(54) Title: ROBOTIC CONTROL OF AN ENDOSCOPE FROM ANATOMICAL FEATURES

FIG. 4

(57) Abstract: A robotic control system employs a robot unit (10) and a control unit (20). The robot unit (10) includes an endoscope (12) for generating an endoscope image (14), and a robot (11) for moving the endoscope (12) within an anatomical region. The control unit (20) includes an endoscope controller (22) for a determination of an endoscope pose within the anatomical region for an intraoperative visualization of the anatomical feature within the endoscope image (14), wherein the endoscope path is derived from a delineation of a volume coordinate position of the anatomical feature within a pre-operative image (43) of the anatomical region. The control unit (20) further includes a robot controller (21) for commanding the robot (11) to move the endoscope (12) to the endoscope pose within the anatomical region to visualize the anatomical feature within the endoscope image (14).

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

ROBOTIC CONTROL OF AN ENDOSCOPE FROM ANATOMICAL FEATURES

The present invention generally relates to robotic control of an endoscope during a minimally invasive surgery (e.g., a minimally invasive coronary bypass grafting surgery). The present invention specifically relates to the robotic control being based upon a determination of an endoscope pose within the anatomical region for visualizing an anatomical feature within an endoscope image.

Minimally invasive surgery is performed using elongated instruments inserted into a patient's body through small ports. For a surgery involving an endoscope, an endoscopic camera is inserted into a port to provide visualization of the surgical site. For example, a surgeon may hold and manually control two (2) laparoscopic instruments during the surgery while a physician assistant controls the endoscope and receives instructions from the surgeon to move the endoscope to specific locations during the surgery.

The surgeon's communication to the physician assistant of an exact desired location of the endoscope may be difficult, especially given the challenging hand-eye coordination required to move the endoscope and instruments around the pivot points at the entrance ports to the body, and given the different positions and frames of reference of the surgeon, physician assistant and a video image of the surgical site. For example, "Left" on the video image, may mean "right and down" at the physician assistant's hands. To overcome these difficulties, controlling the endoscope using an automated device or robot has been proposed in prior art, essentially removing the physician assistant from this task during surgery. However, given that the surgeon is controlling two (2) laparoscopic instruments with both hands, the method with which the physician can control the robotic endoscope is important, and a number of propositions have been addressed in prior art.

Generally, the prior art methods for guiding a robotic system are premised on (1) guiding the robot using different input devices (e.g., head motion sensors, a joystick or voice control), (2) guiding the robot using live endoscope images by determining a three-dimensional position of an anatomical feature with respect to the endoscope and moving the endoscope or a surgical instrument toward that anatomical feature, or (3) guiding the robot from other types of images using live image and recorded intra-operative images.

More particularly, human-robot interaction methods known in art use either specialized hardware or live and/or recorded intra-operative images to move the robot to a desired location. These methods assume that the user knows location of the anatomical feature of interest with respect to the endoscope and that the particular anatomical feature is

visible in the endoscope view. This is not always true, as the anatomical feature may be obstructed within the endoscope view (e.g., coronary arteries may be covered with fat) or may be outside of the endoscope view.

The present invention provides methods for delineating a volume coordinate position of an anatomical feature within a pre-operative image of the anatomical region to facilitate an intra-operative visualization of the anatomical feature within an endoscope image of the anatomical region, particularly for an anatomical feature partially or entirely invisible in the endoscope image (e.g., obstructed within endoscope view or outside of endoscope view).

The term "visualize" or any variation thereof as used herein is broadly defined to describe a robotic control of an endoscope within an anatomical region whereby an anatomical feature of interest or section(s) therefore are either visible, partially or entirely, within the endoscope image or obstructed from being visible within the endoscope image yet susceptible to a surgeon forming a mental picture of an outline of the anatomical feature or section(s) thereof, partially or entirely, within the endoscope image.

One form of the present invention is a robotic control system employing a robot unit and a control unit. The robot unit includes an endoscope for generating an endoscope image, and a robot for moving the endoscope within an anatomical region. The control unit includes an endoscope controller to determine an endoscope pose within the anatomical region for an intra-operative visualization of an anatomical feature within the endoscope image, wherein the endoscope pose is derived from a delineation of a volume coordinate position of the anatomical feature within a pre-operative image of the anatomical region. The control unit further includes a robot controller to command the robot to move the endoscope to the endoscope pose within the anatomical region to visualize the anatomical feature within the endoscope image.

A second form of the present invention is a robotic control method for an endoscope for generating an endoscope image and a robot for moving the endoscope within the anatomical region. The robotic control method involves a determination of an endoscope pose within the anatomical region for an intra-operative visualization of an anatomical feature within the endoscope image, wherein the endoscope pose is derived from a delineation of a volume coordinate position of the anatomical feature within a pre-operative image of the anatomical region. The robotic control method further involves commanding the robot to move the endoscope to the endoscope pose within the anatomical region to visualize the anatomical feature within the endoscope image.

The term "pre-operative" as used herein is broadly defined to describe any activity executed before, during or after an endoscopic imaging of an anatomical region for purposes of acquiring a three-dimensional ("3D") image of the anatomical region. Examples of pre-operative imaging of the anatomical region includes, but are not limited to, computed

5   tomography ("CT") imaging, magnetic resonance ("MR") imaging, X-ray imaging, and 3D ultrasound ("3D US") imaging before, during or after an endoscopic imaging of an anatomical region.

The term "intra-operative" as used herein is broadly defined to describe any activity executed by the robot unit and/or the control unit during an endoscopic imaging of the

10   anatomical region. Examples of endoscopic imaging of the anatomical region include, but are not limited to, a coronary artery bypass grafting, a bronchoscopy, a colonscopy, a laparascopy, and a brain endoscopy.

Those having ordinary skill will appreciate the meaning of an "anatomical region" and an "anatomical feature" as known in the art. Nonetheless, examples of an anatomical

15   region include, but are not limited to, head, neck, thorax, abdomen, back, pelvis and perineum. Also, examples of an anatomical feature include, but are not limited to, components and areas of an organ/organ system (e.g., blood vessels of a heart, a trachea of a respiratory system, a cerebellum of a brain, a fundus of a gallbladder, an area of a sigmoid colon).

20   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 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

25   invention being defined by the appended claims and equivalents thereof.

FIG. 1 illustrates an exemplary embodiment of a robotic control system in accordance with the present invention.

FIG. 2 illustrates a flowchart representative of an exemplary embodiment of a robotic control method in accordance with the present invention.

30   FIG. 3 illustrates an exemplary surgical implementation of the flowchart shown in FIG. 2.

FIG. 4 illustrates an exemplary embodiment of an anatomical feature delineation module in accordance with the present invention.

FIGS. 5 and 6 illustrate exemplary implementations of an endoscope movement in accordance with the flowchart shown in FIG. 2.

As shown in FIG. 1, a robotic guiding system employs a robot unit 10 and a control unit 20 for any endoscopic procedure involving an endoscopic imaging of one or more anatomical features of an anatomical region (e. Examples of such endoscopic procedures include, but are not limited to, minimally invasive cardiac surgery, minimally invasive diagnostic interventions (e.g., arthoscopy), laparoscopic surgery, natural orifice transluminal surgery, single incision laparoscopic surgery and pulmonary /bronchoscopic surgery.

In practice, the endoscopic imaging may be of any anatomical feature or section(s) therefore within any anatomical region. Nonetheless, to facilitate an understanding of the present invention, exemplary embodiments will be described in the context of an endoscopic imaging of a left anterior descending artery of a heart within a thorax region of a patient.

Robot unit 10 includes a robot 11, an endoscope 12 rigidly attached to robot 11 and a video capture device 13 attached to the endoscope 12.

Robot 11 is broadly defined herein as any robotic device structurally configured with motorized control of one or more joints for maneuvering an end-effector as desired for the particular endoscopic procedure. In practice, robot 11 may have four (4) degrees-of-freedom, such as, for example, a serial robot having joints serially connected with rigid segments, a parallel robot having joints and rigid segments mounted in parallel order (e.g., a Stewart platform known in the art) or any hybrid combination of serial and parallel kinematics.

Endoscope 12 is broadly defined herein as any device structurally configured with ability to image from inside a body. Examples of endoscope 12 for purposes of the present invention include, but are not limited to, any type of scope, flexible or rigid (e.g., endoscope, arthroscope, bronchoscope, choledochoscope, colonoscope, cystoscope, duodenoscope, gastroscope, hysteroscope, laparoscope, laryngoscope, neuroscope, otoscope, push enteroscope, rhinolaryngoscope, sigmoidoscope, sinuscope, thorascope, etc.) and any device similar to a scope that is equipped with an image system (e.g., a nested cannula with imaging). The imaging is local, and surface images may be obtained optically with fiber optics, lenses, and miniaturized (e.g. CCD based) imaging systems.

In practice, endoscope 12 is mounted to the end-effector of robot 11. A pose of the end-effector of robot 11 is a position and an orientation of the end-effector within a coordinate system of robot 11 actuators. With endoscope 12 mounted to the end-effector of

robot 11, any given pose of the field-of-view of endoscope 12 (i.e., endoscope pose) within an anatomical region corresponds to a distinct pose of the end-effector of robot 11 within the robotic coordinate system. Consequently, each individual endoscope image of the anatomical region generated by endoscope 12 may be linked to a corresponding pose of the field-of-view of endoscope 12 within the robotic coordinate system.

Video capture device 13 is broadly defined herein as any device structurally configured with a capability to convert an endoscopic video signal from endoscope 12 into a computer readable temporal sequence of an endoscope image ("IOEI") 14. In practice, video capture device 13 may employ a frame grabber of any type for capturing individual digital still frames from the endoscopic video signal.

Still referring to FIG. 1, control unit 20 includes a robot controller 21 and an endoscope controller 22.

Robot controller 21 is broadly defined herein as any controller structurally configured to provide one or more robot actuator commands ("RAC") 29 to robot 11 for controlling a pose of the end-effector of robot 11 as desired for the endoscopic procedure. More particularly, robot controller 21 converts endoscope position commands ("EPC") 28 from endoscope controller 22 into robot actuator commands 29. For example, endoscope position commands 28 may indicate an endoscope path leading to desired three-dimensional position of a field-of-view of endoscope 12 within an anatomical region whereby robot controller 21 converts command 28 into commands 29 including an actuation current for each motor of robot 11 as needed to move endoscope 12 to the desired three-dimensional position of the field-of-view of endoscope 12 within an anatomical region.

Endoscope controller 22 is broadly defined herein as any controller structurally configured for implementing a robotic control method in accordance with the present invention and exemplary shown in FIG. 2. To this end, endoscope controller 22 may incorporate anatomical feature delineation module ("AFDM") 23, an image registration module ("IRM") 24, anatomical feature selection module ("AFSM") 25 and a visual servo module ("VSM") 26.

Anatomical feature delineation module 23 is broadly defined herein as any module structurally configured for processing a user input ("UI") 27 to delineate a volume coordinate position (X, Y, Z) for each anatomical feature of interest thereof within a pre-operative image 43 of the anatomical region for an intra-operative visualization of the anatomical feature(s) within endoscope image 14. In particular, an anatomical feature delineation as exemplarily implemented by a stage S31 of flowchart 30 as shown in FIG. 2.

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Image registration module 24 is broadly defined herein as any module structurally configured for registering pre-operative image 43 and endoscope image 14 as known in the art. In particular, an image registration as exemplarily implemented by a stage S32 of flowchart 30 shown in FIG. 2.

5   Anatomical feature selection module 25 is broadly defined herein as any module structurally configured for processing a user input 26 of a endoscopic viewing selection of a particular anatomical feature of interest or section(s). In particular, an anatomical feature selection exemplarily implemented by a stage S33 of flowchart 30 shown in FIG. 2.

Again, in context of FIG. 1, the term "visualize" as used herein is broadly defined to
10   describe a robotic control of endoscope 12 within an anatomical region whereby an anatomical feature of interest or section(s) thereof is either visible, partially or entirely, within endoscope image 14 or obstructed from being visible within endoscope image 14 yet susceptible to a surgeon forming a mental picture of an outline of the anatomical feature or section(s) thereof, partially or entirely, within endoscope image 14.

15   Visual servo module 26 is broadly defined herein as any module structurally configured for determining and moving endoscope 12 to an endoscope pose within the anatomical region that facilitates a visualization of the selected anatomical feature(s) or section(s) thereof within endoscope image 14. In particular, an endoscope pose determination as exemplarily implemented by a stage S34 of flowchart 30 shown in FIG. 2.

20   A description of flowchart 30 will now be provided herein to facilitate a further understanding of endoscope controller 22.

Referring to FIG. 2, a stage S31 of flowchart 30 encompasses anatomical feature delineation module 23 acquiring pre-operative image 43. For example, as shown in FIG. 3, an imaging device 41 (e.g., a CT device, a MRI device, an X-ray device or a 3D US device)
25   is operated to generate pre-operative image 43 of a thorax region of a patient 50 illustrating left and right coronary arteries 51 and 52 of patient 50. Anatomical feature delineation module 23 may acquire pre-operative image 43 as pre-operative image 43 is being generated by imaging device 41 as exemplarily shown in FIG. 3 or as previously stored in a database 42 as exemplarily shown in FIG. 3.

30   Anatomical feature delineation module 23 processes pre-operative image 43 to delineate a volume coordinate position for each anatomical feature of interest or section(s) thereof within the anatomical region. In practice, anatomical feature delineation module 23 may execute any technique for delineating the anatomical feature(s) of interest or section(s) thereof within pre-operative image 43. In one embodiment as shown in FIG. 4, anatomical

feature delineation module 23 provides four (4) modes 23a-23d for delineating volume

coordinate position(s) of anatomical feature(s) within pre-operative image 43.

Referring to FIG. 4, a volume coordinate position ("VCP") mode 23a delineates a

volume coordinate position of each anatomical feature within pre-operative image 43 as

5   selected by a user of module 23. Specifically, pre-operative image has a 3D coordinate

system defined by an X-axis, a Y-axis and a Z-axis. A user may move a cursor arrow to an

anatomical feature of interest or section(s) thereof within pre-operative image 43 or a two-

dimensional view 44 of the cursor within preoperative image 43 defined by a x-axis and a y-

axis. Upon a desired positioning of the cursor, the user may make a selection (e.g., a mouse

10   click) of the anatomical feature or section(s) thereof facilitating a delineation of a volume

coordinate position (X, Y, Z) of the anatomical feature. Additionally, the user may be able to

rotate pre-operative image 43 and corresponding two-dimensional view 44 of the cursor

within preoperative image 43 to orient the anatomical feature for desired view in the

endoscope image. In this case, an orientation of the anatomical feature is delineated with the

15   volume coordinate position (X, Y, Z). The cursor movement and user selection may be

repeated as desired for other areas of the selected anatomical feature and/or for additional

anatomical features.

Furthermore, a name may be assigned by the user to the selected anatomical feature(s)

or section(s) thereof (e.g., "left anterior descending artery"). Particularly, when the user has

20   interest in different sections of an anatomical feature (e.g., "upper section of left anterior

descending artery", "middle section left anterior descending artery", and "lower section of

left anterior descending artery").

An anatomical feature landmark ("AFL") mode 23b provides a pre-defined listing 45a

of landmark names for each anatomical feature or section(s) thereof within pre-operative

25   image 43 for VCP mode 23a. Any landmark selected in listing 45a (e.g., left anterior

descending artery as landmark 3) is highlighted within pre-operative image 43 via a cursor

arrow. The user may move the cursor arrow relative to the highlighted anatomical feature to

select section(s) of interest of the anatomical feature. Upon a desired positioning of the

cursor, the user may make a selection (e.g., a mouse click) of the anatomical feature

30   facilitating a delineation of a volume coordinate position (X, Y, Z) and optional orientation of

the anatomical feature or section thereof as described by VCP mode 23a and to name the

anatomical feature, particularly selected section(s).

A natural language interpretation mode ("NTLI") 23c utilizes a text interpreter ("TI")

47 to interpret natural language to generates a landmark listing 45b for VCP 23a.

Specifically, text interpreter 47 is used to interpret and convert free-text instructions generated during surgical planning to anatomical features which are then stored to be used to move endoscope 12 during the delineation process and/or endoscopic surgery. Anatomical descriptions are extracted into codes in a well-defined medical ontology (e.g., Systematized
5   Nomenclature of Medicine ("SNOMED") or the Foundational Model of Anatomy ("FMA").

       The following is an example of a free text report: *"EKG showed nonspecific ST segment changes. Echocardiography showed a normal left ventricle with some mild hypertrophy. On diagnostic cardiac catheterization, a lesion to the left anterior descending artery was identified. There was about 80% stenosis in the circumflex system. The posterior*
10   *descending artery had about a 70% stenosis. Bypass surgery recommended. "* From this report, text interpreter 47 extracts anatomical features: left anterior descending artery, circumflex system, posterior descending artery, etc. Further, from the ontology, the text interpreter 47 may determine anatomical relationship between identified anatomy (e.g., left descending artery and left circumflex artery arise from the left main artery). Further, general
15   location markers, such as "posterior" may be extracted and associated with a specific landmark. Thereafter, landmark listing 45b may be used in the same manner as landmark listing 45a to highlight anatomical features within pre-operative image 43 of the anatomical region for VCP mode 23a.

       Atlas registration ("AR") mode 23d involves a registration of an atlas of the
20   anatomical region to pre-operative image 43 whereby each anatomical feature of the atlas are associated with a corresponding anatomical feature within the pre-operative image. Consequently, a user may utilize the atlas of the anatomical region to select and delineate anatomical features of interest or section(s) thereof analogous to VCP mode 23a. For example, a registration of atlas 48 of the thorax region (shown as a picture of the heart in FIG.
25   4) to pre-operative image 43 enables anatomical features of atlas 48 to be associated with corresponding anatomical features within pre-operative image 43 (e.g. left anterior descending artery 49 of atlas 48). Thus, a selection of an anatomical feature or section thereof of atlas 48 delineates a volume coordinate position and an optional orientation within pre-operative image 43.

30   Referring back to FIG. 2, a stage S32 of flowchart 30 encompasses image registration module 24 acquiring and registering endoscope image 14 with pre-operative image 43 as known in the art. In one embodiment, module 24 may implement a point based registration of endoscope image 14 with pre-operative image 43. In another embodiment, module 24 may implement a graphical matching registration of endoscope image 14 with pre-operative image

43 involving a matching of graphical representations of anatomical features (e.g., blood vessel trees) in endoscope image 14 and pre-operative image 43.

Upon completion of stage S32, a stage S33 of flowchart 30 encompasses anatomical feature selection module 25 receiving a user input to VSM 26 (FIG. 1) of an anatomical feature of interest or section thereof to facilitate a subsequent determination of an endoscope pose of endoscope 12 within the anatomical region for visualizing the anatomical feature or section thereof within endoscope image 14. In practice, module 25 may provide one or more views of the anatomical region in dependence of the mode (FIG. 4) used to delineate the volume coordinate position and optional orientation of the anatomical features. For example, marked or named anatomical features or section(s) thereof may be shown in an image of the anatomical region or a designed computer screen whereby the user may interact with image or the screen to select the anatomical feature or section thereof (e.g., a keyboard, a mouse, a touchscreen, a voice command, a gesture, etc.). Also by example, the registered atlas may be presented whereby the user may interact with the atlas to select the anatomical feature or section thereof. By further example, a listing of landmark names may be presented to facilitate a selection of an anatomical feature or section thereof.

Still referring to FIG. 2, a stage S34 of flowchart 30 encompasses visual servo module 26 determining an endoscope pose of endoscope 12 within the anatomical region for visualizing the selected anatomical feature or section thereof within endoscope image 14, and generating endoscope position commands 28 to robot controller 21 to thereby guide endoscope 12 (FIG. 1) to the determined endoscope pose.

Specifically, from the image registration of stage S32 and the anatomical feature selection of stage S33, the delineated volume coordinate position (X, Y, Z) within pre-operative image 43 corresponds to a frame coordinate position (x, y) within endoscope image 14 that provides for a visualization of the anatomical feature at volume coordinate position (X, Y, Z) (e.g., a center frame coordinate position of endoscope image 14) of pre-operative image 43. Additionally, the frame coordinate position (x, y) may be oriented in accordance with a delineated endoscopic view orientation.

If endoscope 12 is calibrated (i.e., the endoscope camera parameters like focal length and optical center of endoscope image 14 are known), then a relationship between frame coordinate position (x, y) within endoscope image 14 and a pose of endoscope 12 within the anatomical region may be established as known in the art. Assuming further that the spatial transformation between endoscope 12 and joints of robot 11 is known from robot calibration procedures known in art, the relationship between the robot joints and image space may be

derived. This relationship is referred to, in art, as Image Jacobian. From the Image Jacobian, robot joint values may be computed whereby, after robot 11 has moved endoscope 12 to the computed volume coordinate position (X, Y, Z), the anatomical feature is located at the desired frame coordinate position (x, y) of endoscope image 14 (e.g., a center of the image).

5   If endoscope 12 is not calibrated and/or the transformation between the endoscope 12 and joints of robot 11 is not known, then uncalibrated visual servoing of robot 11 as known in the art may be utilized to determine and move endoscope 12 to a pose within the anatomical region to visualize the anatomical feature or section thereof in accordance with the frame coordinate position (x, y) within endoscope image 14 (e.g., an uncalibrated velocity

10   optimization method

For example, referring to FIG. 5, an anatomical feature 51 within an endoscope image 14a is covered by fat and obstructed from view. Nonetheless, once a surgeon picks the anatomical feature, endoscope 12 may be moved on a semi-sphere (touching the sphere) so that anatomical feature 51 goes in the middle of an endoscope image 14b. Note that

15   endoscope 12 is pivoted around a fixed point based on distance between anatomical feature 51 as shown in images 14a and 14b.

By further example, referring to FIG. 6, a selected anatomical feature 52 is outside the view of endoscope image 14c. Endoscope 12 may be moved again on a sphere 50 to anatomical feature 52 in the middle of endoscope image 14d. More particularly, an

20   analogous distance between points within endoscope image 14c may serve to ascertain correction motion parameters for uncalibrated visual servoing of robot 11.

Referring back to FIG. 2, stages S33 and S34 may be executed in a loop until such time robot 11 has moved endoscope 12 to each desired pose within the anatomical region.

In practice, modules 23-26 (FIG. 1) may be implemented by hardware, software

25   and/or firmware integrated within endoscope controller 22 as shown.

Robot controller 21 and endoscope controller 22 may be physically separate controllers or logically controllers integrated within a single physical controller.

From the description of FIGS. 1-6 herein, those having ordinary skill in the art will appreciate the numerous benefits of the present invention including, but not limited to, an

30   application of the present invention to any type of endoscopy surgery involving a visualization of a particular anatomical feature or section thereof within an anatomical region.

Although the present invention has been described with reference to exemplary aspects, features and implementations, the disclosed systems and methods are not limited to such exemplary aspects, features and/or implementations. Rather, as will be readily

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apparent to persons skilled in the art from the description provided herein, the disclosed systems and methods are susceptible to modifications, alterations and enhancements without departing from the spirit or scope of the present invention. Accordingly, the present invention expressly encompasses such modification, alterations and

5   enhancements within the scope hereof.

CLAIMS

1.   A robotic control system, comprising:

a robot unit (10) including

an endoscope (12) operable to generate an endoscope image (14), and

a robot (11) operable to move the endoscope (12) within an anatomical region;
and

a control unit (20) including

an endoscope controller (22) operable to determine an endoscope pose within
the anatomical region for an intra-operative visualization of an anatomical feature within the
endoscope image (14),

wherein the endoscope pose is derived from a delineation of a volume
coordinate position of the anatomical feature within a pre-operative image (43) of the
anatomical region, and

a robot controller (21) operable to command the robot (11) to move the
endoscope (12) to the endoscope pose within the anatomical region to visualize the
anatomical feature within the endoscope image (14).

2.   The robotic control system of claim 1, wherein the endoscope controller (22) is
further operable to provide a description of the anatomical feature to facilitate a selection of
the anatomical feature for visualization in the endoscope image (14).

3.   The robotic control system of claim 2, the description of the anatomical feature
includes at least one of a landmark name and a code of the anatomical feature.

4.   The robotic control system of claim 1, wherein the endoscope controller (22) is
further operable to provide an atlas (48) of the anatomical region registered to the pre-
operative image (43) to facilitate a delineation of the volume coordinate position of the
anatomical feature within the pre-operative image (43) of the anatomical region.

5.   The robotic control system of claim 1, wherein the endoscope pose is further derived
from a delineation of an endoscopic view orientation of the anatomical feature within the pre-
operative image (43) of the anatomical region.

6.   The robotic control system of claim 1, wherein the endoscope controller (22) is further operable to provide a listing of landmark names of the anatomical region to facilitate a delineation of the volume coordinate position of the anatomical feature.

7.   The robotic control system of claim 1, wherein the endoscope controller (22) is further operable to interpret natural language surgical instructions for the anatomical region to facilitate a delineation of the volume coordinate position of the anatomical feature.

8.   The robotic control system of claim 1, wherein the endoscope controller (22) is further operable to translate the volume coordinate position (X, Y, Z) of the anatomical feature within the pre-operative image (43) to a frame coordinate position (x, y) of the anatomical feature within the endoscope image (14).

9.   A control unit (20) for an endoscope (12) operable to generate an endoscope image (14) and a robot (11) operable to move the endoscope (12) within an anatomical region, the control unit (20) comprising:

        an endoscope controller (22) operable to determine an endoscope pose within the anatomical region for an intra-operative visualization of an anatomical feature within the endoscope image (14),

               wherein the endoscope pose is derived from a delineation of a volume coordinate position of the anatomical feature within a pre-operative image (43) of the anatomical region; and

        a robot controller (21) operable to command the robot (11) to move the endoscope (12) to the endoscope pose within the anatomical region to visualize the anatomical feature within the endoscope image (14).

10.   The control unit (20) of claim 9, wherein the endoscope controller (22) is further operable to provide a description of the anatomical feature to facilitate a selection of the anatomical feature for visualization within the endoscope image (14).

11.   The control unit (20) of claim 9, wherein the endoscope controller (22) is further operable to provide an atlas (48) of the anatomical region registered to the pre-operative image (43) to facilitate a selection of the endoscope pose within the anatomical region.

12.   The control unit (20) of claim 9, wherein the endoscope pose is further derived from a delineation of an endoscopic view orientation of the anatomical feature within the pre-operative image (43) of the anatomical region.

13.   The control unit (20) of claim 9, wherein the endoscope controller (22) is further operable to provide a listing of landmark names of the anatomical region to facilitate a delineation of the volume coordinate position of the anatomical feature.

14.   The control unit (20) of claim 9, wherein the endoscope controller (22) is further operable to interpret natural language surgical instructions for the anatomical region to facilitate a delineation of the volume coordinate position of the anatomical feature.

15.   The control unit (20) of claim 9, wherein the endoscope controller (22) is further operable to translate the volume coordinate position (X, Y, Z) of the anatomical feature within the pre-operative image (43) to a frame coordinate position (x, y) of the anatomical feature within the endoscope image (14).

16.   A robotic control method for an endoscope (12) operable to generate an endoscope image (14) and a robot (11) operable to move the endoscope (12) within an anatomical region, the robotic control method comprising:

        determining an endoscope pose within the anatomical region for an intra-operative visualization of an anatomical feature within the endoscope image,

            wherein the endoscope pose is derived from a delineation of a volume coordinate position of the anatomical feature within a pre-operative image (43) of the anatomical region; and

        commanding the robot (11) to move the endoscope (12) to the endoscope pose within the anatomical region to visualize the anatomical feature within the endoscope image (14).

17.   The robotic control method of claim 16, wherein the endoscope pose is further derived from a delineation of an endoscopic view orientation of the anatomical feature within the pre-operative image (43) of the anatomical region.

18.   The robotic control method of claim 16, wherein the endoscope controller (22) is further operable to provide a listing of landmark names of the anatomical region to facilitate a delineation of the volume coordinate position of the anatomical feature.

19.   The robotic control method of claim 16, wherein the endoscope controller (22) is further operable to interpret natural language surgical instructions for the anatomical region to facilitate a delineation of the volume coordinate position of the anatomical feature.

20.   The robotic control method of claim 16, wherein the endoscope controller (22) is further operable to translate the volume coordinate position (X, Y, Z) of the anatomical feature within the pre-operative image (43) to a frame coordinate position (x, y) of the anatomical feature within the endoscope image (14).

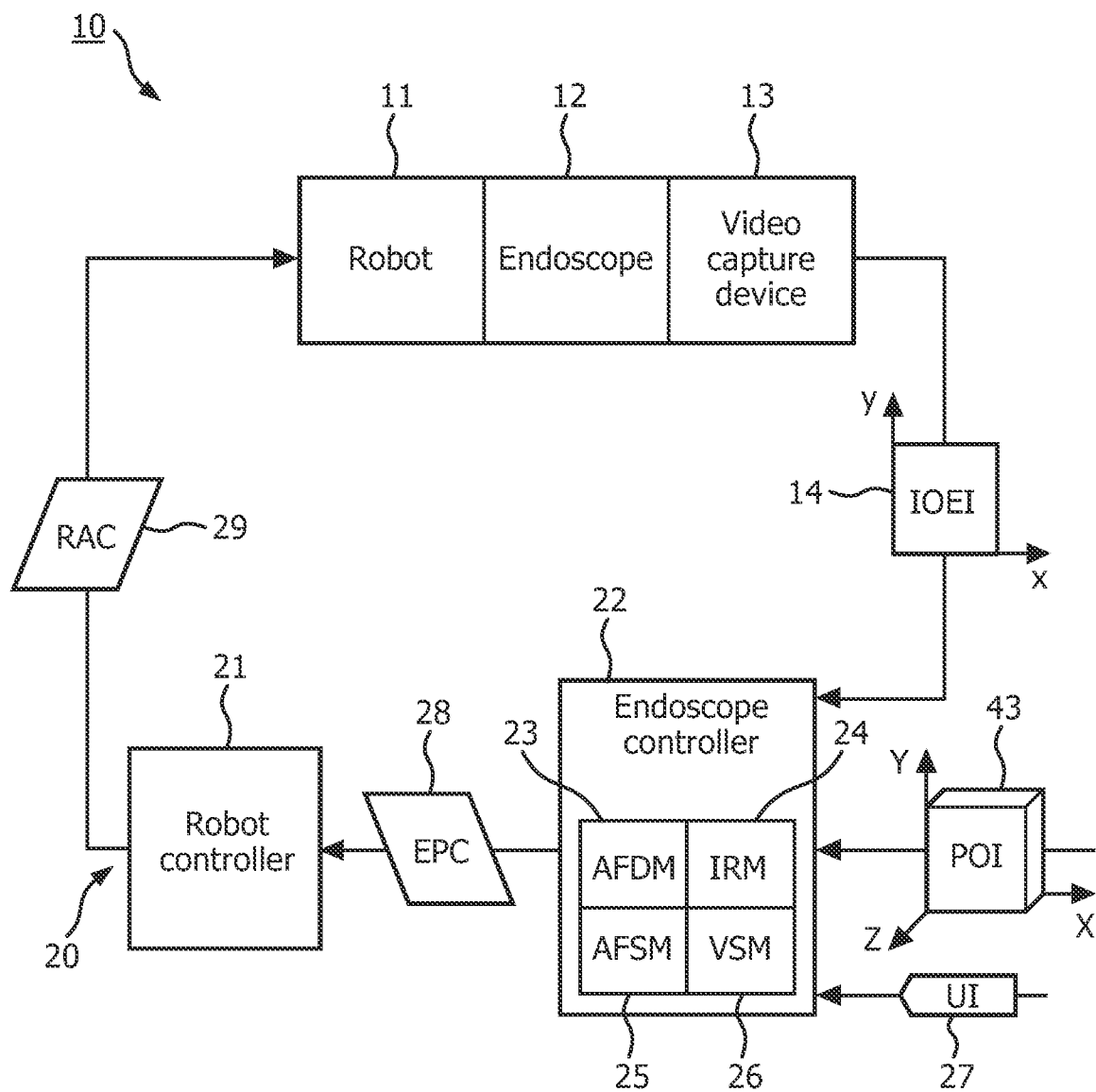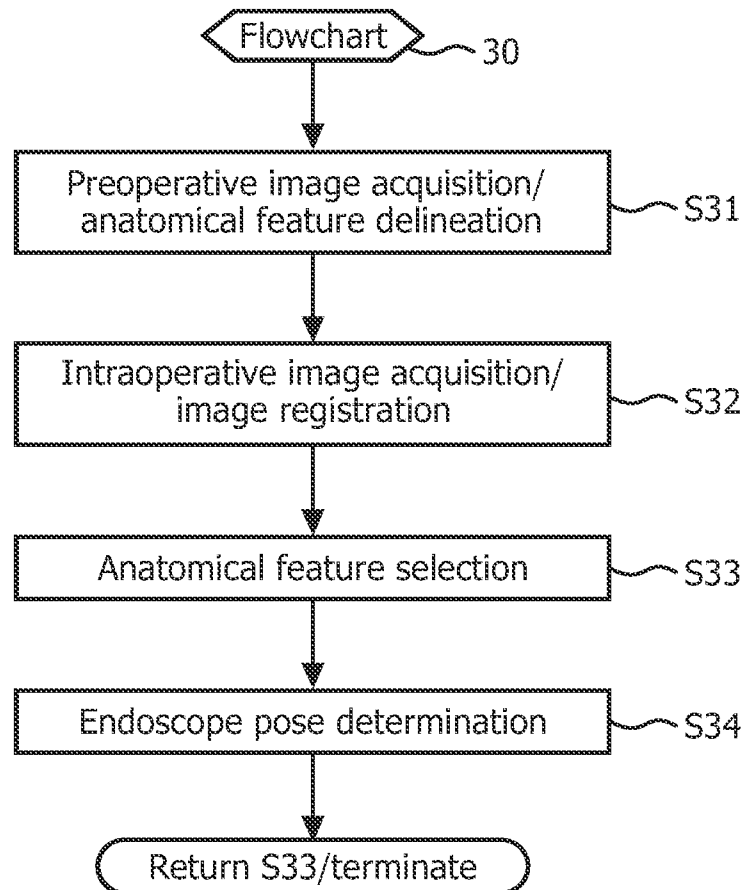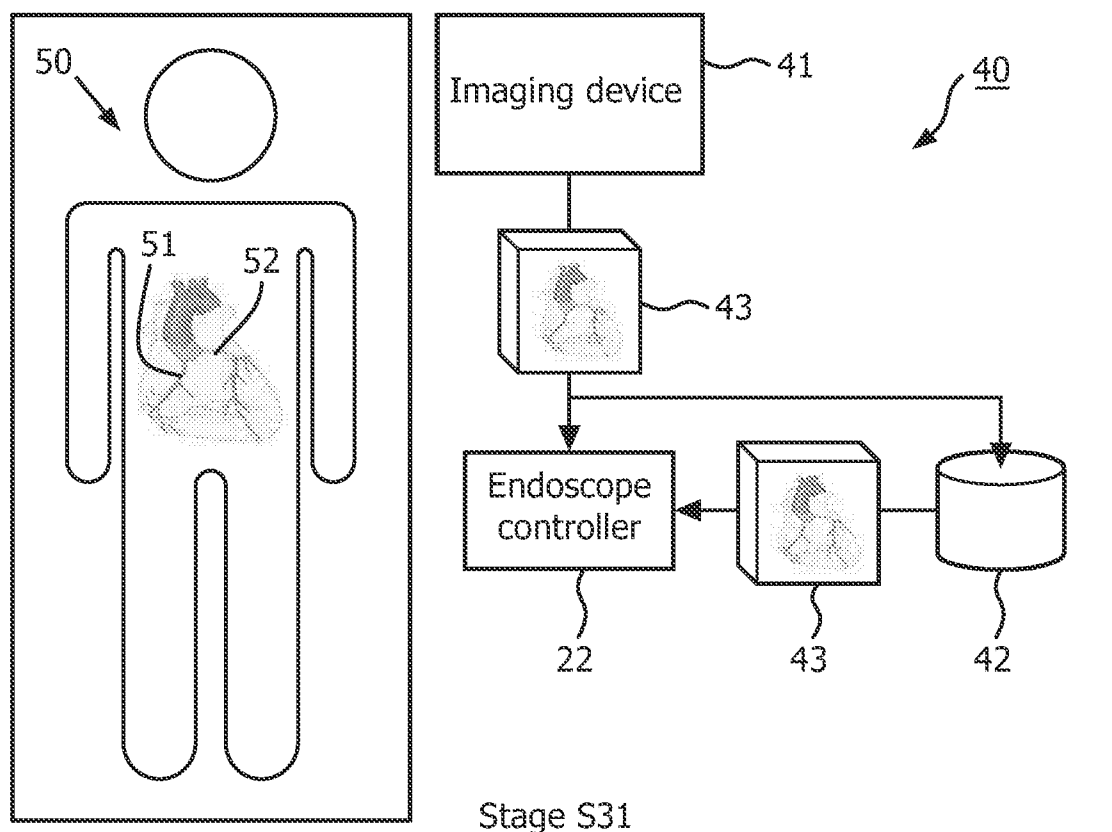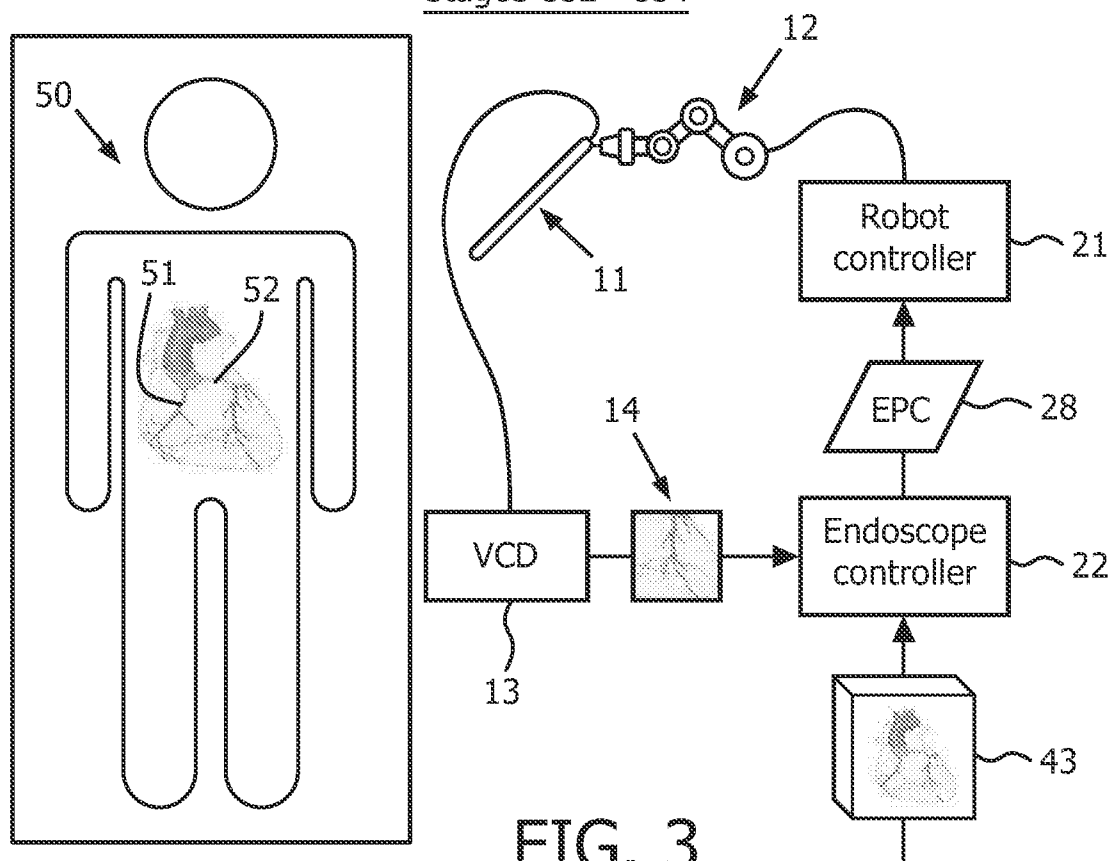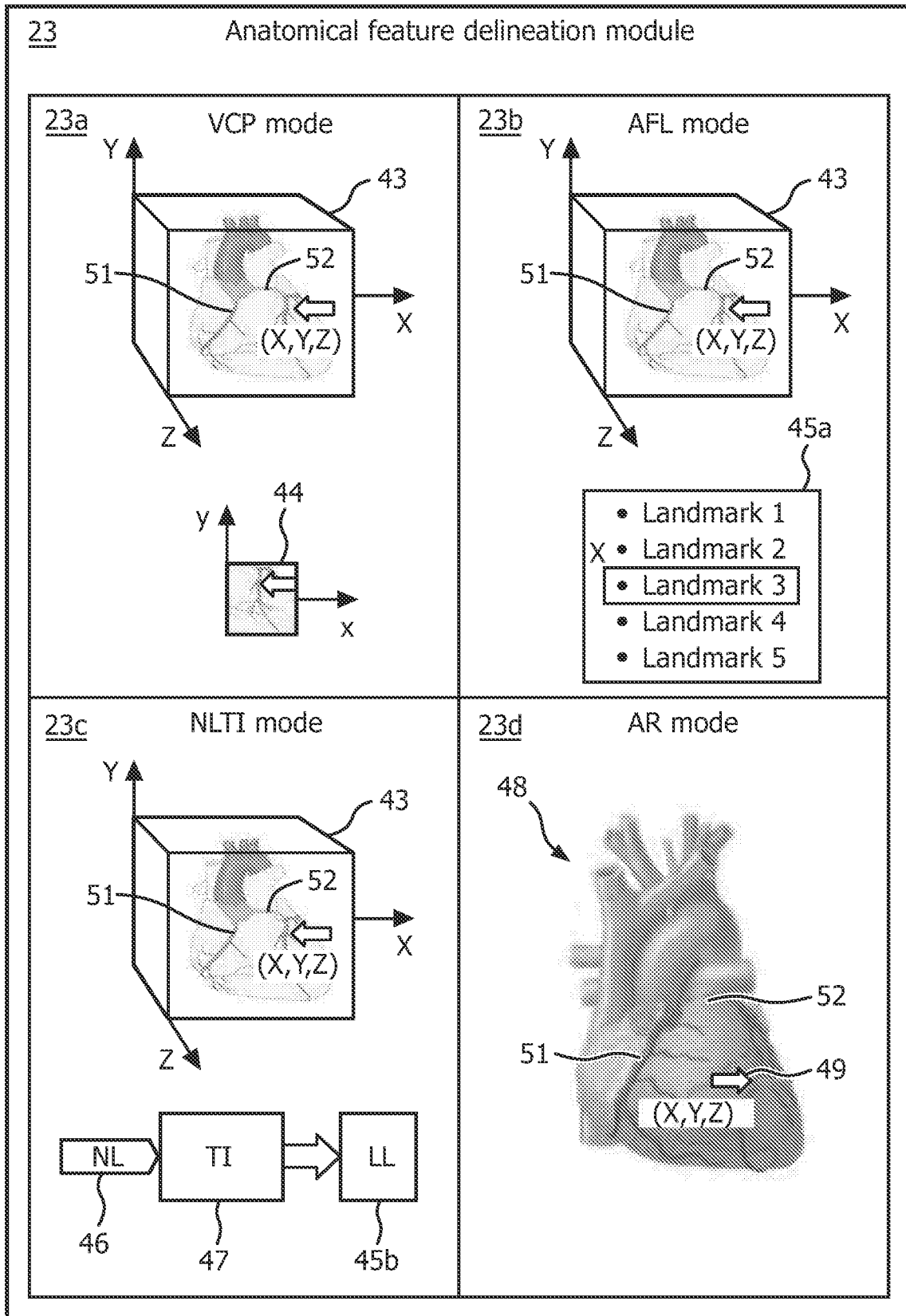FIG. 1

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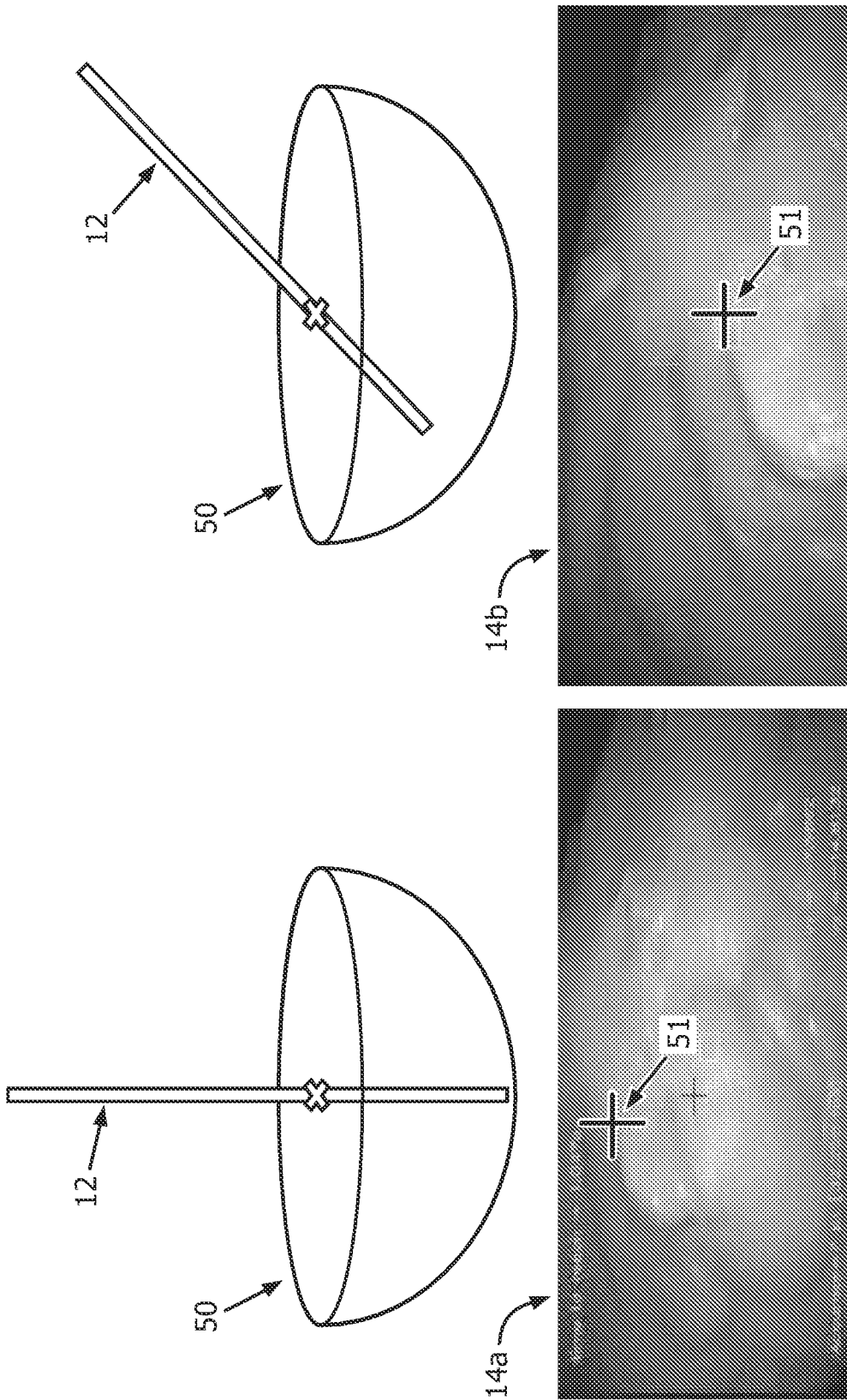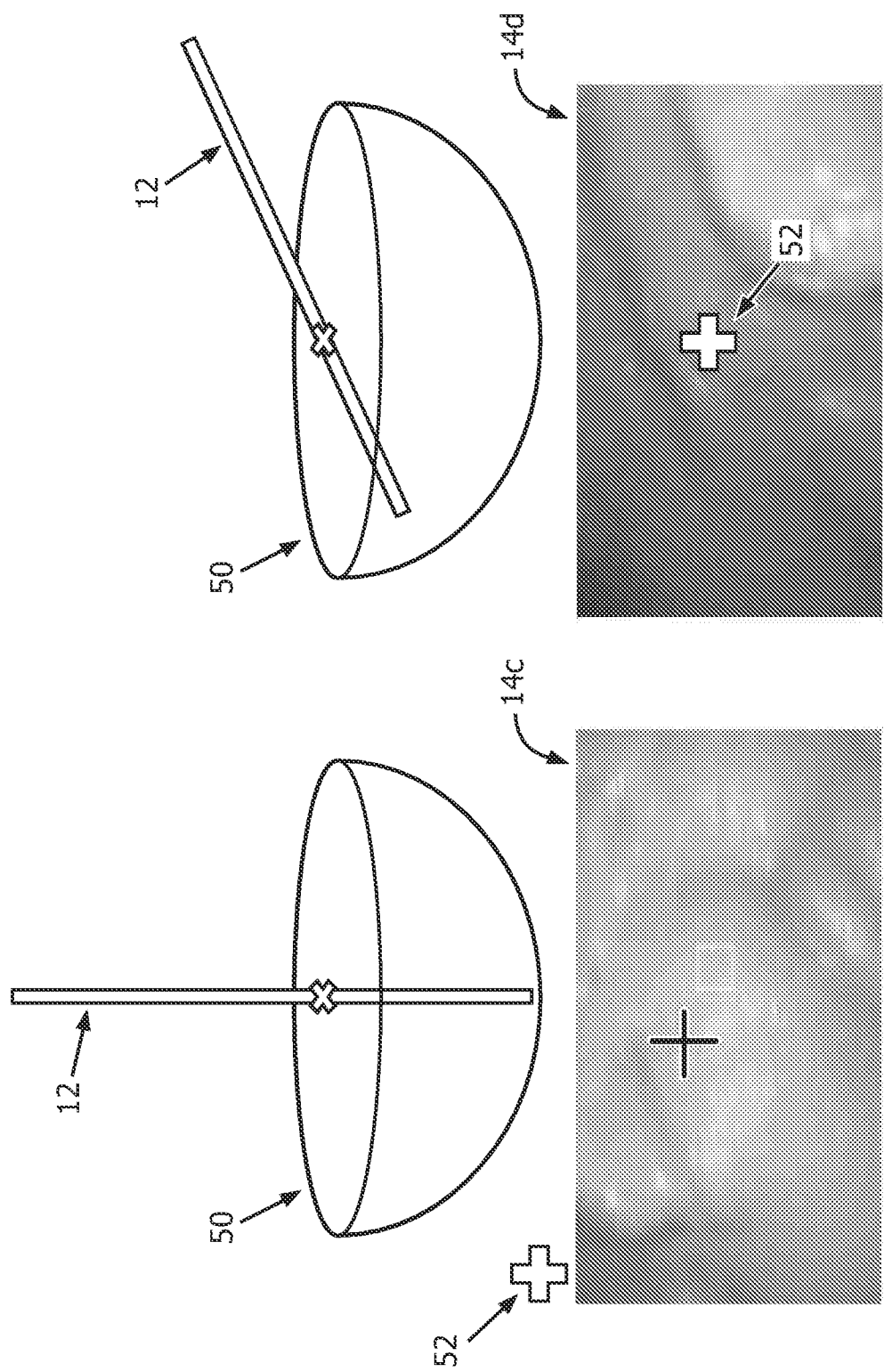FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2014/061100

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B19/00   G06T7/00
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   G06T

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 practicable, 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	US 2008/123927 AI (MIGA MICHAEL I [US] ET AL) 29 May 2008 (2008-05-29)	1,4,5,8, 9,11,12, 15
Y	the whole document	2,3,6,7, 10,13,14

X	WO 2012/035492 AI (KONINKL PHILIPS ELECTRONICS NV [NL]; POPOVIC ALEKSANDRA [RS]) 22 March 2012 (2012-03-22)	1,4,5,8, 9,11,12, 15
Y	the whole document	2,3,6,7, 10,13,14

Y	WO 2012/071571 A2 (AGENCY SCIENCE TECH & RES [SG]; UNIV MASSACHUSETTS [US]; YANG GUOLIANG) 31 May 2012 (2012-05-31) page 11, line 8 - page 17, line 14; figures 1,5-6C	2,3,6,7, 10,13,14

☐ Further documents are listed in the continuation of Box C.   ☒ 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 application or patent 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
18 July 2014	28/07/2014

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	Schindler, Martin

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

INTERNATIONAL SEARCH REPORT

Box No. II   Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.:   16-20
because they relate to subject matter not required to be searched by this Authority, namely:

   see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III   Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos. :

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos. :

Remark on Protest   [ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

Form PCT/ISA/21 0 (continuation of first sheet (2)) (April 2005)

FURTHER INFORMATION CONTINUED FROM   PCT/ISA/ 210

Continuation of Box II.I

Claims Nos.:   16-20

Claims 16 to 20 refer to a method for treatment of the human or animal
body by surgery,   because the method comprises the step of "move the
endoscope to the endoscope pose within the anatomical region", which is
within the human or animal body. Thus the claimed method qualifies as
surgery according to Rule 39.1 (iv) PCT. No written opinion will be
drafted   in respect to these claims (see Art. 17(2) (a) PCT, Rule 66.1(e)
PCT).

FURTHER INFORMATION CONTINUED FROM   PCT/ISA/ 210

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2008123927	A1	29-05-2008	CA	2670261	A1	29-05-2008
			EP	2081494	A2	29-07-2009
			US	2008123927	A1	29-05-2008
			US	2013063434	A1	14-03-2013
			WO	2008063494	A2	29-05-2008
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			EP	2615993	A1	24-07-2013
			JP	2013541365	A	14-11-2013
			US	2013165948	A1	27-06-2013
			WO	2012035492	A1	22-03-2012
WO 2012071571	A2	31-05-2012	SG	190383	A1	28-06-2013
			US	2013251233	A1	26-09-2013
			WO	2012071571	A2	31-05-2012