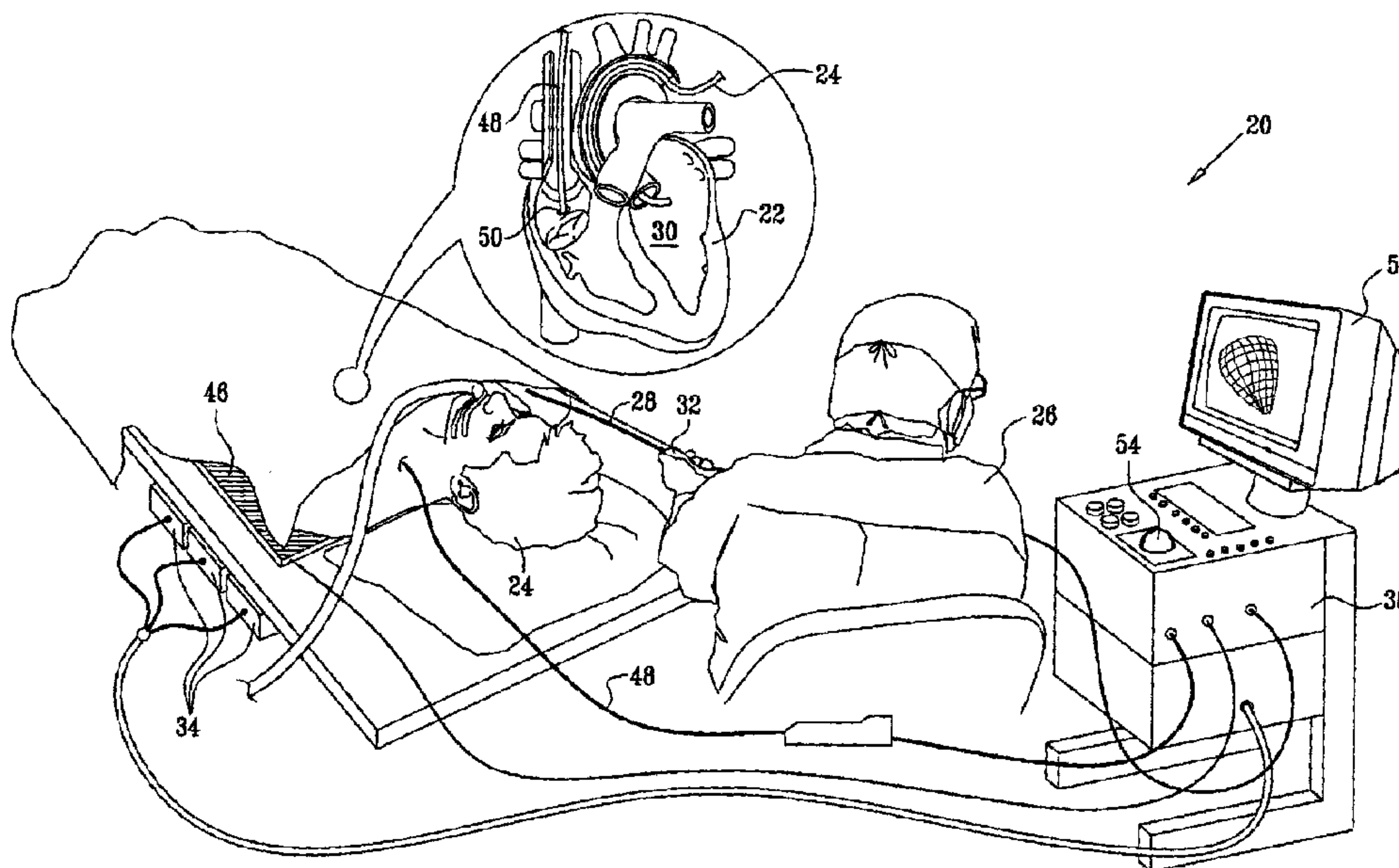




(22) **Date de dépôt/Filing Date:** 2008/06/03
 (41) **Mise à la disp. pub./Open to Public Insp.:** 2008/12/04
 (45) **Date de délivrance/Issue Date:** 2016/07/12
 (30) **Priorités/Priorities:** 2007/06/04 (US60/941,767);
 2008/05/29 (US12/129,012)

(51) **Cl.Int./Int.Cl. A61M 25/095** (2006.01),
 A61B 8/12 (2006.01), A61B 5/06 (2006.01)
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(54) **Titre : SYSTEME DE LOCALISATION INTRACORPOREL AVEC COMPENSATION DES MOUVEMENTS**
 (54) **Title: INTRACORPOREAL LOCATION SYSTEM WITH MOVEMENT COMPENSATION**



(57) **Abrégé/Abstract:**

A method for position tracking includes placing an internal reference probe in a reference location within a heart of a subject, and collecting and processing first location coordinates of the internal reference probe during one or more respiratory cycles so as to define a range of the location coordinates corresponding to the reference location. An active device is inserted into the heart, and second location coordinates of the active device are collected. The first and second location coordinates are jointly processed so as to find relative location coordinates of the active device in a cardiac frame of reference. When a deviation of the first location coordinates from the range is detected, the relative location coordinates are corrected to compensate for displacement of the reference probe from the reference location.

ABSTRACT

A method for position tracking includes placing an internal reference probe in a reference location within a heart of a subject, and collecting and processing first
5 location coordinates of the internal reference probe during one or more respiratory cycles so as to define a range of the location coordinates corresponding to the reference location. An active device is inserted into the heart, and second location coordinates of the active
10 device are collected. The first and second location coordinates are jointly processed so as to find relative location coordinates of the active device in a cardiac frame of reference. When a deviation of the first location coordinates from the range is detected, the
15 relative location coordinates are corrected to compensate for displacement of the reference probe from the reference location.

INTRACORPOREAL LOCATION SYSTEM WITH MOVEMENT
COMPENSATION

5 **FIELD OF THE INVENTION**

The present invention relates generally to medical instruments, and specifically to position sensing systems for tracking the location of invasive devices inside the body.

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BACKGROUND OF THE INVENTION

In intracardiac tracking systems, such as CARTO™ (produced by Biosense Webster, Diamond Bar, California), the position coordinates of a catheter inside the heart are determined relative to a reference location outside the patient's body. In CARTO, for example, both the catheter and a reference pad under the patient's back contain miniature coils, which sense the amplitude and direction of a magnetic field. As the patient breathes, however, the resulting movement of the patient's thorax causes the heart to shift position relative to the reference pad, so that the coordinates of the catheter will change during the respiratory cycle even while the catheter is stationary relative to the heart.

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U.S. Patent 5,391,199, describes an apparatus and method for mapping and treatment of cardiac arrhythmias using a catheter with location sensing capability inside the heart. To correct for displacement of the heart chamber that may occur because of breathing or patient movement, a set of more than two locatable catheters may

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be placed at specific points in the heart chamber during the mapping procedures to serve as reference catheters. The location of these reference catheters supplies the necessary information for proper three-dimensional
5 correspondence of the mapping catheter location within the heart chamber.

SUMMARY OF THE INVENTION

The use of a reference probe, such as a catheter, in
10 a stable position inside the heart can enhance accuracy in measuring the position of an active device, such as a mapping catheter, as the active device is maneuvered within the heart. The reference probe is held stationary and serves as a reference point for measuring the
15 relative coordinates of the active device. Since respiratory motion affects both the reference catheter and the active device in roughly the same way, the effect of respiratory motion on the coordinates of the active device can thus be largely eliminated.

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In practice, however, it can be difficult to maintain the stability of the reference probe. Even small displacements of the reference probe can seriously compromise the accuracy of measurement of the position of
25 the active device. Embodiments of the present invention that are described hereinbelow provide methods and systems that can be used to address this problem, and thus provide accurate position readings even when the reference probe is not entirely stable.

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There is therefore provided, in accordance with an embodiment of the present disclosure, a method for position tracking, including:

5 placing an internal reference probe, which includes a first position transducer, in a reference location within a heart of a subject;

10 collecting and processing first location coordinates of the internal reference probe in a fixed frame of reference, using the first position transducer, during one or more respiratory cycles of the subject so as to define a range of the location coordinates corresponding to the reference location;

inserting an active device, which includes a second position transducer, into the heart;

15 collecting second location coordinates of the active device in the fixed frame of reference, using the second position transducer, and jointly processing the first and second location coordinates so as to find relative location coordinates of the active device in a cardiac frame of reference;

20 after defining the range of the location coordinates corresponding to the reference location, detecting a deviation of the first location coordinates from the range, thereby identifying a displacement of the reference probe from the reference location; and

correcting the relative location coordinates so as to compensate for the displacement.

In a disclosed embodiment, the internal reference probe and the active device include catheters, and the first and second position transducers include magnetic field sensors, which are configured to output position signals responsively to magnetic fields generated by field generators in the fixed frame of reference.

In one embodiment, jointly processing the first and second location coordinates includes taking a vector difference between the first and second location coordinates in order to find the relative location coordinates.

The method made include collecting third location coordinates, in the fixed frame of reference, of a reference pad that is fixed to a body of the subject, wherein jointly processing the first and second location coordinates includes referring at least the first location coordinates to the third location coordinates. Typically, detecting the deviation includes comparing the first location coordinates to the third location coordinates so as to determine whether the deviation is due to the displacement of the reference probe from the reference location or due to a movement of the body of the subject.

In a disclosed embodiment, correcting the relative location coordinates includes computing a correction vector responsively to the displacement, and applying the

coordinates based on the first and second location coordinates. Typically, computing the correction vector includes collecting and processing further location coordinates of the internal reference probe so as to
5 define a new range of the location coordinates corresponding to the reference location, and comparing the new range to the range that was defined by collecting and processing the first location coordinates.

10 In one embodiment, the method includes sensing a local electrogram signal at the reference location within the heart using an electrode on the internal reference probe, wherein detecting the deviation includes detecting a change in the local electrogram signal.

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There is also provided, in accordance with another embodiment of the present disclosure, an apparatus for position tracking, including:

an internal reference probe, which includes a first
20 position transducer and is configured to be placed in a reference location within a heart of a subject;

an active device, which includes a second position transducer and is configured to be introduced into the heart; and

25 a positioning processor, which is coupled to collect and process first location coordinates of the internal reference probe in a fixed frame of reference, using the first position transducer, during one or more respiratory cycles of the subject so as to define a range of the

location coordinates corresponding to the reference location, and to collect second location coordinates of the active device in the fixed frame of reference, using the second position transducer, and to jointly process the
5 first and second location coordinates so as to find relative location coordinates of the active device in a cardiac frame of reference,

wherein the positioning processor is configured, after defining the range of the location coordinates
10 corresponding to the reference location, to detect a deviation of the first location coordinates from the range, thereby identifying a displacement of the reference probe from the reference location, and to correct the relative location coordinates so as to
15 compensate for the displacement.

In one aspect, there is provided an apparatus for position tracking, which includes:

an internal reference probe, which includes a first
20 position transducer and is configured to be placed in a fixed reference location within a heart of a subject;

an active device, which includes a second position transducer and is configured to be introduced into the heart; and

25 a positioning processor, which is coupled to collect and process first location coordinates of the internal reference probe in an externally fixed frame of reference, using the first position transducer, during one or more respiratory cycles of the subject so as to define a first

range of the location coordinates corresponding to the reference location of the internal reference probe, and to establish a permitted threshold for a deviation of the location coordinates from the first range, and to collect
5 second location coordinates of the active device in the externally fixed frame of reference, using the second position transducer, and to jointly process the first location coordinates and the second location coordinates so as to find relative location coordinates of the active
10 device in a cardiac frame of reference. The positioning processor is configured, after defining the first range of the location coordinates corresponding to the reference location, upon detecting a deviation of the first location coordinates from the first range that is more than the
15 permitted threshold, establishing a second range of location coordinates corresponding to the reference location that are outside of the first range and more than the permitted threshold and establishing a correction vector based on the deviation of the location coordinates
20 of the first range, thereby identifying a displacement of the reference probe from the fixed reference location, and to correct the relative location coordinates of the active device in the cardiac frame of reference using the correction vector so as to compensate for the
25 displacement.

The present invention will be more fully understood from the following detailed description of the embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic, pictorial illustration of a cardiac catheterization system, in accordance with an embodiment of the present invention;

5 Fig. 2 is a schematic side view of the distal end of a catheter, in accordance with an embodiment of the present invention;

Figs. 3 and 4 are vector diagrams that schematically illustrate a method for finding location coordinates of a

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catheter, in accordance with an embodiment of the present invention;

Fig. 5 is a flow chart that schematically illustrates a method for finding location coordinates of a catheter, in accordance with an embodiment of the present invention; and

Fig. 6 is a graphical representation of sets of position measurements of a reference catheter, in accordance with an embodiment of the present invention.

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DETAILED DESCRIPTION OF EMBODIMENTS

Reference is now made to Figs. 1 and 2, which schematically illustrate a system 20 for catheterization of a heart 22 of a patient 24, in accordance with an embodiment of the present invention. The system comprises, *inter alia*, a catheter 28, which is inserted by a physician 26 into a chamber 30 of the heart through a vein or artery. Fig. 1 is a pictorial view of the system as a whole, while Fig. 2 shows details of the distal end of the catheter.

Catheter 28 may serve as an active device for a variety of purposes, including diagnostic applications such as mapping or imaging of the heart, as well therapeutic applications, such as ablation-based treatment of arrhythmias. Catheter 28 typically comprises a handle 32 for operation of the catheter by the physician. Suitable controls (not shown) on the handle enable the physician to steer, position and orient the distal end of the catheter as desired. In the

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example configuration shown in Fig. 2, catheter 24 comprises, at its distal end, a number of functional components, including an electrode 40, which may be used for electrical sensing and/or ablation inside heart 22, as well as an acoustic transducer 42, which may be used for ultrasonic imaging. These components, however, are shown solely by way of illustration, and the principles of the present invention are equally applicable to other types of catheters, as well as other invasive devices.

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System 20 comprises a positioning sub-system, which measures location and orientation coordinates of catheter 28. (Throughout this patent application and in the claims, the term "location" refers to the spatial coordinates of the catheter, and the term "orientation" refers to its angular coordinates. The term "position" refers to the full positional information of the catheter, which may comprise both location and orientation coordinates.) For the purpose of these coordinate measurements, the distal end of catheter 28 contains a position sensor 36, which generates signals that are used by a positioning processor 38 in computing position coordinates of the catheter inside the heart. Sensor 36, as well as the functional components in catheter 28, are connected to processor 38 by cables 44 running through the catheter.

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In one embodiment, the positioning sub-system comprises a magnetic position tracking system that determines the location and orientation of catheter 28.

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The positioning sub-system generates magnetic fields in a predefined working volume the vicinity of heart 22 and senses these fields at the catheter. For this purpose, the positioning sub-system typically comprises a set of
5 external radiators, such as field generator coils 34, which are located in fixed, known positions external to patient 24 and generate electromagnetic fields in the vicinity of heart 22. The fields generated by coils 34 thus define a fixed frame of reference. Position sensor
10 36 in this embodiment may comprise one or more coils, which sense the fields generated by coils 34 and convey to processor 38 signals that are proportional to directional components of the fields. The processor typically receives, amplifies, filters, digitizes, and
15 processes these signals in order to determine the coordinates of the sensor in the frame of reference of coils 34. In an alternative embodiment, a radiator, such as a coil, in the catheter generates electromagnetic fields, which are received by sensors outside the
20 patient's body.

The principles of operation of this sort of positioning sub-system are further described in the above-mentioned U.S. Patent 5,391,199. Other position
25 tracking systems that operate in this general manner are described, for example, in U.S. Patents 6,690,963, 6,618,612 and 6,332,089, and U.S. Patent Application Publications 2002/0065455 A1, 2004/0147920 A1 and 2004/0068178 A1. Integration of the positioning sub-

system with the ultrasonic imaging capabilities of transducer 42 is described in U.S. Patent Application Publication 2006/0241445. Although the positioning sub-system of Fig. 1 uses magnetic fields, the methods
5 described below may likewise be implemented using any other suitable positioning sub-system, such as systems based on electrical impedance or acoustical measurements. The term "position transducer," in the context of the present patent application and in the claims, thus refers
10 generically to any sort of component that can be used in an invasive device, such as a catheter, to generate signals indicative of the coordinates of the component, whether by transmission or reception of radiation. Magnetic position sensor 36 is one type of position
15 transducer and is described here solely by way of illustration, and not limitation.

Position sensor 36 is located within the distal end of catheter 28, adjacent to electrode 40 and transducer
20 42, as shown in Fig. 2. Typically, the mutual locational and orientational offsets between the position sensor, electrode, and transducers are constant. These offsets are used by positioning processor 38 to derive the coordinates of electrode 40 and transducer 42, given the
25 measured position of position sensor 36.

In order to reduce possible errors in the position coordinates of catheter 28 that are computed by processor 38, system 20 comprises two position reference elements:

- A reference pad 46, which is typically attached to the back of patient 24. Pad 46 comprises one or more position transducers, such as a position sensor similar to sensor 36 in catheter 28. (In fact, the pad may itself simply comprise another catheter like catheter 28.) The signal that is output by the sensor in pad 46 thus provides a stable position reference, which does not move during the procedure carried out by physician 26 unless the patient himself moves. The reference pad may, for example, be a QWIKSTAR back pad, which is supplied as part of the above-mentioned CARTO system.
- A reference catheter 48, which is typically inserted by physician 26 into heart 22 and is positioned within the heart at a known, stable reference location. Catheter 48 likewise comprises one or more position transducers and thus serves as the reference probe for finding relative location coordinates of catheter 28 in a cardiac frame of reference, i.e., a reference frame that is anchored in heart 22, rather than external to the patient's body, as described further hereinbelow. The reference catheter may, for example, be a CARTO NAVISTAR catheter.

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In the inset in Fig. 1, for example, catheter 48 is fed through the superior vena cava into the right atrium of heart 22, and its distal end is inserted into a coronary sinus 50. In general, in this sort of position, catheter 48 is not expected to move relative to the heart

during the procedure (and the coronary sinus itself moves relatively little in the course of the heart cycle). On the other hand, respiratory motion of the thorax of patient 24 will cause the position of catheter 48, relative to reference pad 46, to shift cyclically along with catheter 28 and the rest of the patient's heart.

Processor 38 jointly processes the coordinates of sensor 36 with the coordinates of catheter 48 in order to find relative location coordinates of catheter 28 that neutralize the effects of respiration and other patient movement, as is described further hereinbelow. The coordinates of reference pad 46 may also be used in this computation in order to enhance the stability of the coordinates against patient movement and changes in the operating environment. The processor typically uses the resulting accurate position measurements in generating maps and/or images of the heart, which are presented on a display 52, and in accurately tracking the location of catheter 28 during diagnostic and therapeutic procedures. A user, such as physician 26, may interact with the display and may control processor using an input device 54, such as a pointing device and/or a keyboard.

Typically, positioning processor 38 comprises a general-purpose computer processor, which is programmed in software to carry out the functions described herein. The software may be downloaded to the computer in electronic form, over a network, for example, or it may, alternatively or additionally, be stored on tangible

media, such as optical, magnetic or electronic memory media. The functions of the positioning processor may be implemented using a dedicated computer, or they may be integrated with other computing functions of system 20. 5 Additionally or alternatively, at least some of the processing functions may be performed using dedicated hardware.

Fig. 3 is a vector diagram that schematically 10 illustrates location coordinates computed by processor 38, in accordance with an embodiment of the present invention. Although the diagram is two-dimensional (for the sake of simplicity and visual clarity), in practice the processor determines location coordinates in system 15 20 in three dimensions. Furthermore, although the embodiments described hereinbelow relate specifically to correction of location coordinates, the principles of the present invention may similarly be applied, *mutatis mutandis*, in reducing errors that may occur in the 20 orientation coordinates of catheter 28, as well.

Fig. 3 shows the following vectors:

- A vector 60 (marked A) represents the coordinates of 25 sensor 36 in catheter 28, which are computed by processor 38 relative to the fixed, external frame of reference of field generator coils 34. These are absolute coordinates, which do not take into account any movement of patient 24, which may occur due to 30 respiration or any other cause.

• Another vector 62 (marked B) represents the coordinates of reference catheter 48, which is supposed to remain stationary (relative to heart 22) within coronary sinus 50. These are, again, absolute coordinates. They are expected to shift cyclically due to respiration of patient 24 and may also exhibit a fixed shift if either patient 24 moves during the procedure or catheter 48 moves within heart 22. Methods for dealing with these sorts of shifts are described hereinbelow.

• A vector 64 (marked C) represents the coordinates of reference pad 46, which are not expected to change at all.

Vectors 60 and 62 are also expected to shift cyclically due to the beating motion of heart 22. In order to neutralize this motion component, the coordinate measurements may be synchronized with the heart cycle, by gating signal capture relative to a body-surface electrocardiogram (ECG) signal or a local intracardiac electrogram. The intracardiac electrogram may be detected, for example, by an electrode on reference catheter 48. A certain point in the heart cycle, such as the peak of the QRS wave in the ECG or a peak in the electrogram, is chosen as an annotation point, and the measurements of vectors 60 and 62 are made at the annotation point in each heart cycle or at a certain fixed delay relative to the annotation point. Once the

effect of the motion of the heart itself has been neutralized in this fashion, vectors 60 and 62 are expected to change identically in response to patient motion (including respiratory motion and small shifts of the patient's body).

Fig. 4 is a vector diagram that schematically illustrates a method applied by processor 38 in computing coordinates of catheter 28 relative to heart 22, in accordance with an embodiment of the present invention. As shown in this figure, vectors 60 and 62 (A and B in Fig. 3) are referred to vector 64 (C) to give location vectors 66 (A-C) and 68 (B-C), corresponding to the location coordinates of catheters 28 and 48, respectively, in the frame of reference of pad 46. This frame of reference is expected to be stationary, except to the extent that patient 24 moves during the procedure. When the patient does move, this movement is neutralized by referencing of the coordinates to pad 46.

20

Processor 38 subtracts vector 68 from vector 66 to give a relative location vector 70 of sensor 36 in the cardiac frame of reference defined by catheter 48. The resulting vector 70 is given by $(A-C) - (B-C) = (A-B)$. As illustrated by this formula, vector 64 drops out of the final calculation, so that pad 46 is not critical in finding the relative location coordinates of catheter 28. The additional reference provided by pad 46 is useful, however, in detecting and compensating for displacement

of catheter 48 from its reference location, as will be explained further hereinbelow.

Fig. 5 is a flow chart that schematically illustrates a method for finding location coordinates of catheter 28 in system 20, in accordance with an embodiment of the present invention. The method assumes, as its starting point, that reference catheter 48 has been inserted into heart 22 and placed in coronary sinus 50, as shown in Fig. 1. Processor 38 collects and processes coordinate readings provided by the position sensor in reference catheter 48 over a number of respiratory cycles of patient 24, at a location learning step 80. System 20 may alert physician 26 that the learning phase is in progress, so that the physician can make sure not to do anything that might move the reference catheter accidentally during this phase.

The coordinate readings collected during step 80 are typically referred to the measured coordinates of reference pad 46, as explained above with reference to Fig. 4. Alternatively, if patient movement (other than respiratory motion) can be neglected, the "raw" coordinates of catheter 48 in the external frame of reference of field generator coils 34 may be used. As noted above, the readings are typically taken at a certain reference point in the patient's heart cycle. Processor 38 applies statistical processing to the coordinate readings in order to define the range of

locations that is normally traversed by catheter 48 over the course of a respiration cycle.

Once the learning phase is complete, physician 26
5 may begin to move catheter 28 within heart 22 in order to perform a diagnostic or therapeutic procedure. Processor 38 receives signals from sensor 36 in catheter 28, as well as from the position sensors in catheter 48 and pad 46. The processor processes these signals to find the
10 raw coordinates of catheters 28 and 48 and of pad 46 in the external frame of reference, and then jointly processes these raw coordinates to find the relative coordinates of catheter 28 in the cardiac frame of reference, as explained above with reference to Figs. 3
15 and 4. In this way, the processor compensates for the effect of patient respiration (as well as other possible movement of the patient) on the location coordinates of catheter 28, at a motion compensation step 82. In other words, the position of catheter 28 that is presented to
20 physician 26 (in a map on display 52, for example) reflects the actual position of the catheter in the frame of reference of the heart, irrespective of the overall movement of the heart due to respiratory motion or other causes.

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Processor 38 continually monitors the coordinates of reference catheter 48 to ensure that they remain within the range that was learned at step 80. If the processor determines that the coordinates have deviated from the
30 range by more than a permitted threshold, it alerts

physician 26, at a reference movement detection step 84. For example, the processor may raise an alert when the reference catheter coordinates are more than 2 mm outside the range that was learned previously. In performing
5 this measurement, it is desirable that processor 38 refer the coordinates of catheter 48 to pad 46, in order to distinguish actual displacement of the reference catheter in the heart from changes in the raw coordinates of the reference catheter that may occur due to movement of the
10 patient during the procedure.

Typically, after receiving the alert, physician 26 has the choice of instructing processor 38 to correct and compensate for the displacement of reference catheter 48,
15 or simply to continue with the procedure, at a user input step 86. Alternatively, system 20 may decide autonomously to perform the correction. In either case, when the decision has been made to correct the coordinates, processor 38 learns the new range of
20 location coordinates of the reference catheter, at a correction step 90. This step is similar to step 80. The processor compares the new range to the previous range in order to compute a correction vector, which estimates the displacement of the reference catheter.

25

Once the processor has found the correction vector, system 20 returns to normal operation at step 82. The processor now subtracts out the correction vector in computing the relative coordinates of catheter 28, and
30 thus compensates for the displacement of reference

catheter 48. As a result, system 20 will continue to display the relative position of catheter 28 in heart 22 as though the reference catheter had not moved from its original position. If the reference catheter moves again
5 subsequently, the processor will repeat steps 84-90, and the new correction vector will then be added cumulatively to the previous correction vector.

Fig. 6 is a schematic, graphical representation of
10 sets of position measurements 92, 96 of reference catheter 48, illustrating the operation of system 20 at steps 80 and 90 in accordance with an embodiment of the present invention. Processor 38 gathers measurement points 92 at step 80. As noted earlier, the measurement
15 points are collected over the course of one or more respiratory cycles, typically at the same annotation point in the patient's heart cycle. Assuming the patient to be supine, respiration causes mainly vertical motion of the reference catheter, as illustrated by points 92.
20 The locations of points 92 defines a range 94. In this case, the range is the smallest ellipse with a vertical major axis that contains all of points 92, but other methods may alternatively be used to define the range.

25 Although the range is shown in Fig. 6 as comprising simply a "cloud" of coordinates, the range may, additionally or alternatively, be defined by kinematic features, such as the path and/or speed of movement from point to point. In this case, displacement of the
30 reference catheter may be detected at step 90 not only

based on excursion of the coordinates outside the "cloud," but also based on kinematic deviation.

5 In any case, after the processor has detected movement of the reference catheter outside the expected range at step 84, it gathers a new set of measurement points 96 at step 90. Typically, this procedure can be completed over one or a few respiratory cycles. Points 10 96 define a new range 98. The processor computes a correction vector 100 by comparing ranges 94 and 98. For example, as shown in Fig. 6, the correction vector may be given by the vector displacement between the centers of mass of old range 94 and new range 98.

15 If reference catheter 48 includes one or more electrodes, displacement of the reference catheter may also be detected electrically. For example, the timing of a peak in the local electrogram detected by the reference catheter electrode may be compared with the QRS 20 peak in the body-surface ECG. A shift in this timing may indicate that the reference catheter has moved. As another example, if the reference catheter has multiple electrodes at different positions along its length, a relative shift in the locations of the peaks in the 25 electrograms detected by the different electrodes may likewise indicate that the reference catheter has moved. These timing changes are independent of the actual position measurements and are generally not sensitive to patient motion.

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It will be appreciated that the embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather,
5 the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description
10 and which are not disclosed in the prior art.

CLAIMS

1. An apparatus for position tracking, comprising:
an internal reference probe, which comprises a first position transducer and is configured to be placed in a fixed reference location within a heart of a subject;
5 an active device, which comprises a second position transducer and is configured to be introduced into the heart; and
a positioning processor, which is coupled to collect
10 and process first location coordinates of the internal reference probe in an externally fixed frame of reference, using the first position transducer, during one or more respiratory cycles of the subject so as to define a first range of the location coordinates
15 corresponding to the reference location of the internal reference probe, and to establish a permitted threshold for a deviation of the location coordinates from the first range, and to collect second location coordinates of the active device in the externally fixed frame of
20 reference, using the second position transducer, and to jointly process the first location coordinates and the second location coordinates so as to find relative location coordinates of the active device in a cardiac frame of reference,
25 wherein the positioning processor is configured, after defining the first range of the location coordinates corresponding to the reference location, upon detecting a deviation of the first location coordinates from the first range that is more than the permitted
30 threshold, establishing a second range of location coordinates corresponding to the reference location that are outside of the first range and more than the

permitted threshold and establishing a correction vector based on the deviation of the location coordinates of the first range, thereby identifying a displacement of the reference probe from the fixed reference location, and to
5 correct the relative location coordinates of the active device in the cardiac frame of reference using the correction vector so as to compensate for the displacement.

10 2. The apparatus according to claim 1, wherein the internal reference probe and the active device comprise catheters.

3. The apparatus according to claim 1, and comprising
15 magnetic field generators, which are configured to generate magnetic fields that define the fixed frame of reference, wherein the first and second position transducers comprise magnetic field sensors, which are configured to output position signals responsively to
20 magnetic fields.

4. The apparatus according to claim 1, wherein the positioning processor is configured to take a vector difference between the first and second location
25 coordinates in order to find the relative location coordinates.

5. The apparatus according to claim 1, and comprising a reference pad that is fixed to a body of the subject, wherein the positioning processor is coupled to collect third location coordinates, in the fixed frame of reference, of the reference pad and to refer at least the first location coordinates to the third location coordinates in order to find the relative location coordinates.

6. The apparatus according to claim 5, wherein the positioning processor is configured to compare the first location coordinates to the third location coordinates so as to determine whether the deviation is due to the displacement of the reference probe from the reference location or due to a movement of the body of the subject.

7. The apparatus according to claim 1, wherein the positioning processor is configured to collect and process further location coordinates of the internal reference probe that are outside of the first range, after detecting the deviation, so as to define the second range of the location coordinates corresponding to the reference location, and to compute the correction vector by comparing the second range to the first range that was defined by collecting and processing the first location coordinates.

25

8. The apparatus according to claim 1, wherein the internal
reference probe comprises an electrode, and wherein the
positioning processor is coupled to receive a local
electrogram signal from the electrode at the reference
5 location within the heart and to detect the deviation by
detecting a change in the local electrogram signal.

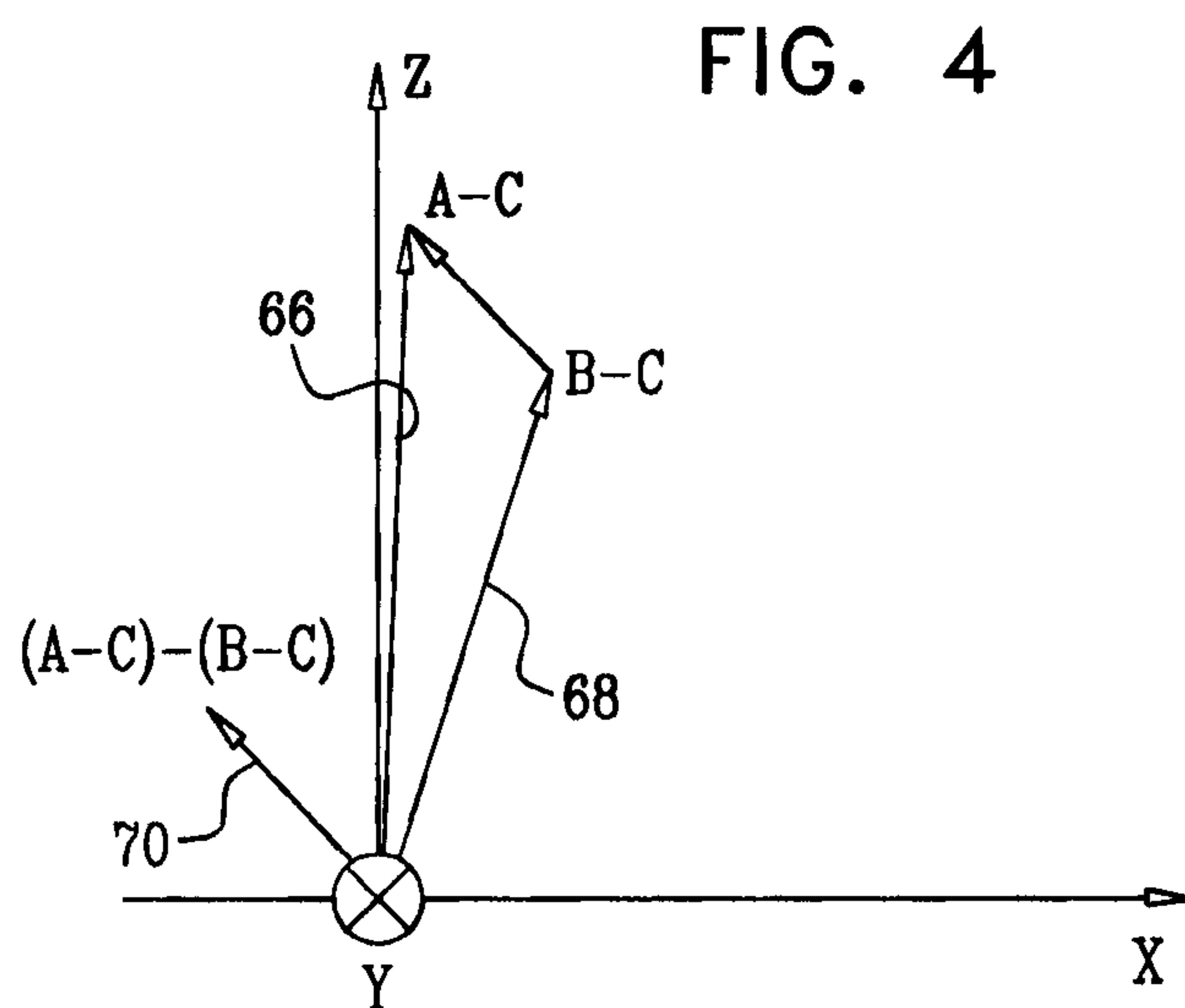
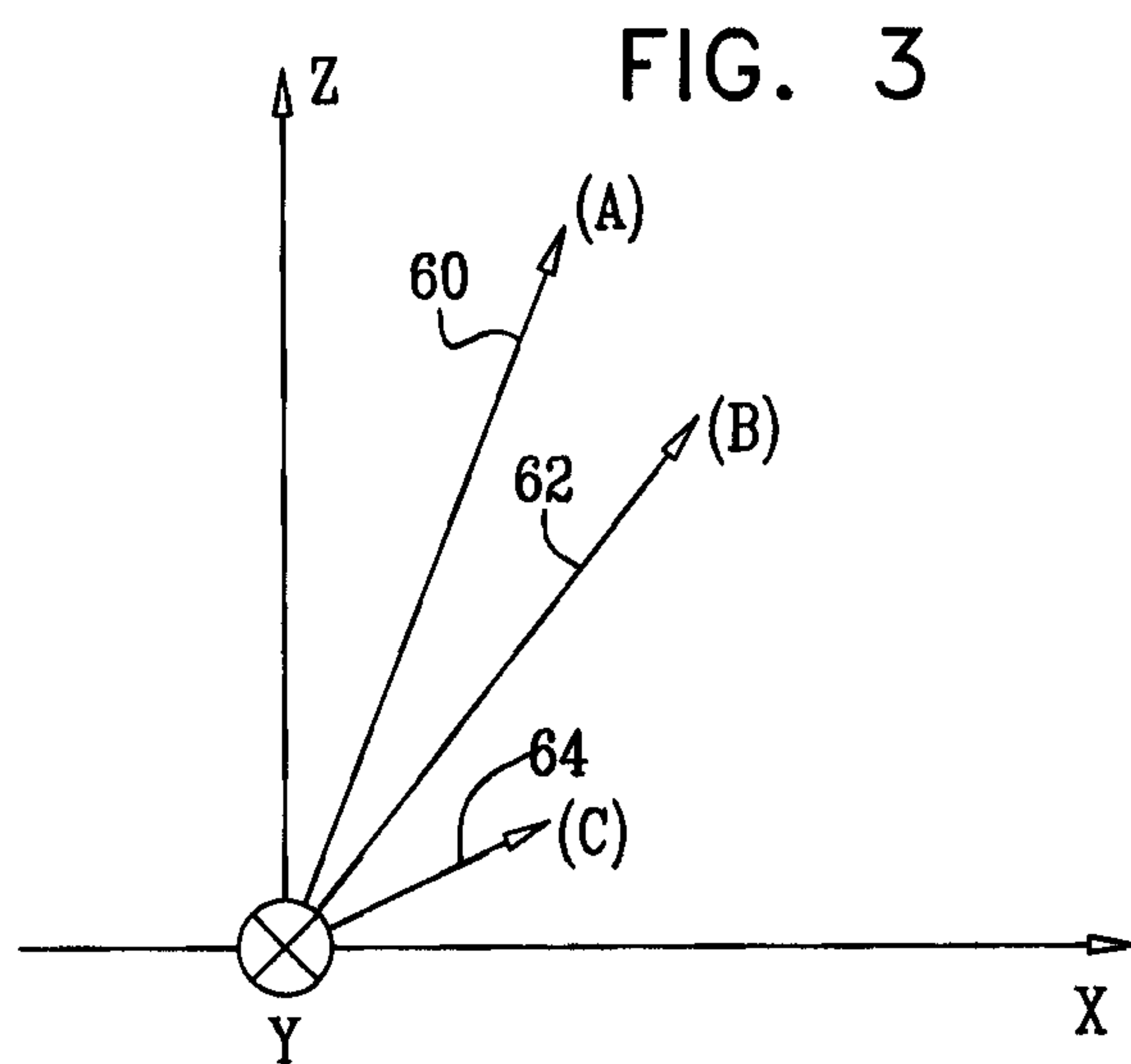
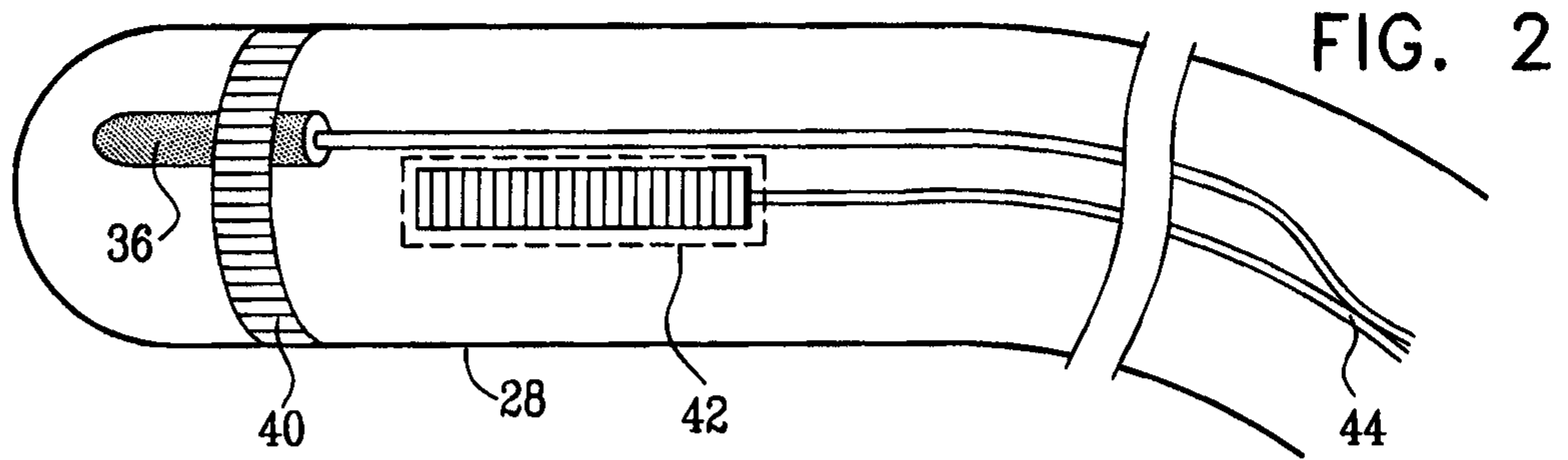


FIG. 5

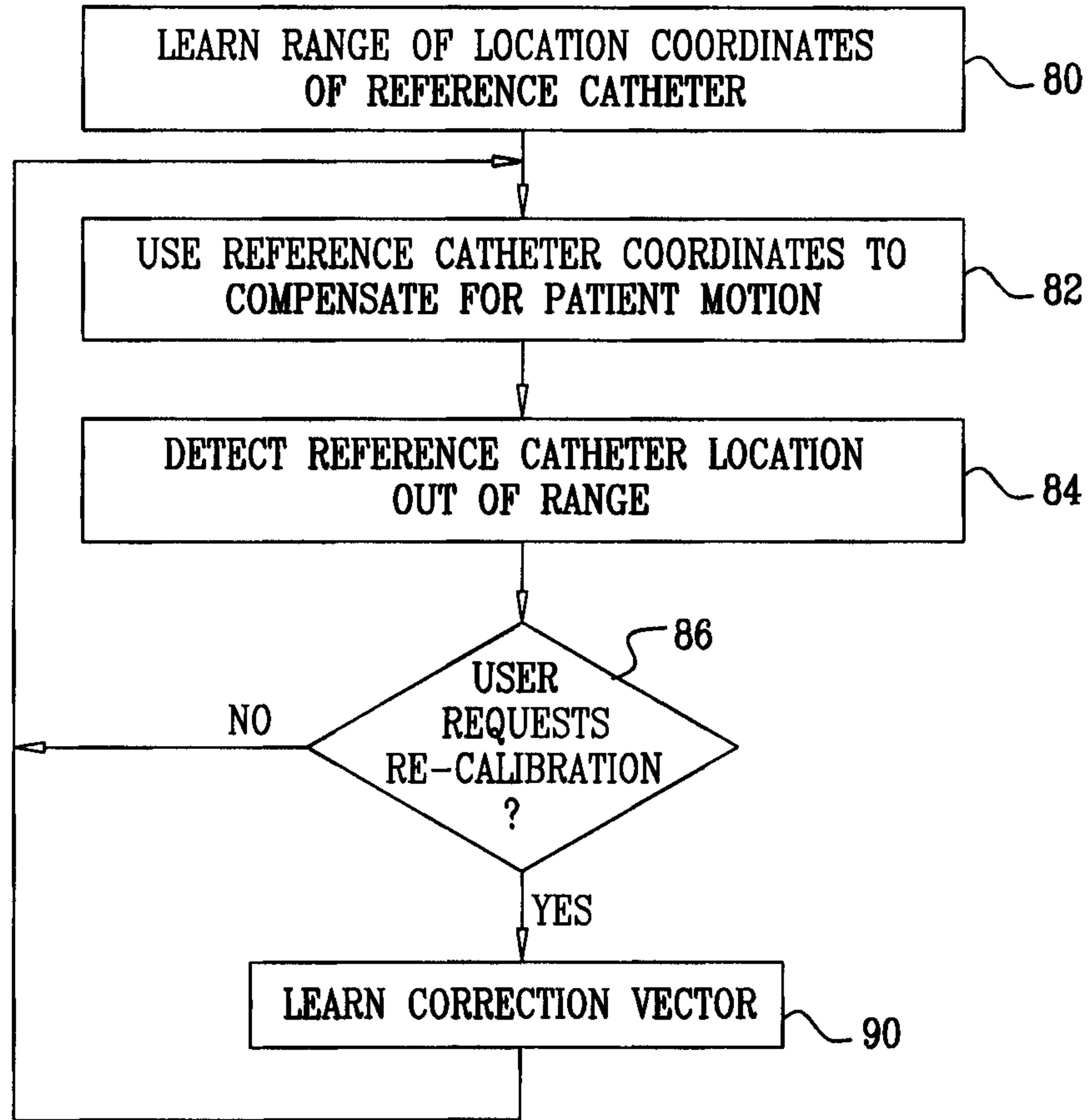


FIG. 6

