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(54) Title: VISUALIZATION OF CATHETER IN THREE-DIMENSIONAL ULTRASOUND

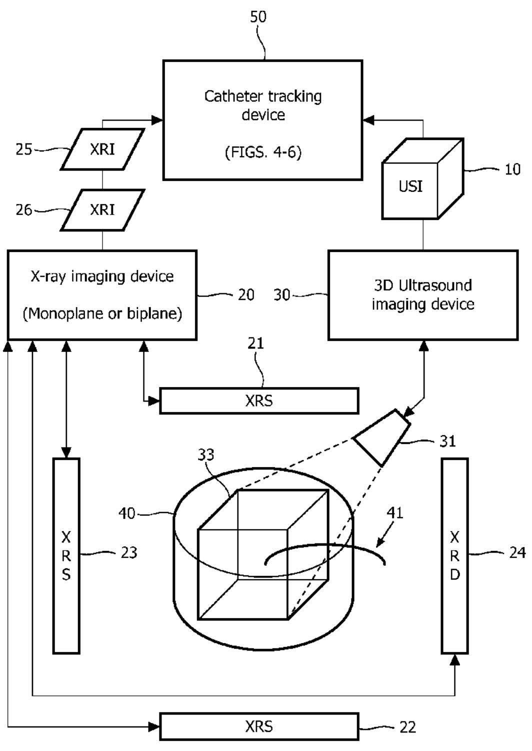

FIG. 1

(57) Abstract: An image-guided system employs an X-ray imaging device (20) for generating one or more X-ray images (25, 26) illustrating a tool (41) within an anatomical region (40) and an ultrasound imaging device (30) for generating an ultrasound image (33) illustrating the tool (41) within the anatomical region (40). The image-guided system further employs a tool tracking device (50) for visually tracking the tool (41) within the anatomical region (40). In operation, the tool tracking device (50) localizes a portion of the tool (41) as located within the ultrasound image (33) responsive to an identification of the portion of the tool (41) as located within the X-ray image(s) (25, 26), and executes an image segmentation of an entirety of the tool (41) as located within the ultrasound image (33) relative to a localization of the portion of the tool (41) as located within the ultrasound image (33).

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Visualization Of Catheter In Three-Dimensional Ultrasound

The present invention generally relates to accurate image guidance for an interventional procedure, particularly an interventional cardiac procedure. The present invention specifically relates to visualization of an interventional tool (e.g., a catheter) in an ultrasound image ("3D US").

Knowing a relative position of an interventional tool (e.g., a catheter) with respect to a pre-procedural planning scan (e.g., a magnetic resonance imaging ("MRI") scan or a computed tomography ("CT") scan) is important for accurate guidance in an interventional procedure, particularly an interventional cardiac procedure. Since X-ray fluoroscopic images provide very highly resolved images of the interventional tool during the procedure, image-guided systems known in the art for providing visual aid in guiding the interventional tool have concentrated on tracking a tip of the tool in fluoroscopic images and overlaying in the pre-procedural scan. It is also well known, for visualization of a 3D shape of the interventional tool in real time, to mount a multitude of position sensors and/or shape sensing sensors on the interventional tool in order to track the 3D shape of the interventional tool.

Increasingly, registering an ultrasound image ("2D US") or 3D US with X-ray imaging has augmented X-ray fluoroscopy as an aid for guiding an interventional procedure. The key role of the 2D US or the 3D US is to augment the pre-procedural scan with real time motion information, while the X-ray fluoroscopic image(s) provide high resolution visualization of the interventional tool in real time. Moreover, with the introduction of 3D US in real time, it is becoming possible to visualize the interventional tool more clearly in ultrasound, thereby enabling ultrasound-only guided interventions.

In cardiac interventional procedures, it is important to visualize the tip of a catheter as well as the orientation of the tip of the catheter. The identification of the catheter tip is difficult in 3D US, especially in a cardiac interventional setting. Therefore, methods for identifying the catheter tip in X-ray images and mapping these points into 3D US for extraction and fusing in a pre-procedural scan is beneficial for the interventional procedure.

One form of the present invention is an image-guided system employing an X-ray imaging device (e.g., monoplane or biplane) for generating one or more X-ray images illustrating a tool within an anatomical region (e.g., a catheter within a cardiac region), and an ultrasound imaging device for generating an ultrasound image illustrating the tool within the anatomical region.

The image-guided system further employs a tool tracking device for visually tracking the tool within the anatomical region. In operation, the tool tracking device localizes a portion of the tool (e.g., a tip of the catheter) as located within the ultrasound image responsive to an identification of the portion of the tool as located within the X-ray image(s), and executes an image segmentation (e.g., a graph cut segmentation) of an entirety of the tool as located within the ultrasound image relative to a localization of the portion of the tool as located within the ultrasound image.

A second form of the present invention is an image-guided method for visually tracking a tool within an anatomical region. The method involves a generation of one or more X-ray images illustrating the tool within an anatomical region (e.g., a catheter within a cardiac region), and a generation of an ultrasound image illustrating the tool within the anatomical region.

The method further involves a localization of a portion of the tool (e.g., a tip of the catheter) as located within the ultrasound image responsive to an identification of the portion of the tool as located within the X-ray image(s), and an execution of an image segmentation (e.g., a graph cut segmentation) of an entirety of the tool as located within the ultrasound image relative to a localization of the portion of the tool as located within the ultrasound image.

The foregoing forms and other forms of the present invention as well as various features and advantages of the present invention will become further apparent from the following detailed description of various exemplary embodiments of the present invention read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the present invention rather than limiting, the scope of the present invention being defined by the appended claims and equivalents thereof.

FIG. 1 illustrates an exemplary embodiment of an image-guided system in accordance with present invention.

FIG. 2 illustrates a flowchart representative of an image-guided method in accordance with the present invention.

FIG. 3 illustrates an exemplary implementation of the image-guided method of FIG. 2 by the image-guided system of FIG. 1.

FIGS. 4-6 illustrate various embodiments of a tool tracking device in accordance with the present invention.

FIG. 7 illustrates an exemplary geometric relationship between an X-ray image and an ultrasound image in accordance with the present invention.

FIG. 8 illustrates an exemplary tool tip movement within an ultrasound image in accordance with the present invention.

FIG. 9 illustrates a flowchart representative of one embodiment of a cardiac interventional procedure incorporating one embodiment of a tool tracking method in accordance with the present invention.

FIG. 10 illustrates a flowchart representative of a second embodiment of a tool tracking method in accordance with the present invention.

FIG. 11 illustrates a flowchart representative of one embodiment of a tool localization method in accordance with the present invention.

FIG. 12 illustrates a flowchart representative of one embodiment of a weighted graph construction method in accordance with the present invention.

FIG. 13 illustrates an exemplary weighted graph corresponding to an energy function in accordance with the present invention.

FIG. 14 illustrates a flowchart representative of one embodiment of an image segmentation method in accordance with the present invention.

As previously stated, the present invention provides various methods for visualizing a three-dimensional shape of the interventional tool in real time inside of a three-dimensional pre-procedural planning scan. As will be appreciated by those having ordinary skill in the art from the following descriptions of FIGS. 1-13, these methods are implemented by a tool tracking device of the present invention utilizing X-ray images and ultrasound images. For purposes of facilitating an understanding of the present invention, the tool tracking device will be described herein for tracking a catheter during a cardiac interventional procedure.

Specifically, FIG. 1 illustrates an image-guiding system employing an X-ray imaging system, a 3D US imaging system and a tool tracking device in the form of a catheter tracking device 50.

For purposes of the present invention, the X-ray imaging system is broadly defined herein as including an X-ray imaging device 20 for controlling an operation of an X-ray source 21 and an X-ray detector 22 structurally configured for generating a X-ray image ("XRI") 25 of an anatomical region (e.g., a cardiac region) represented by a volume 40 and/or for controlling an operation of an X-ray source 23 and an X-ray detector 24 structurally configured for generating a X-ray image ("XRI") 26 of anatomical region 40. In practice, components 20-22 exclusive of components 23 and 24 represent a monoplane X-ray system of any type, and components 21-24 collectively represent a bi-plane X-ray system of any type. Examples of the X-ray imaging system include, but are not limited to, any type of

X-ray system for performing a cardiac interventional procedure. In one embodiment, an X-ray system from the Allure Xper series commercially sold by Philips Medical Systems may serve as the X-ray imaging system.

For purposes of the present invention, the 3D US imaging system is broadly defined herein as including 3D US imaging device 30 for controlling an operation of 3D US probe 31 structurally configured for generating an ultrasound image ("USI") 32 of anatomical region 40. Examples of the 3D US imaging system include, but are not limited to, any type of ultrasound imaging system, particularly one utilizing a 3D TEE probe. In one embodiment, the iEEE intelligent echo system commercially sold by Philips Medical Systems may serve as 3D US imaging system.

For purposes of the present invention, catheter tracking device 50 is broadly defined herein as any device structurally configured for registering X-ray image(s) 25/26 and ultrasound image 31 for purposes of identifying a tip of a catheter 41 within anatomical region 40, and for visualizing a 3D shape of catheter 41 in real time inside of a 3D pre-procedural planning scan inclusive of anatomical region 40. To this end, catheter tracking device 50 executes an image-guided method represented by a flowchart 60 as shown in FIG. 2.

Referring to FIG. 2, a stage S61 of flowchart 60 encompasses a pre-operative planning of an interventional procedure involving a 3D scan (e.g., a MRI scan or a CT scan) of an anatomical region of a patient. For example, as shown in FIG. 3, stage S61 may encompass a 3D pre-procedural scan 72 of a cardiac region 71 of a patent 70 and a storage of 3D pre-procedural scan 72 within a database 73.

A stage S62 of flowchart 60 encompasses a registration by catheter tracking device 50 of X-ray image(s) and an ultrasound image of the anatomical region of the patient. For example, as shown in FIG. 3, X-ray image 25 and/or X-ray image 26 of cardiac region 71 as well as ultrasound image 31 of cardiac region 71 are generated by the X-ray imaging system and the 3D US imaging system, respectively, whereby catheter tracking device 50 registers X-ray image 25 and/or X-ray image 26 to ultrasound image 31. In practice, the registration may be involved a conversion of X-ray coordinates into 3D US real-time coordinates using a combination of system calibration and real-time tracking as known in the art. For example, the registration may include manual alignment or an electromagnetic tracking technique.

A stage S63 of flowchart 60 encompasses an identification of a portion of the catheter (e.g., a tip of the catheter) within the ultrasound image. In one embodiment as related to FIG. 3, stage S63 involves an automatic or a manual identification of the tip of catheter 41 within

X-ray image 25 and/or X-ray image 26 and a localization of the tip of catheter 41 within ultrasound image 33 derived the X-ray/3D US registration as known in the art.

A stage S64 of flowchart 60 encompasses an image segmentation of catheter 41 within ultrasound image 33 with the catheter tip serving as an initialization point for the image segmentation process.

A stage S65 of flowchart 60 encompasses a tracking of the catheter within a pre-procedural scan of the anatomical region derived from the image segmentation of the 3D shape of the catheter within the ultrasound image. For example, as shown in FIG. 3, stage S65 involves catheter tracking device 50 displaying 3D pre-procedural scan 72 on a display 80 with a tracking overlay 75 of catheter 41 projected within scan 72 as derived from previous image segmentation of the 3D shape of catheter 41 within the ultrasound image 33.

A description of FIGS. 4-13 will now be provided herein to provide a detailed explanation of various embodiments of a catheter tracking device of the present invention including modules structurally configured with hardware, software and/or firmware for implementing stages S63 and S64 of flowchart 60 (FIG. 2).

Specifically, FIG. 4 illustrates a catheter image tracking module 51a for implementing stages S63 and S64 in accordance with a process known herein as “tip detection mode” in view of the fact the manner by which the tip is detected may serve as a boundary constraint for subsequent image segmentation.

Generally, the “tip detection mode” utilizes a geometric relationship of an X-ray image and an ultrasound volume whereby a tool tip in the X-ray image corresponds to a line or a line set going through the ultrasound image after transformation using an X-ray/3D US registration. For example, as shown in FIG. 7, an X-ray projection 90 of a catheter 41 onto X-ray detector 22 via X-ray source 21 corresponds to a line set 91 of three (3) lines going through an ultrasound volume 32 after transformation using an X-ray/3D US registration. By using the illustrated geometric constraint, a six (6) degree of freedom (“DOF”) catheter tracking problem [x, y, z, a, b, c], where xyz are translations and a, b, and c are rotations, is reduced into a four (4) DOF problem with [r, a, b, c], where r is a translation along a tracing line 92 associated with the catheter tip shown in FIG. 7. In practice, this catheter tracking problem may be efficiently solved by using a Kalman filter or particle filter based visual tracker, which has been extensively studied in computer vision. The reduction of search space to four (4) DOF significantly improves the step of the visual tracking algorithms as described below.

For example, a particle filter is used to illustrate how to build the catheter tracking module 51. Specifically, let X= [r, a, b, c] denote the state vector representing the location and the pose of catheter 41. The catheter tracking problem may be described by $p(X_t|\mathbf{V}_{us}^t)$, i.e., to estimate state vector X using the ultrasound volume history. By using Bayes' rule, the following equation [1] is derived for tracking purposes:

$$p(X_t|\mathbf{V}_{us}^t) = p(V_{us}^t|X_t)\int p(X_t|X_{t-1})p(X_{t-1}|\mathbf{V}_{us}^{t-1})dX_{t-1} \qquad [1]$$

By assuming the dynamic change from X_{t-1} to X_t as shown in FIG. 8 from a point 93 to a point 94 in 3D US volume 32 follows some distribution $p(X_t|X_{t-1})$, the particles sampled from the previous 3D US volume $p(X_{t-1}|\mathbf{V}_{us}^{t-1})$ may be propagated to the next frame, where the fitness of an estimated tool tip to the current 3D US frame is measured by $p(V_{us}^t|X_t)$. By applying the geometric constraint from a single X-ray image 25 as shown in FIG. 8, the number of variables in the state vector X is reduced from six (6) to (4), which in turn reduces the number of samples used in the particle filter and shortens the tracking time by one-third (1/3) for an equivalent tracking accuracy compared to the unconstrained tracking in 3D US. In other words, with the same computational time, the proposed scheme can use more samples to make the catheter visualization in 3D US volume 32 more accurate and more robust.

FIG. 9 illustrates a flowchart 100 representative of a cardiac interventional procedure incorporating the "tip detection mode" of the present invention via a tracking loop including stages S104-S106 of flowchart 100.

Specifically, stage S104 encompasses a generation of a single X-ray image of the heart cavity during a 3D US probe of the heart cavity. The single X-ray image is utilized by tool identification module 52a during stage S105 to identify the tip of the catheter in an ultrasound image of the heart cavity in one time phase or ECG phase.

In one embodiment of stage S105, the tip of the catheter is manually identified in a ultrasound image via a user input of the 3D US imaging system and a line extending from the X-ray source through 3D US volume to the catheter tip as projected on the X-ray detector is determined.

In a second embodiment of stage S105, the tip of the catheter is manually identified in the X-ray image via a user input of the X-ray image system and then mapped to the ultrasound image based on the X-ray/3D US registration. Additionally, a line extending from the X-ray source through 3D US volume to the catheter tip as projected on the X-ray detector is determined.

In a third embodiment of stage S105, the tip of the catheter is automatically identified in the X-ray image via a known template matching algorithm and then mapped to the ultrasound image based on the X-ray/3D US registration. Again, a line extending from the X-ray source through 3D US volume to the catheter tip as projected on the X-ray detector is determined.

In a fourth embodiment of stage S105, the catheter tip may be automatically detected in the ultrasound image using learning based techniques, where the appearance model can come from manual identification of catheter tip in sample 3D US images or from biplane X-ray images. In this appearance modelling process, 3D image patches are first extracted from the training 3D US volumes around the identified catheter tip. Each patch is reshaped into a vector and may be considered as a column of a matrix M. The singular value decomposition ("SVD") may be applied to the constructed matrix to extract the principal components U of the training patches. That is $M = U\Sigma V^T$.

During the detection process, the search is performed along the line back projected from the identified catheter tip in X-ray image to the 3D US volume. For each search location, a patch I_p with the same size as the training patch is extracted. The patch can then be decomposed into $b = U^T I_p$ and the distance from the patch to the learned model is measured by $\|b\|^2$. The catheter tip location may be detected as the point with the smallest distance.

Stage S106 encompasses image segmentation module 53a visualizing the 3D shape of the catheter within the ultrasound image. In practice, the present invention does not impose any restrictions or limitations to the segmentation of the catheter for visualization purposes. Nonetheless, during stage S106, the back-projected line or line set may serve as a boundary constraint for the catheter segmentation in the ultrasound image, i.e. the catheter tip has to be located somewhere along this line or line set. The catheter segmentation may be further constraint by the dimensions of the ultrasound image. Additionally, a priori knowledge of the catheter shape may be further used to determine statistically likely poses given the before mentioned boundary conditions.

One advantage of the execution of the tracking loop stages S104-S106 is the use of a monoplane X-ray imaging system.

Referring to on overall execution of flowchart 100, a stage S101 of flowchart 100 encompasses an insertion of a catheter into a heart cavity. Upon the insertion, a 3D US probe (e.g., probe 31 shown in FIG. 1) is utilized to selectively trigger the tracking loop as needed. Specifically, if the 3D US probe illustrates the catheter is at the heart wall and on target, then flowchart 100 from stage S101 through stages S102 and S103 to termination. Otherwise, if the 3D US probe illustrates the catheter is not at the heart wall during stage S102, then tracking loop stages S104-S106 are executed. Alternatively, if the 3D US probe illustrates the catheter is not on target at the heart wall during stage S103, then the catheter is retracted during a stage S107 prior to an execution of tracking loop stages S104-S106.

FIG. 5 illustrates a catheter image tracking module 51b for implementing stages S63 and S64 (FIG. 2) in accordance with a process known herein as "graph-cut segmentation mode" in view of the fact the manner by which catheter is segmented is based on a graph-cut method.

Generally, the "graph-cut segmentation mode" implements a flowchart 110 shown in FIG. 10 involving a catheter tip location in 3D US volume space during a stage S111 and a catheter segmentation in 3D US volume space during a stage S112.

In one embodiment of stage S111, the catheter tip may be manually identified in the 3D US volume space.

In a more reliable second embodiment of stage S111, a flowchart 120 representative of a catheter tip localization method of the present invention as shown in FIG. 11 is executed.

Referring to FIG. 11, upon the catheter being inserted within an anatomical region, a stage S121 of flowchart 120 encompasses an X-ray image acquisition of the catheter at a 1^{st} gantry angle during a specified cardiac phase (e.g., an end diastole phase) and a specified respiratory phase (e.g., an end respiratory phase) using known cardiac and respiratory gating techniques and a stage S122 of flowchart 120 encompasses a manual or automatic segmentation of the catheter tip in the X-ray image acquired during stage S121.

For a monoplane X-ray imaging system, a stage S123 of flowchart 120 encompasses an X-ray image acquisition of the catheter at a 2nd gantry angle during the same specified cardiac phase and the same specified respiratory phase using known cardiac and respiratory gating techniques and a stage S124 of flowchart 120 encompasses a manual or automatic segmentation of the catheter tip in the X-ray image acquired during stage S123.

For a biplane X-ray imaging system, stages S121/S122 and stages S123/S124 may be executed simultaneously.

For either X-ray imaging system, a corresponding 3D location of the catheter tip in the 2D X-ray coordinate system is reconstructed during a stage S125 of flowchart 120. In one embodiment of stage S125, a known epipolar constraint is utilized to reconstruct the 3D location of the catheter tip in the 2D X-ray coordinate system.

Thereafter, during a stage S126 of flowchart 120, a reconstructed 2D X-ray coordinate location of the catheter tip is converted into a 3D US real-time coordinate location using system calibration and real-time tracking. In one embodiment of stage S126, a manual alignment is used as the basis for the conversion. In a second embodiment of stage S126, a known electromagnetic tracking technique is used as the basis for the conversion.

Referring back to FIG. 10, flowchart 120 facilitates an execution of a flowchart 150 (FIG. 14) during stage S112.

Flowchart 150 is premised on a minimization of the following energy functional [2]:

$$\{x_p\} = \min_{\{x_p\}} \sum_{p} D_p(x_p) + \sum_{p \sim q} w_{pq}[x_p \neq x_q] \qquad [2]$$

where x_p is the label of the pixel p and $p \sim q$ indicates that the pixels p and q are neighbors. The first term of the energy functional $D_p(x_p)$ describes the cost of assigning a pixel to foreground or to background based on its label. The cost of assigning a pixel to the foreground is chosen as the absolute difference between the filter response f_p at that pixel and the minimum filter response ε of the image. This cost gets its minimum value at the pixels inside the catheter as the filter that highlights the catheter gives its lowest response at those pixels. In a similar way, the cost of assigning a pixel to background is chose as the absolute difference between the filter response f_p at that pixel and the mean filter response μ of the image.

On the other hand, the second pair wise part works as a regularization term. When two neighboring pixels p and q, have different labels x_p and x_q, the predicate $[x_p \neq x_q]$ takes the value 1 and w_{pq} accumulates to the energy, otherwise it takes the value 0 and w_{pq} has no contribution to the energy. As a natural choice for w_{pq} that favors the assignment of the same label to the nearby pixels with similar filter response, the similarity measure $w_{pq} = e^{-\beta|f_p - f_q|}$ may be utilized.

To find the global minimum of equation [2], a flowchart 130 as shown in FIG. 12 is executed for constructing a weighted graph, such as, for example, a weighted graph 140 shown in FIG. 13.

Referring to FIGS. 12 and 13, a stage S131 of flowchart 130 encompasses a construction of a node to the graph for each pixel. As this is a binary optimization problem, a stage S132 of flowchart 130 encompasses an addition of two (2) terminal nodes s and t representing background and foreground, respectively. Next, a stage S133 of flowchart 130 encompasses a connection of terminal node s to each node representing pixels and assignment of the weight, and a connection of terminal node t to each node and assignment of the weight $|f_p - \mu|$ to those edges. Finally, a stage S134 of flowchart 130 encompasses an addition of edges that connect the nodes representing neighboring pixels, and assignment of the weight w_{pq} to the edges.

Referring now to FIG. 14, flowchart 150 is executed for segmenting the catheter in the 3D US volume space. Specifically, a localized tool tip in 3D US volume space as determined by flowchart 120 (FIG. 11) is utilized as the initial seed point and a stage S151 of flowchart 150 encompasses a generation of a small neighborhood around the identified tool tip to compute a probability distribution function (PDF) of the catheter intensity. Next, a stage S152 of flowchart 150 encompasses a computation of the term $D_p(x_p)$ for equation [2] to assign the weight to each terminal link for purposes of constructing the weighted graph, and a stage S153 of flowchart 150 encompasses an application of a graph-cut to the constructed graph to obtain an initial segmentation.

The initial segmentation may not be ideal, because not only the catheter itself but also some other structure around it with similar appearance may be included into the segmentation. Thus, a stage S154 of flowchart 150 encompasses an application of a catheter shape filter to refine the initial segmentation. The catheter shape filter is designed to exploit the tubular structure of the catheter and may be a 2^{nd} derivative of 2D Gaussian kernel with 3D orientation in the design. In one embodiment, an orientation of the filter is set by computing the principal direction of the initial segmentation.

Upon completion of stage S154, a stage S155 of flowchart 150 encompasses a construction of a new 3D graph the same manner as stage S152. A final catheter segmentation is done by applying graph-cut again on this new graph during a stage S156 of flowchart 150.

From the description of FIGS. 7-14, those having ordinary skill in the art will appreciate the “tip detection mode” and the “graph-cut segmentation mode” of catheter tracking device 51a (FIG. 4) and catheter tracking device 51b (FIG. 5), respectively. FIG. 6 illustrates a catheter image tracking module 51c for implementing stages S63 and S64 in accordance with a combination of “tip detection mode” as executed by a tool detection module 52c and the “graph-cut segmentation mode” as executed by the image segmentation module 53c.

From the description of FIGS. 1-14, those having skill in the art will have a further appreciation on how to implement a tool tracking method for any application in accordance with the present invention.

In practice, any number of X-ray imaging device 20, 3D US imaging device 30 and a tool tracking device may be integrated into a single device.

While various exemplary embodiments of the present invention have been illustrated and described, it will be understood by those skilled in the art that the exemplary embodiments of the present invention as described herein are illustrative, and various changes and modifications may be made and equivalents may be substituted for elements thereof without departing from the true scope of the present invention. In addition, many modifications may be made to adapt the teachings of the present invention without departing from its central scope. Therefore, it is intended that the present invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out the present invention, but that the present invention includes all embodiments falling within the scope of the appended claims.

Claims

1. An image-guided system, comprising:

an X-ray imaging device (20) for generating at least one X-ray image (25, 26) illustrating a tool (41) within an anatomical region (40);

an ultrasound imaging device (30) for generating an ultrasound image (33) illustrating the tool (41) within the anatomical region (40); and

a tool tracking device (50) for tracking the tool (41) within the anatomical region (40),

wherein the tool tracking device (50) is operable to localize a portion of the tool (41) as located within the ultrasound image (33) responsive to an identification of the portion of the tool (41) as located within the at least one X-ray image (25, 26), and

wherein the tool tracking device (50) is further operable to execute an image segmentation of an entirety of the tool (41) as located within the ultrasound image (33) relative to a localization of the portion of the tool (41) as located within the ultrasound image (33).

2. The image-guided system of claim 1, wherein the tool (41) is a catheter.

3. The image-guided system of claim 1, wherein a portion of the tool (41) is a tip of the tool (41).

4. The image-guided system of claim 1, wherein the X-ray imaging device (20) is one of a group including a monoplane X-ray imaging device and a bi-plane X-ray imaging device.

5. The image-guided system of claim 1, wherein a localization of the portion of the tool (41) as located within the ultrasound image (33) responsive to the identification of the portion of the tool (41) as located within the at least one X-ray image (25, 26) includes:

localizing the portion of the tool (41) along at least one line extending from a X-ray source (21) to an X-ray detector (22) through an ultrasound volume (32).

6. The image-guided system of claim 5, wherein the at least one line serves as at least one boundary constraint for an execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33).

7. The image-guided system of claim 1, wherein an execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33) relative to the localization of the portion of the tool (41) as located within the ultrasound image (33) includes:

constructing an initial weighted energy graph (140); and

executing a graph-cut segmentation of the initial weighted energy graph (140).

8. The image-guided system of claim 7, wherein the execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33) relative to the localization of the portion of the tool (41) as located within the ultrasound image (33) further includes:

applying a shape filter to the graph-cut segmentation of the initial weighted energy graph (140);

constructing a final weighted energy graph (140) as a function of the application of the shape filter to the graph-cut segmentation of the initial weighted energy graph (140); and

executing a graph-cut segmentation of the final weighted energy graph (140).

9. A tool tracking device (50) for tracking a tool (41) within an anatomical region (40), the tool tracking device (50) comprising:

a tool (41) identification module operable to localize a portion of the tool (41) as located within an ultrasound image (33) illustrating the tool (41) within the anatomical region (40) responsive to an identification of the portion of the tool (41) as located within the at least one X-ray image (25, 26) illustrating the tool (41) within the anatomical region (40), and

an image segmentation module operable to execute an image segmentation of an entirety of the tool (41) as located within the ultrasound image (33) relative to a localization of the portion of the tool (41) as located within the ultrasound image (33).

10. The tool tracking device (50) of claim 9, wherein the tool (41) is a catheter.

11. The tool tracking device (50) of claim 9, wherein a portion of the tool (41) is a tip of the tool (41).

12. The tool tracking device (50) of claim 9, wherein a localization of the portion of the tool (41) as located within the ultrasound image (33) responsive to the identification of the portion of the tool (41) as located within the at least one X-ray image (25, 26) includes:

localizing the portion of the tool (41) along at least one line extending from a X-ray source (21) to an X-ray detector (22) through an ultrasound volume (32).

13. The tool tracking device (50) of claim 12, wherein the at least one line serves as at least one boundary constraint for an execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33).

14. The tool tracking device (50) of claim 9, wherein an execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33) relative to the localization of the portion of the tool (41) as located within the ultrasound image (33) further includes:

constructing an initial weighted energy graph (140); and

executing a graph-cut segmentation of the initial weighted energy graph (140).

15. The tool tracking device (50) of claim 14, wherein the execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33) relative to the localization of the portion of the tool (41) as located within the ultrasound image (33) further includes:

applying a shape filter to the graph-cut segmentation of the initial weighted energy graph (140);

constructing a final weighted energy graph (140) as a function of the application of the shape filter to the graph-cut segmentation of the initial weighted energy graph (140); and

executing a graph-cut segmentation of the final weighted energy graph (140).

16. An image-guided method for tracking a tool (41) within an anatomical region (40), comprising:

generating at least one X-ray image (25, 26) illustrating the tool (41) within an anatomical region (40);

generating an ultrasound image (33) illustrating the tool (41) within the anatomical region (40);

localizing a portion of the tool (41) as located within the ultrasound image (33) responsive to an identification of the portion of the tool (41) as located within the at least one X-ray image (25, 26); and

executing an image segmentation of an entirety of the tool (41) as located within the ultrasound image (33) relative to a localization of the portion of the tool (41) as located within the ultrasound image (33).

17. The image-guided method of claim 16, wherein localizing the portion of the tool (41) as located within the ultrasound image (33) responsive to the identification of the portion of the tool (41) as located within the at least one X-ray image (25, 26) includes:

localizing the portion of the tool (41) along at least one line extending from a X-ray source (21) to an X-ray detector (22) through an ultrasound volume (32).

18. The image-guided method of claim 17, wherein the at least one line serves as at least one boundary constraint for an execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33).

19. The image-guided method of claim 16, wherein an execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33) relative to the localization of the portion of the tool (41) as located within the ultrasound image (33) further includes:

constructing an initial weighted energy graph (140); and

executing a graph-cut segmentation of the initial weighted energy graph (140).

20. The image-guided method of claim 19, wherein the execution of the image segmentation of the entirety of the tool (41) as located within the ultrasound image (33) relative to the localization of the portion of the tool (41) as located within the ultrasound image (33) further includes:

applying a shape filter to the graph-cut segmentation of the initial weighted energy graph (140);

constructing a final weighted energy graph (140) as a function of the application of the shape filter to the graph-cut segmentation of the initial weighted energy graph (140); and

executing a graph-cut segmentation of the final weighted energy graph (140).

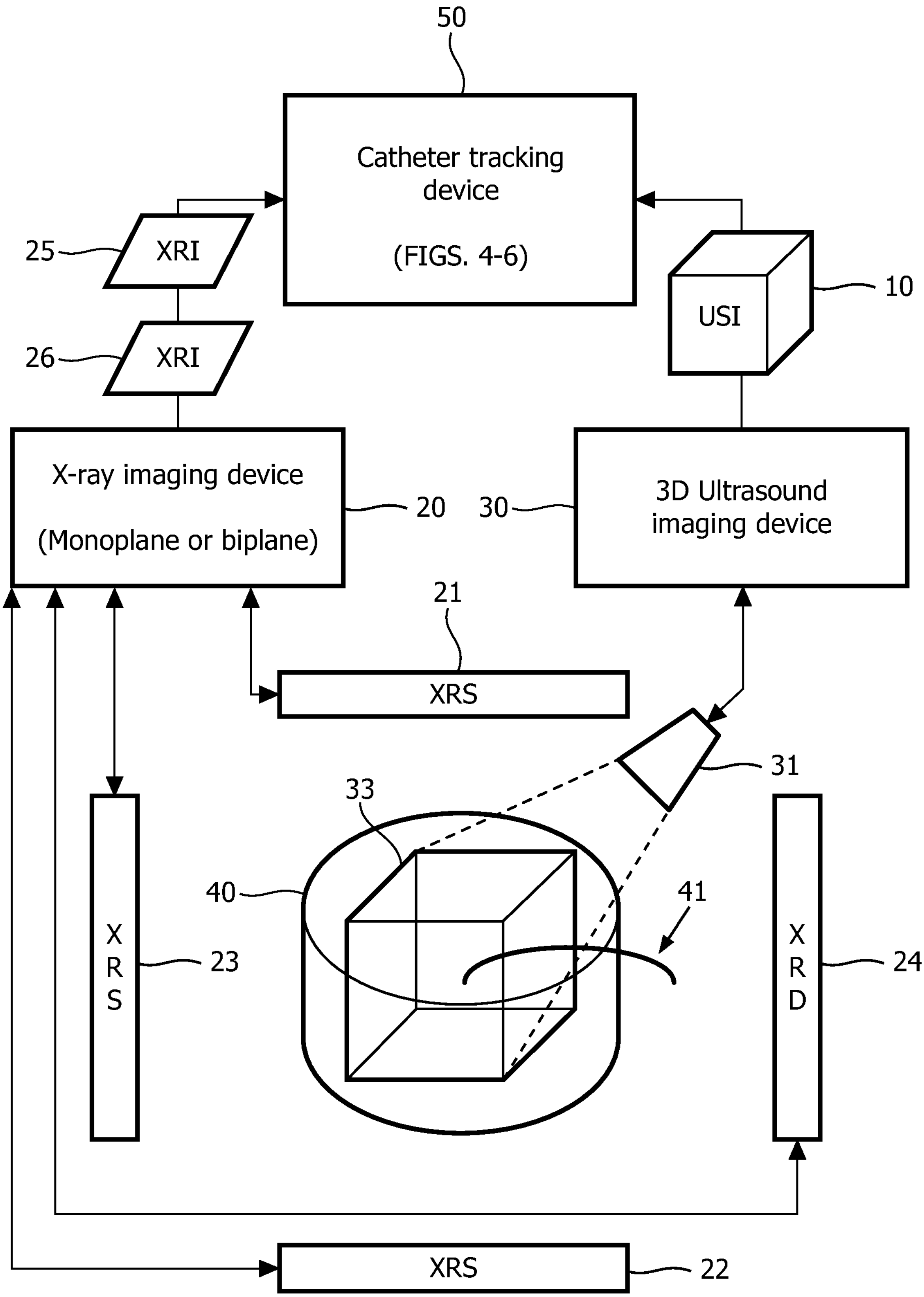
50
Catheter tracking device
(FIGS. 4-6)
25
XRI
26
XRI
USI
10
X-ray imaging device
(Monoplane or biplane)
20
30
3D Ultrasound imaging device
21
XRS
31
33
40
41
X R S
23
X R D
24
XRS
22

FIG. 1

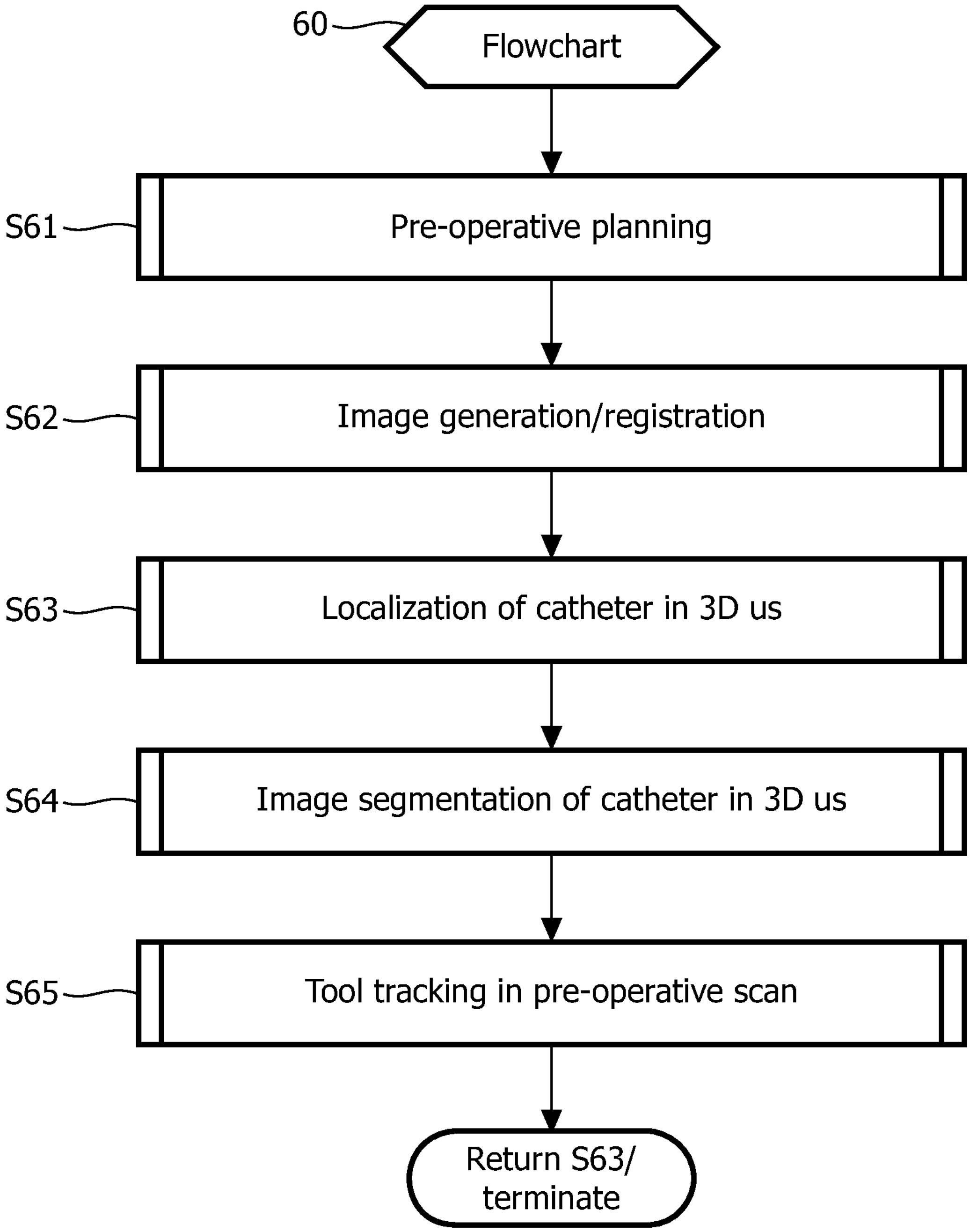
60
Flowchart
S61
Pre-operative planning
S62
Image generation/registration
S63
Localization of catheter in 3D us
S64
Image segmentation of catheter in 3D us
S65
Tool tracking in pre-operative scan
Return S63/
terminate

FIG. 2

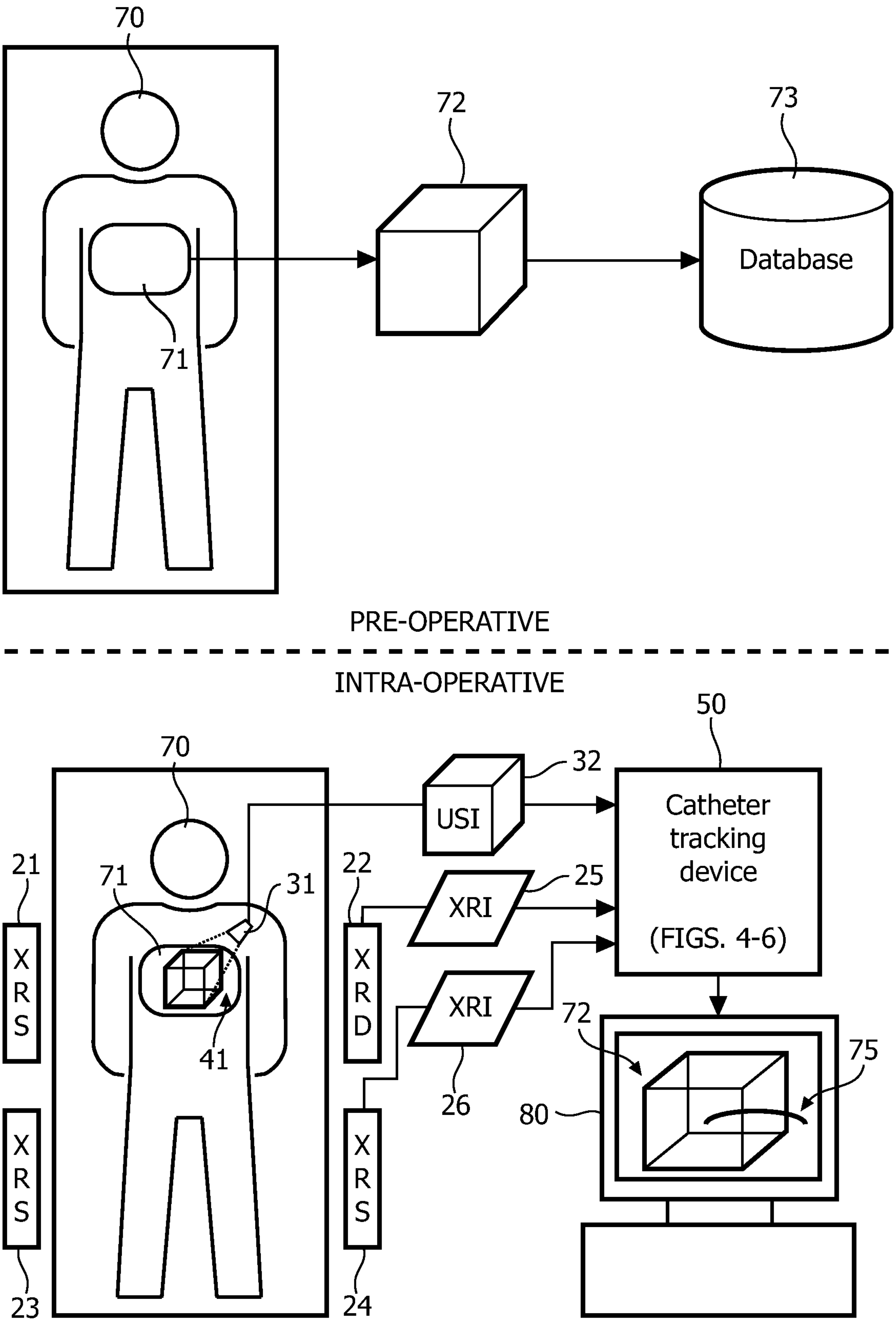
70
72
73
Database
71
PRE-OPERATIVE
INTRA-OPERATIVE
50
70
32
USI
Catheter
tracking
device
(FIGS. 4-6)
21
71
31
22
XRI
25
X
R
S
X
R
D
41
XRI
72
75
26
80
X
R
S
X
R
S
23
24

FIG. 3

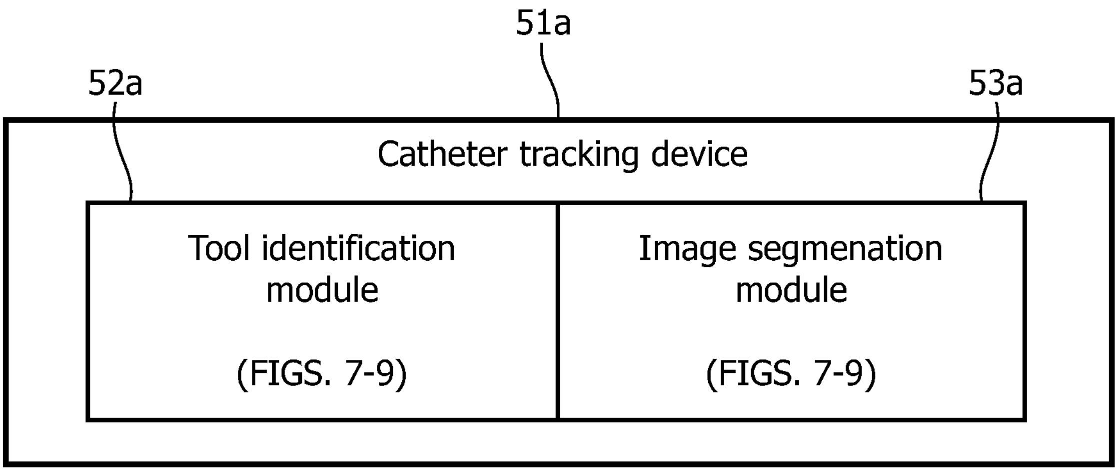

FIG. 4

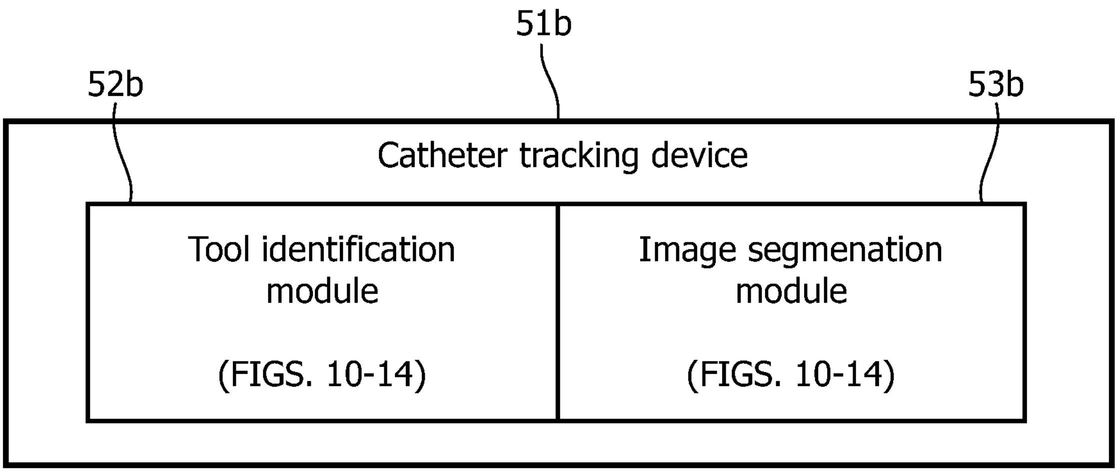

FIG. 5

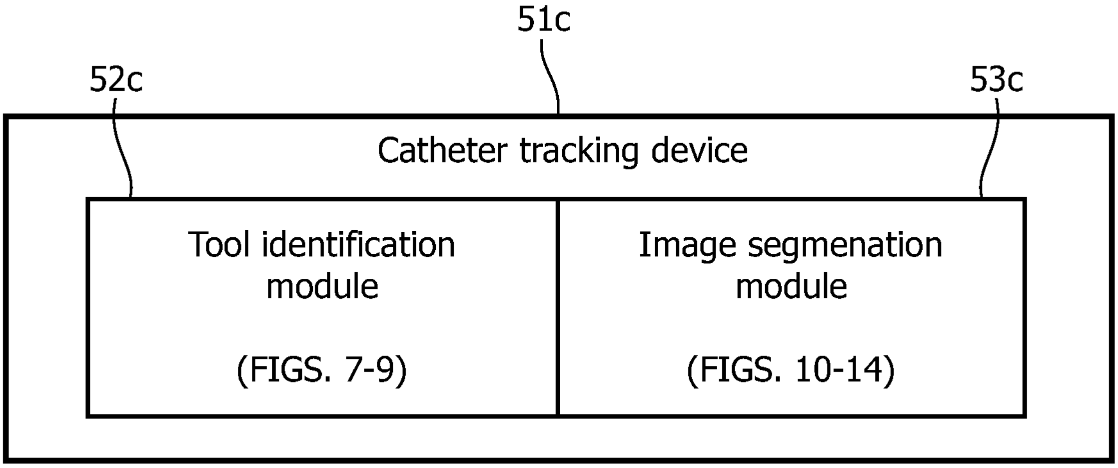

FIG. 6

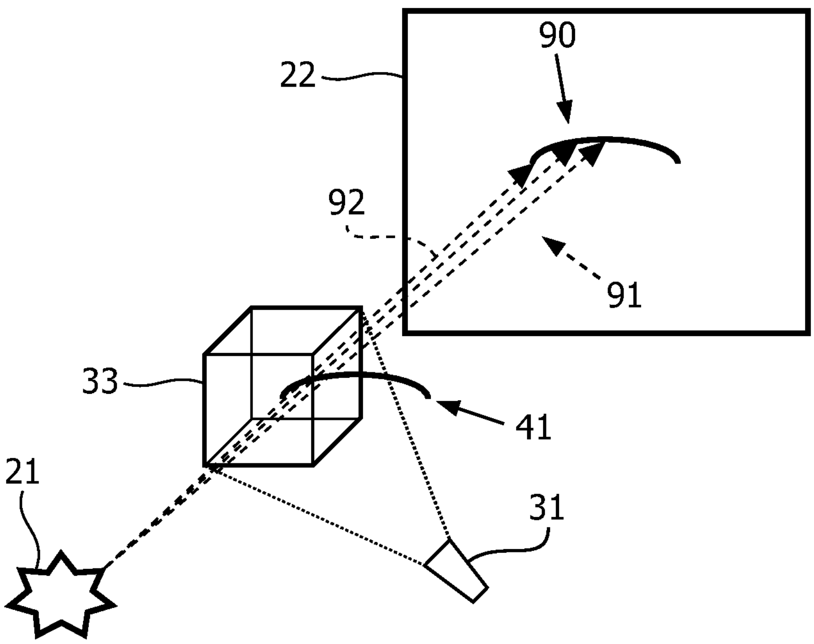

FIG. 7

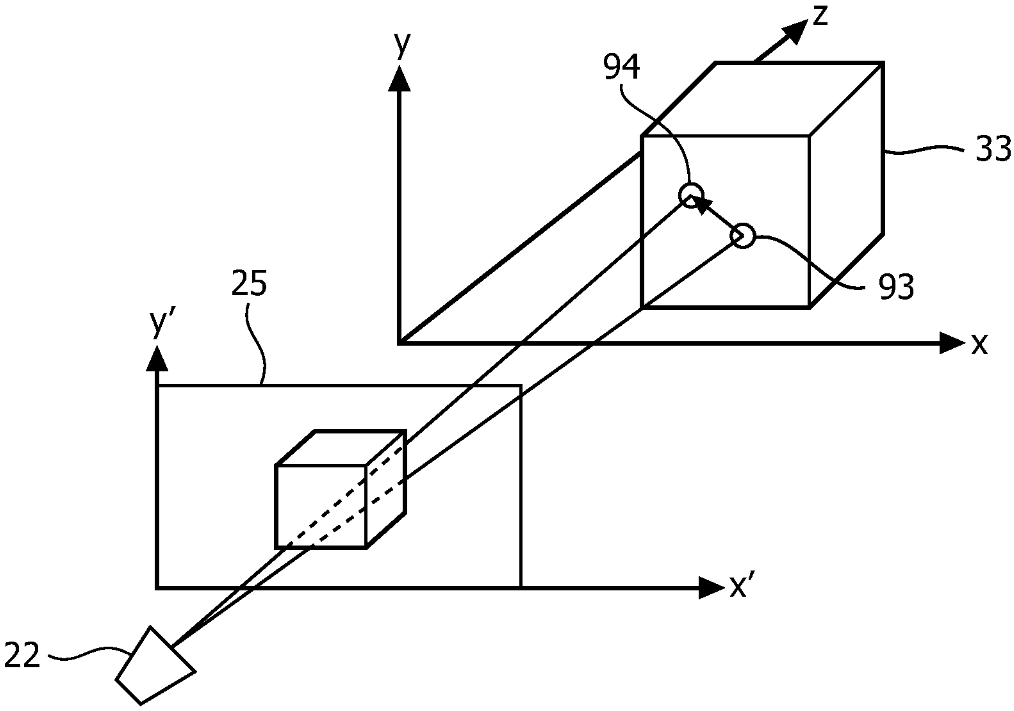

FIG. 8

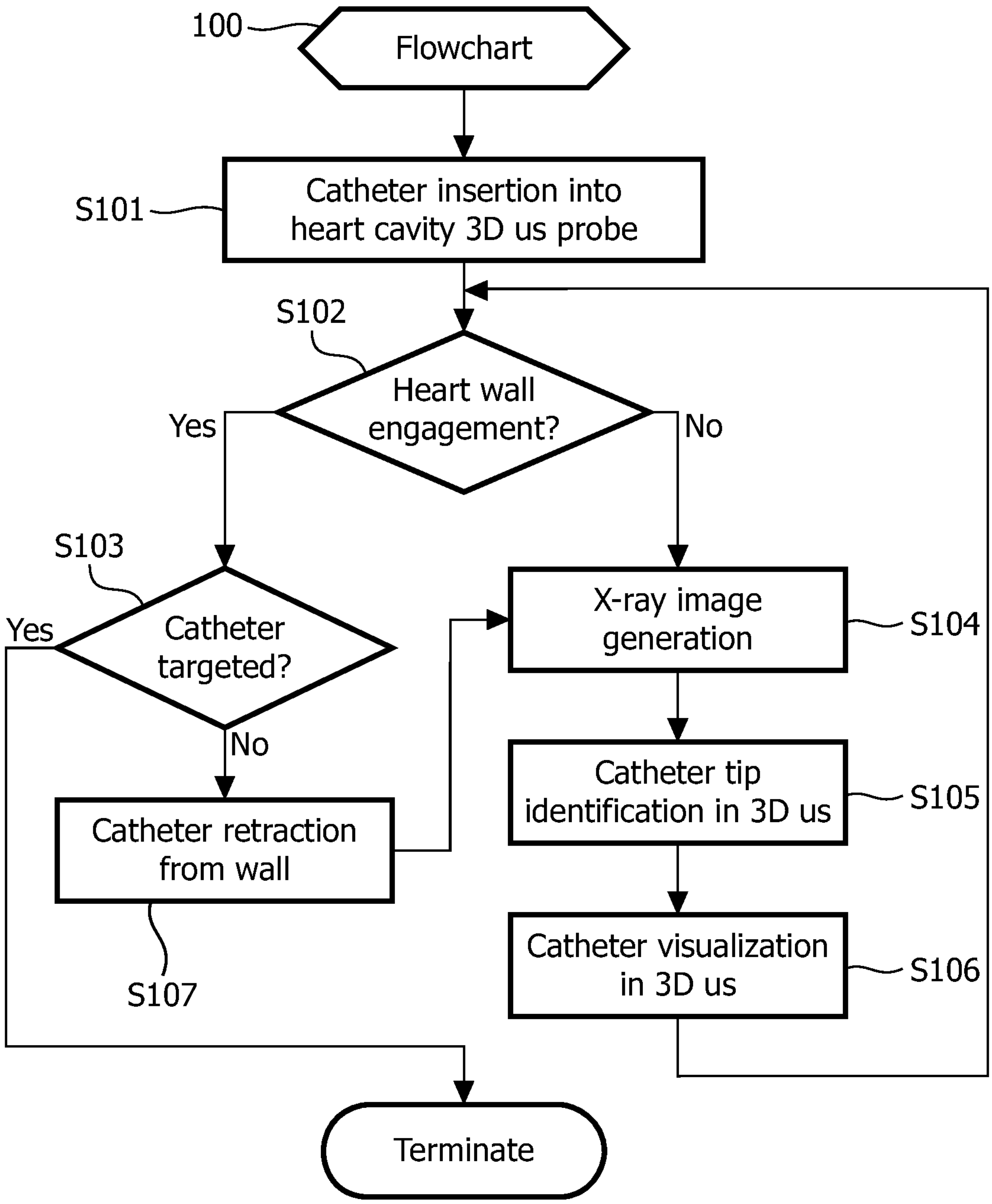
100
Flowchart
S101
Catheter insertion into heart cavity 3D us probe
S102
Heart wall engagement?
Yes
No
S103
Catheter targeted?
Yes
No
X-ray image generation
S104
Catheter tip identification in 3D us
S105
Catheter retraction from wall
S107
Catheter visualization in 3D us
S106
Terminate

FIG. 9

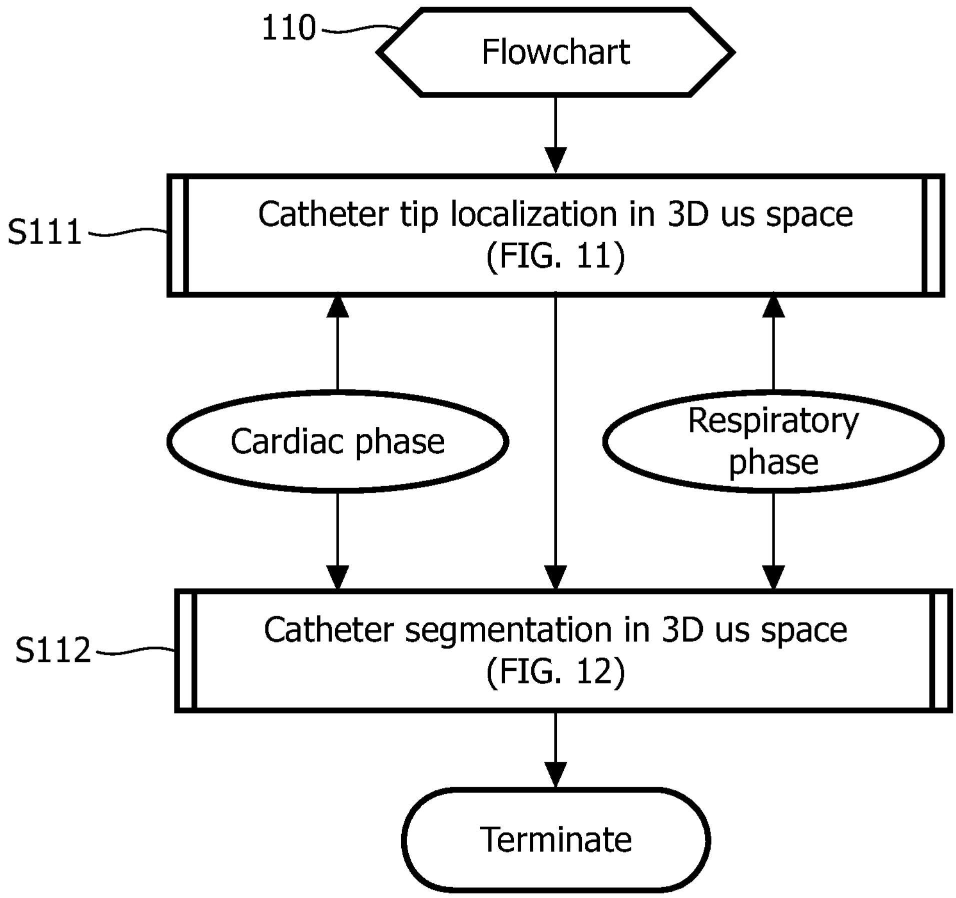
110
Flowchart
S111
Catheter tip localization in 3D us space
(FIG. 11)
Cardiac phase
Respiratory
phase
S112
Catheter segmentation in 3D us space
(FIG. 12)
Terminate

FIG. 10

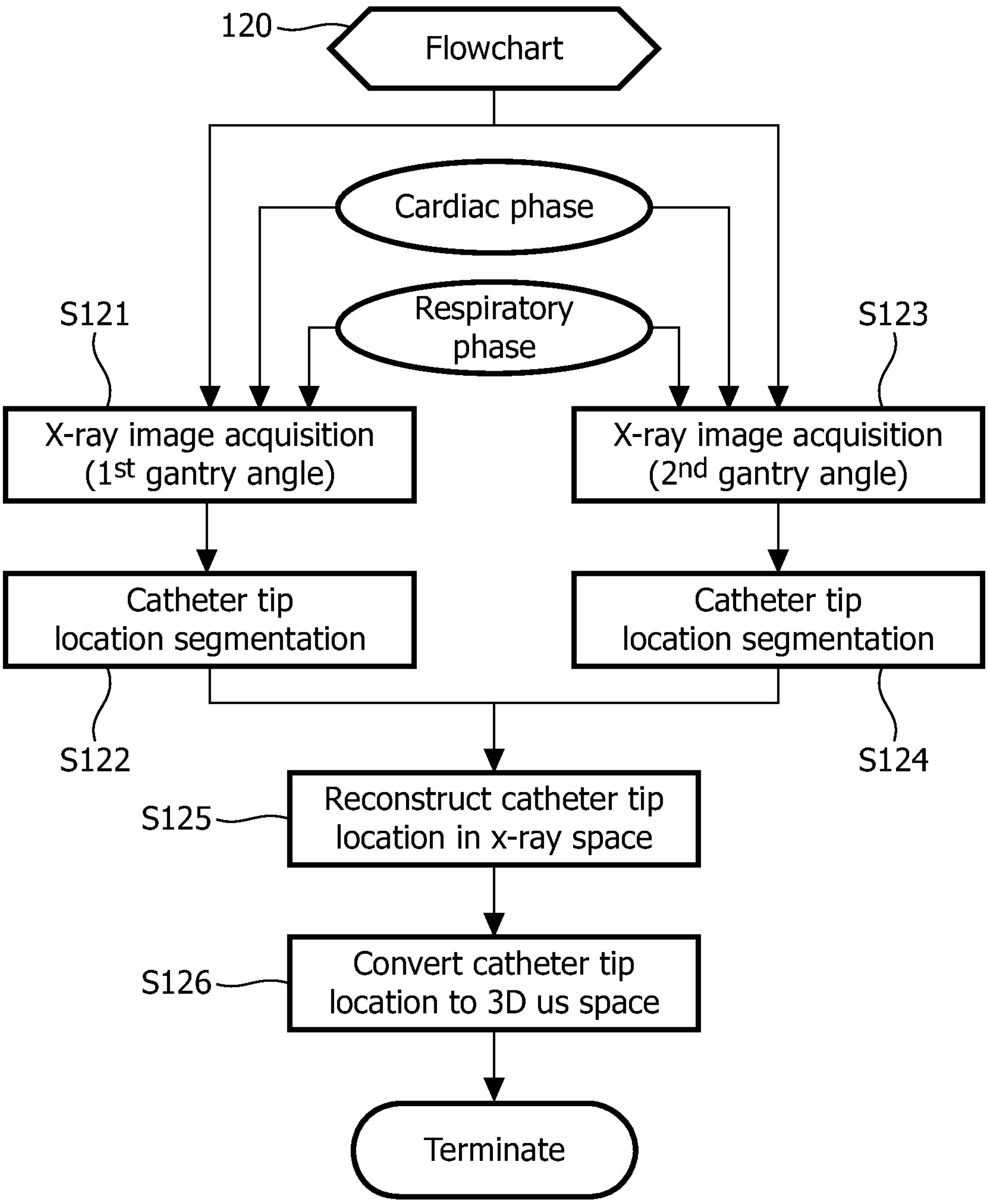
120
Flowchart
Cardiac phase
Respiratory phase
S121
S123
X-ray image acquisition (1st gantry angle)
X-ray image acquisition (2nd gantry angle)
Catheter tip location segmentation
Catheter tip location segmentation
S122
S124
S125
Reconstruct catheter tip location in x-ray space
S126
Convert catheter tip location to 3D us space
Terminate

FIG. 11

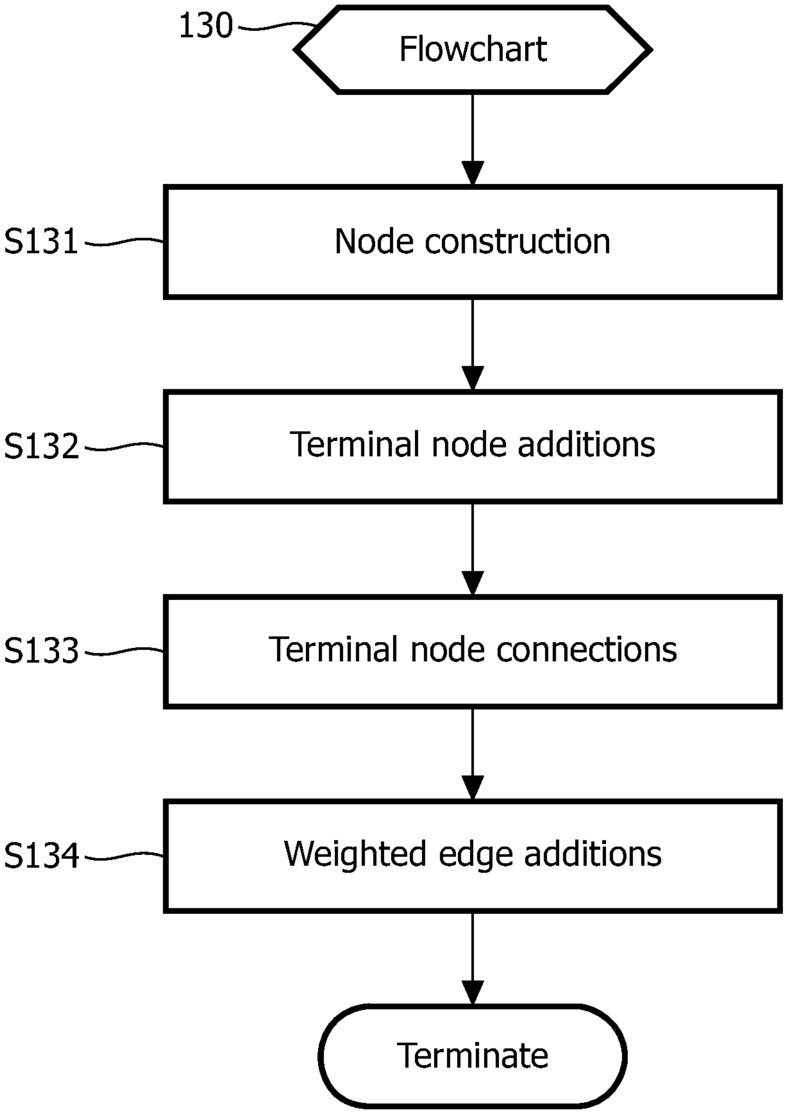
130
Flowchart
S131
Node construction
S132
Terminal node additions
S133
Terminal node connections
S134
Weighted edge additions
Terminate

FIG. 12

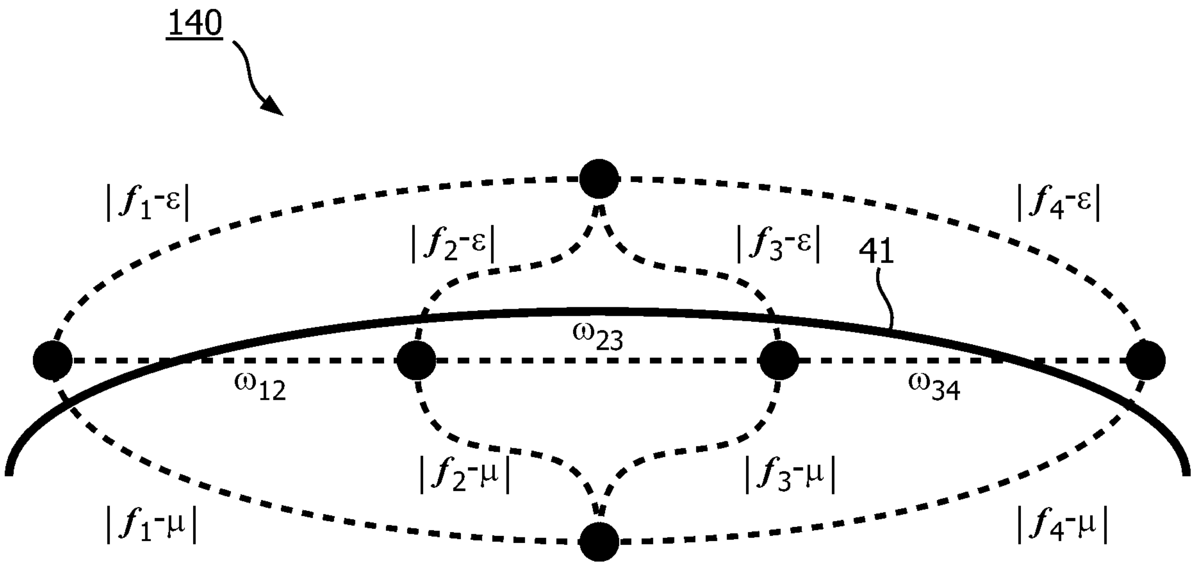
140
|f_1-ε|
|f_4-ε|
|f_2-ε|
|f_3-ε|
41
ω_{23}
ω_{12}
ω_{34}
|f_2-μ|
|f_3-μ|
|f_1-μ|
|f_4-μ|

FIG. 13

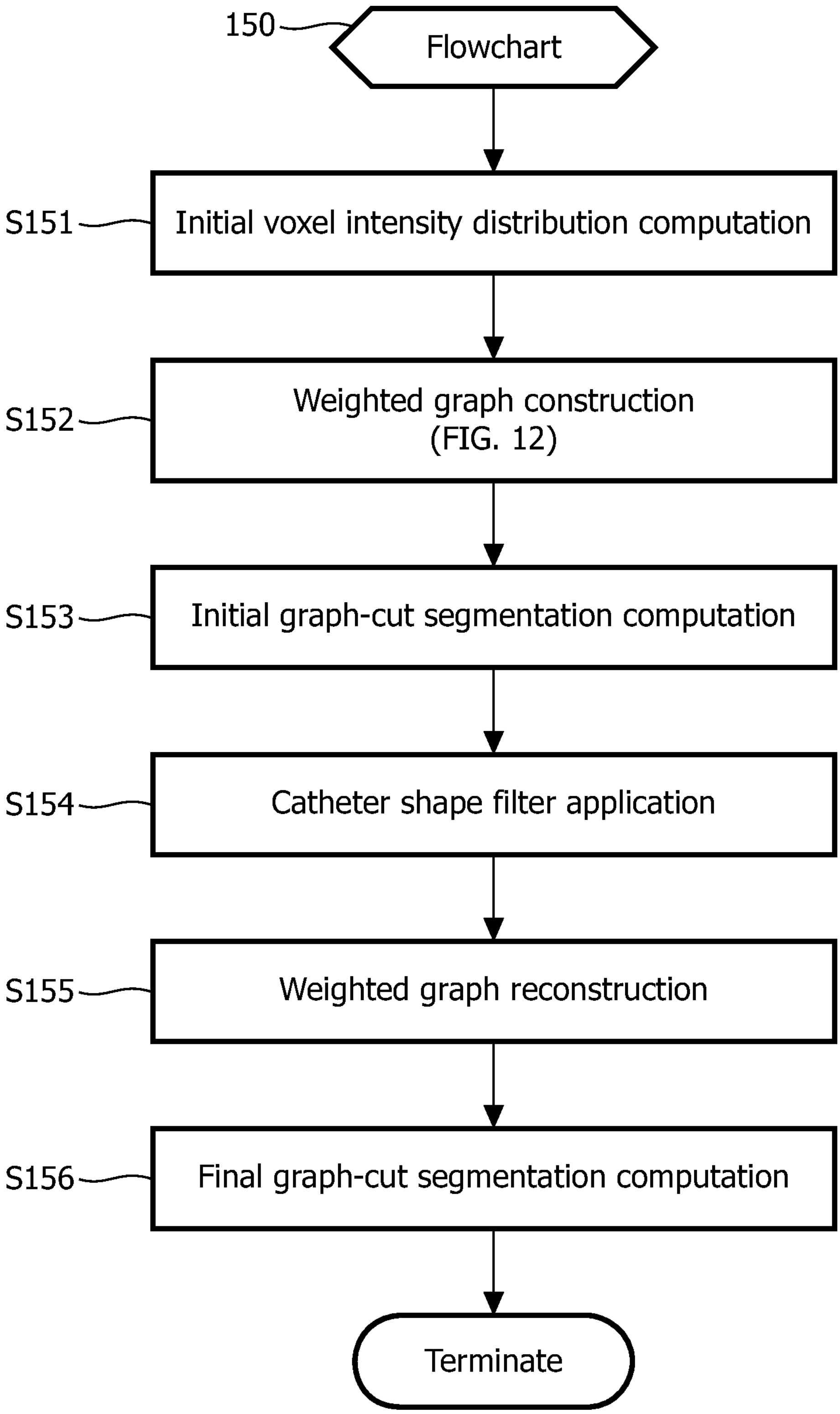
150
Flowchart
S151
Initial voxel intensity distribution computation
S152
Weighted graph construction
(FIG. 12)
S153
Initial graph-cut segmentation computation
S154
Catheter shape filter application
S155
Weighted graph reconstruction
S156
Final graph-cut segmentation computation
Terminate

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/050109

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/12 A61B8/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	DE 102 10 648 A1 (SIEMENS AG [DE]) 2 October 2003 (2003-10-02) paragraphs [0022], [0021]	1-4, 9-11,16 5-8, 12-15, 17-20
Y	US 6 389 104 B1 (BANI-HASHEMI ALI [US] ET AL) 14 May 2002 (2002-05-14) column 4, lines 55-58	5,6,12, 13,17,18
Y	US 2009/136103 A1 (SONKA MILAN [US] ET AL) 28 May 2009 (2009-05-28) paragraphs [0279], [0276]	7,8,14, 15,19,20
A	WO 2005/092198 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; GERARD OLIVIER [FR]; FLORENT RAOU) 6 October 2005 (2005-10-06) the whole document	1,9,16

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 March 2012	30/03/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Anscombe, Marcel

Form PCT/ISA/210 (second sheet) (April 2005)

International application No
PCT/IB2012/050109

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2001/029334 A1 (GRAUMANN RAINER [DE] ET AL) 11 October 2001 (2001-10-11) the whole document -----	1,9,16
A	US 2003/199748 A1 (CAMUS ESTELLE [DE] ET AL) 23 October 2003 (2003-10-23) the whole document -----	1,9,16

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2012/050109

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2001029334 A1	11-10-2001
US 2003199748 A1	23-10-2003	DE 10210650 A1	16-10-2003
		US 2003199748 A1	23-10-2003

patsnap

专利名称(译)	三维超声中导管的可视化		
公开(公告)号	EP2663237A1	公开(公告)日	2013-11-20
申请号	EP2012701029	申请日	2012-01-10
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	YAN PINGKUN PARTHASARATHY VIJAY MANZKE ROBERT JAIN AMEET KUMAR		
发明人	YAN, PINGKUN PARTHASARATHY, VIJAY MANZKE, ROBERT JAIN, AMEET KUMAR		
IPC分类号	A61B6/12 A61B8/08		
CPC分类号	A61B34/20 A61B6/12 A61B8/0883 A61B8/466 A61B8/483		
代理机构(译)	STEFFEN , THOMAS		
优先权	61/432327 2011-01-13 US		
其他公开文献	EP2663237B1		
外部链接	Espacenet		

摘要(译)

图像引导系统采用X射线成像装置（20）产生一个或多个X射线图像（25,26），示出解剖区域（40）内的工具（41）和超声成像装置（30）用于产生描绘解剖区域（40）内的工具（41）的超声图像（33）。图像引导系统还采用工具跟踪装置（50），用于在视觉上跟踪解剖区域（40）内的工具（41）。在操作中，工具跟踪装置（50）响应于工具（41）的部分的识别位于X射线图像内而将工具（41）的一部分定位在超声图像（33）内（s）（25,26），并且相对于位于超声图像内的工具（41）的部分的定位，执行位于超声图像（33）内的整个工具（41）的图像分割。（33）。