162_3
RX_N
162_N
ADC
164_1
ADC
164_2
ADC
164_3
ADC
164_N
SENSOR INTERFACE
166
LOCATION & ORIENTATION PROCESSOR
150
SENSORS LOCATION AND ORIENTATION

FIG.4

REFERENCES CITED IN THE DESCRIPTION

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