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(54) Title: RAPID SHAPE RECONSTRUCTION OF OPTICAL FIBERS

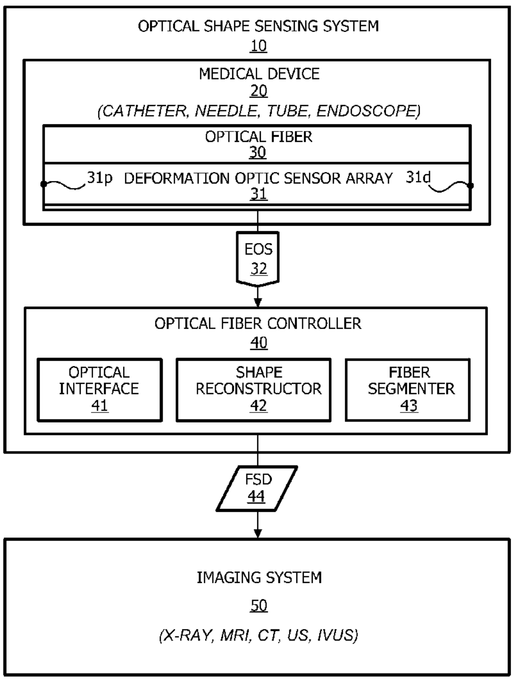

FIG. 1

(57) Abstract: An optical sensing system (10) employs a flexible optical fiber (30) and a optical fiber controller (40). The optical fiber (30) includes a deformation optic sensor array (31) having a proximal endpoint (31p) and a distal endpoint (31d), and may be adjoined to a medical device (20) for generating encoded optical signal (32) indicative of a change in a shape of the optical fiber (30) responsive to movement of the medical device (20) within a defined space. The optical fiber controller (40) utilizes the encoded optical signal (32) for reconstructing a portion or an entirety of a shape of the optical fiber (30) between the proximal endpoint (31p) and the distal endpoint (31d). To this end, the optical fiber controller (40) segments the optical fiber (30) into an anchor fiber segment and an active fiber segment relative to an anchor point having a fixed sampling location within the defined space as designated by the optical fiber controller (40).

WO 2011/141830 A1

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RAPID SHAPE RECONSTRUCTION OF OPTICAL FIBERS

The present invention generally relates to a shape reconstruction of optical fibers. The present invention specifically relates to a specification of different segments of an optical fiber for shape reconstruction at different temporal rates.

Minimally invasive medical procedures are performed by inserting a needle, catheter, tube, endoscope or other medical device percutaneously through a small incision in the skin or through a natural cavity or orifice (e.g., a nose or a mouth). Oftentimes, the location of a medical device inside a body is monitored using a real-time medical imaging device (e.g., a two-dimensional or three-dimensional ultrasound ("2DUS" or "3DUS") device, an X-ray fluoroscopy device, a magnetic resonance imaging ("MRI") device and a computed tomography ("CT") device).

In specific applications, non-imaging tracking technologies are used to localize the position of a medical device in order to reduce procedure time or to minimize exposure to ionizing radiation. Current tracking systems may be based on sensing with electromagnetic, acoustic, impedance, and optical technologies, and may use principles such as signal strength (and/or attenuation), signal phase/frequency shifts, and/or time-of-flight to triangulate a sensor in 3-dimensional space.

Optical fiber based localization technology involves reconstructing a shape of an optical fiber by encoding geometric changes into the transmitted light. Specifically, shape reconstruction of an optical fiber may be performed by making use of variations in an optical refractive index that occur due to introduction of fiber Bragg gratings in the optical fiber or due to natural inhomogeneities in optical refraction arising from the manufacturing process of the optical fiber. A fiber Bragg grating is a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by adding a periodic variation of the refractive index in the fiber core, which generates a wavelength-specific dielectric mirror. A fiber Bragg grating is sensitive to strain, which causes a shift in the Bragg wavelength $\Delta\lambda_B$ of the fiber Bragg grating in proportion to the magnitude of strain. A primary advantage of using fiber Bragg gratings for distributed sensing is that a large number of deformation optic sensors may be interrogated along a length of a single optical fiber. In similar fashion, fiber deformation can be sensed using a Rayleigh scattering approach that exploits the natural variation in optical refractive index occurring along a length of an optical fiber.

The shape sensing ability of optical fiber is accomplished by measuring a three-dimensional ("3D") deformation at each sensed location along the length of the optical fiber starting from a proximal end of the optical fiber and ending at a distal end of the optical fiber. Reconstruction is then possible by integration of strains along the fiber length or by using any of a multitude of estimation methods for solving inverse problems. Moreover, the process is integrative, meaning that the 3D location of one deformation optic sensor at one point along the optical fiber can only be computed if all the deformation optic sensors before that point in the optical fiber have also been reconstructed in 3D.

In the context of minimally invasive medical procedures, a surgeon may only be interested in a distal portion of the optical fiber that is near the anatomic region of interest. However, in order to derive the shape of that distal portion of the optical fiber, the shape of the entire proximal portion of the optical fiber needs to be reconstructed including the part of the optical fiber outside of the patient's body.

The disadvantage of this approach is that shape reconstruction becomes very computationally expensive. For example, a 1.0 meter fiber has approximately 25,000 deformation optic sensors, each of which must report its raw data back to a reconstruction engine for processing. The result is low temporal resolution, with current systems limited to 2.5 Hz for a 1.0 meter fiber. This level of temporal sampling is incompatible with many interventional procedures.

The present invention provides a fiber segmentation technique for segmenting the optical fiber into an anchor fiber segment and an active fiber segment relative to an anchor point with the anchor fiber segment extending between a proximal endpoint of the optical fiber and the anchor point, and the active fiber segment extending between the anchor point and a distal endpoint of the optical fiber. The fiber segmentation technique assumes the anchor point is fixed in space for fiber shape sampling purposes whereby, during a shape sampling of the optical fiber, the active fiber segment may be measured and reconstructed without having to measure and reconstruct the anchor fiber segment.

One form of the present invention is an optical shape sensing system employing one or more flexible optical fibers and a optical fiber controller for use in imaging an anatomical region of a body. Each optical fiber includes an array of deformation optic sensors (e.g., a fiber Bragg gratings array) having a proximal endpoint and a distal endpoint. Upon being adjoined to a medical device (e.g., a catheter, a needled, a tube or an endoscope), the optical fiber is operated to generate an encoded optical signal indicative of each change in the shape of the optical fiber responsive to movement of the medical device within a defined space. For example, the optical fiber may be inserted within a lumen of a catheter whereby the shape of the optical fiber within and/or without the lumen changes as a distal tip of the catheter is navigated to an anatomical region of interest during a surgical procedure.

The optical fiber controller processes the encoded optical signal for reconstructing a portion of or an entire shape of the optical fiber between the proximal endpoint and the distal endpoint. For implementing the segmentation technique of the present invention, the optical fiber controller segments the optical fiber into an anchor fiber segment and an active fiber segment relative to an anchor point having a sampling location within the defined space as designated by the optical fiber controller. The anchor fiber segment extends between the proximal endpoint and the anchor point, and the active fiber segment extends between the anchor point and the distal endpoint. More particularly, the anchor fiber segment is inclusive or exclusive of the proximal endpoint, and is inclusive or exclusive of the anchor point. Similarly, the active fiber segment is inclusive or exclusive of the anchor point, and is inclusive or exclusive of the distal endpoint.

In a low spatial temporal shape sampling mode, the optical fiber controller sequentially reconstructs a shape of the anchor fiber segment of the optical fiber and a shape of the active fiber segment of the optical fiber.

In a high spatial temporal shape sampling mode, the optical fiber controller exclusively reconstructs the shape of the active fiber segment of the optical fiber.

In an anchor point update sampling, the optical fiber controller exclusively reconstructs the shape of the anchor fiber segment of the optical fiber.

The foregoing form 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 a medical imaging system in accordance with present invention.

FIGS. 2 and 3 illustrate exemplary embodiments of an optical fiber as known in the art.

FIG. 4 illustrates an exemplary embodiment of an optical fiber segmentation in accordance with the present invention.

FIG. 5 illustrates an exemplary embodiment of an optical fiber shape reconstruction in accordance with the present invention.

FIG. 6 illustrates an exemplary embodiment of the medical imaging system shown in FIG. 1 in accordance with the present invention.

FIG. 7 illustrates an exemplary embodiment of a table of parameter input options in accordance with the present invention.

FIG. 8 illustrates an exemplary embodiment of a GUI parameter input option in accordance with the present invention.

FIG. 9 illustrates an exemplary embodiment of a fiber imaging parameter input option in accordance with the present invention.

As shown in FIG. 1, a medical imaging system of the present invention employs an optical shape sensing system 10 and an imaging system 50 (e.g., an X-ray system, a MRI system, a CT system, an US system or a IVUS system).

System 10 employs an optical fiber 30 that may be adjoined to a medical device 20 (e.g., a catheter, a needle, a tube or an endoscope). For purposes of the present invention, optical fiber 30 is broadly defined herein as any article or device structurally configured for transmitting light by means of successive internal optical reflections via a deformation optic sensor array 31 having a proximal endpoint 31p and a distal endpoint 31d, and each deformation optic sensor of array 31 is broadly defined herein as any article structurally configured for reflecting a particular wavelength of light while transmitting all other wavelengths of light whereby the reflection wavelength may be shifted as a function of an external stimulus applied to optical fiber 30. Examples of optical fiber 30 and deformation optic sensor array 31 include, but are not limited to, a flexible optically transparent glass or plastic fiber incorporating an array of fiber Bragg gratings integrated along a length of the fiber as known in the art, and a flexible optically transparent glass or plastic fiber having naturally variations in its optic refractive index occurring along a length of the fiber as known in the art.

Also for purposes of the present invention, the term “adjoined” encompasses any manner by which optical fiber 30 is affixed to or contiguous with medical device 20. Examples of optical fiber 30 being adjoined to medical device 20 include, but are not limited to, optical fiber 30 being inserted inside a lumen of a catheter or an endoscope as known in the art.

In operation with optical fiber 30 being adjoined to medical device 20, optical fiber 30 generates an encoded optical signal ("EOS") 32 via deformation optic sensor array 31 as known in the art that indicates a shape of optical fiber 30 at any instantaneous shape sampling of optical fiber 30 and more particularly over the course of multiple shape samplings, encoded optical signal 32 indicates each change to the shape of optical fiber 30 that occurs as medical device 20 is being moved within a defined space. Encoded optical signal 32 therefore facilitates a use of optical fiber 30 in visually displaying a position and orientation of medical device 20 within the defined space at any instantaneous time, and in visually displaying a movement tracking of medical device 20 within the defined space. For example, encoded optical signal 32 will indicate the shape of optical fiber 30 at any instantaneous shape sampling of optical fiber 30 for visually displaying a position and an orientation of a catheter or an endoscope within a patient during a medical procedure, and more particularly over the course of multiple shape samplings, encoded optical signal 32 will indicate each change in the shape of optical fiber 30 due to movement of the catheter or the endoscope within the patient to thereby utilize optical fiber 30 for visually displaying a movement tracking of the catheter or the endoscope within the patient.

To this end, system 10 further employs an optical fiber controller 40 incorporating an optical interface 41, a shape reconstructor 42 and a fiber segmenter 43 for processing encoded optical signal 32 to thereby periodically reconstruct a portion or an entire shape of optical fiber 30. For purposes of the present invention, optical interface 41 is broadly defined herein as any device or system structurally configured for transmitting light through optical fiber 30 from proximal endpoint 31p to distal endpoint 31d to receive encoded optical signal 32 as generated by the successive internal reflections of the transmitted light via deformation optic sensor array 31. An example of optical interface 41 includes, but is not limited to, an arrangement of an optical coupler, a broadband reference reflector and a frequency domain reflectometer as known in the art for transmitting light through optical fiber 30 from proximal endpoint 31p to distal endpoint 31d and for receiving encoded optical signal 32 as generated by the successive internal reflections of the transmitted light via deformation optic sensor array 31.

For purposes of the present invention, shape reconstructor 42 is broadly defined as any article or device structurally configured for processing encoded optic signal 32 to partially or entirely reconstruct the shape of optical fiber 30 and for generating fiber shape data 44 in an appropriate form that enables imaging system 50 to visually display an instantaneous position and orientation of medical device 20 and more particularly, a movement tracking of medical device 20. An example of shape reconstructor 42 includes, but is not limited to, a reconstruction engine installed as software and/or firmware on any type of computer for implementing a known shape reconstruction technique. In particular, a known shape reconstruction technique for correlating encoded optic signal 32 into strain/bend measurements that are integrated into a shape of optical fiber 30. In practice, the reconstruction engine may or may not be integrated into imaging system 50.

For purposes of the present invention, fiber segmenter 43 is broadly defined herein as any article or device for implementing the fiber segmentation technique of the present invention. Specifically, fiber segmenter 43 segments optical fiber 30 into an anchor fiber segment and an active fiber segment relative to an anchor point with the anchor fiber segment extending between proximal endpoint 31p and the anchor point, and the active fiber segment extending between the anchor point and distal endpoint 31d. In practice, the anchor fiber segment may be inclusive or exclusive of the proximal endpoint 30 and active fiber segment may be inclusive or exclusive of the distal endpoint 31d. Also in practice, the anchor point may or may not coincide with an array location of a deformation optic sensor, and therefore the anchor fiber segment, the active fiber segment or neither segment may be inclusive of the anchor point.

The fiber segmentation technique assumes the anchor point has a permanent or temporary fixed sampling location within the defined space associated with medical device 20 whereby, during a shape sampling of optical fiber 30, shape reconstructor 42 may measure and reconstruct the active fiber segment without having to measure and reconstruct the anchor fiber segment. More particularly, for a low spatial temporal shape sampling of optical fiber 30, shape reconstructor 42 will sequentially measure and reconstruct the shapes of the anchor fiber segment and the active fiber segment, and for a high spatial temporal shape sampling of optical fiber 30, shape reconstructor 42 will exclusively measure and reconstruct the shape of the active fiber segment.

In practice, fiber segmenter 43 may designate the anchor point as having a permanently or temporarily fixed sampling location within the defined space associated with medical device 20 for purposes of spatial temporal shape samplings despite the fact that the anchor point may or may not be moving within the defined space or alternatively, fiber segmenter 43 may periodically update the sampling location of the anchor point within the defined space based on an anchor point update sampling of optical fiber 30 involving an exclusive reconstruction of the anchor fiber segment.

For example, with optical fiber 30 being inserted within a lumen of a catheter, fiber segmenter 43 may establish the anchor point at the boundary between a main body of the catheter and the steerable tip of the catheter. As such, the anchor fiber segment is within the main body of the catheter and the active fiber segment is within the steerable tip of the catheter. Fiber segmenter 43 will instruct shape reconstructor 42 when to execute a low spatial temporal shape sampling of optical fiber 30 involving a sequential reconstruction of the shapes of the anchor fiber segment and the active fiber segment to thereby monitor and track both the main body and the steerable tip of the catheter within a patient. Fiber segmenter 43 will also instruct shape reconstructor 42 when to execute a high spatial temporal shape sampling of optical fiber 30 involving an exclusive reconstruction of the shape of the active fiber segment to thereby only monitor and track the steerable tip of the catheter. And if applicable, fiber segmenter 43 will instruct shape reconstructor 42 when to execute an anchor point update sampling of optical fiber 30 involving an exclusive reconstruction of the shape of the anchor fiber segment to thereby update the sampling location of the anchor point within the patient.

In an alternative embodiment, fiber segmenter 43 may segment optical fiber 30 into the anchor fiber segment, the active fiber segment and an untracked fiber segment relative to the anchor point and a tracking point. In this alternative embodiment, the anchor fiber segment extends between the proximal endpoint 31p and the anchor point, the active fiber segment extends between the anchor point and the tracking point, and the untracked fiber segment extends between the tracking point and distal endpoint 31d. This embodiment assumes the untracked fiber segment is of no consequence to the movement tracking of medical device 20 within the defined space and therefore allows for both low and high spatial temporal shape sampling of optical fiber 30 without having to measure and reconstruct the untracked fiber segment. In practice, the tracking point may or may not coincide with an array location of a deformation optic sensor, and therefore the active fiber segment may or may not be inclusive of the tracking point.

In operation, fiber segmenter 43 utilizes various parameters for specifying conditions necessary for implementing the fiber segmentation technique of the present invention. For example, fiber segmenter 43 may utilize parameter(s) specifying (1) an initial sampling location of the anchor point along optical fiber 30, (2) if applicable, a time interval for updating the sampling location of the anchor point along optical fiber 30, (3) an initial length of the active fiber segment from the anchor point along optical fiber 30, (4) a time interval for updating the length of the active fiber segment based of a reconstruction speed specified by imaging system 50, and/or (5) if applicable, an initial sampling location of the tracking point along optical fiber 30. To this end, during a pre-operative phase and/or an intra-operative phase of a medical procedure, fiber segmenter 43 may automatically generate the parameters and/or interactively receive parameter inputs.

An example of fiber segmenter 43 includes, but is not limited to, a module installed as software and/or firmware on any type of computer for implementing the fiber segmentation technique of the present invention. In practice, fiber segmenter 43 may or may not be integrated into shape reconstructor 42 and/or imaging system 50.

A description of an exemplary shape reconstruction in accordance with the fiber segmentation technique of the present invention as shown in FIGS. 2-5 will now be provided herein to facilitate a further understanding of the present invention.

FIG. 2 shows an optical fiber 34 inserted within a lumen of catheter 21 and having one or more fiber Bragg gratings arrays 35 extending from a proximal endpoint 35p to a distal endpoint 35d. In practice, for three-dimensional bending sensing, optical fiber 34 may include any number of arrays 35 or more than one optical fiber may be utilized as would be appreciated by those having ordinary skill in the art. For example, in one version as shown in FIG. 3A, optical fiber 34 may include three (3) fiber Bragg grating arrays 35 arranged at 120° spacing as required for three-dimensional bend sensing. Alternatively, as shown in FIG. 3B, three (3) optical fibers 34b are utilized with each optical fiber 34b having a single fiber Bragg grating array 35 and with each fiber Bragg grating array 35 arranged at 120° spacing as required for three-dimensional bend sensing. By further example, as shown in FIG. 3C, optical fiber 34 may include four (4) fiber Bragg grating arrays 35 with an on-axis array 35(4) encircled by arrays 35(1)-35(3) arranged at 120° spacing. In this version, optical fiber 34 has a permanent helical twist (now shown) to enhance the three-dimensional bend sensing.

FIG. 4 shows a segmentation of optic fiber 34 in accordance with fiber segmentation technique of the present invention. Specifically, an anchor point 36 is specified as being the boundary between main body 21a and steerable tip 21b of catheter 21 (FIG. 2) whereby optic fiber 34 is segmented into anchor fiber segment 37 and active fiber segment 38. Anchor fiber segment 27 extends between proximal endpoint 35p and anchor point 36, and active fiber segment 38 extends between anchor point 36 and distal endpoint 35d.

More particularly, anchor fiber segment 37 may be inclusive of proximal endpoint 35p or may be exclusive of proximal endpoint 35p with an endpoint 37a for example, and anchor fiber segment 37 may be inclusive of anchor point 36 or exclusive of anchor point 36 with an endpoint 37b for example. Similarly, active fiber segment 38 may be inclusive of anchor point 36 or may be exclusive of anchor point 36 with an endpoint 38a for example, and active fiber segment 38 may be inclusive of distal endpoint 35d or exclusive of distal endpoint 35d with an endpoint 38b for example.

FIG. 5 shows a state diagram of an exemplary shape reconstruction of optical fiber 34 in accordance with the fiber segmentation shown in FIG. 4. Specifically, upon catheter 21 being introduced into the patient, anchor point 36 of optical fiber 34 is moving within the patient space as the entire catheter 21 is being navigated to an anatomical region of interest within the patient. Thus, the entire catheter 21 is being tracked and the sampling state of optical fiber 34 is a low spatiotemporal shape sampling 60 that involves a sequential reconstruction of the shapes of anchor fiber segment 37 and active fiber segment 38.

Upon a determination 63 that anchor point 36 may be designated by optical fiber controller 40 as being in a fixed sampling location within the patient space whereby only steerable tip 21b of catheter 21 will be moved to implement specific steps of the medical procedure, the sampling state of optical fiber 34 is a high spatiotemporal shape sampling 61 that involves an exclusive reconstruction of the shape of active fiber segment 38. This will enable fast reconstruction of active fiber segment 38 for purposes of exclusively tracking steerable tip 21b of catheter 21.

During the high spatiotemporal shape sampling 61, a position of anchor point 36 within the patient space may need to be updated. Upon each determination 64 of a need to update the sampling location of anchor point 36 within the patient space, the sampling state of optical fiber 34 is an anchor point update sampling 62 that involves an exclusive reconstruction of the shape of the anchor fiber segment 37. Upon an update 65 of the sampling location of anchor point 36 within the patient space, the sampling state of optical fiber 34 returns to high spatiotemporal shape sampling 61 that again involves an exclusive reconstruction of the shape of active fiber segment 38.

Upon a determination 66 that the medical procedure is complete and catheter 21 may be removed from the patient, the sampling state of optical fiber 34 returns to low spatiotemporal shape sampling 60 that again involves a sequential reconstruction of the shapes of anchor fiber segment 37 and active fiber segment 38 until such time catheter 21 is removed from the patient.

From the description of FIGS. 2-5, those having skill in the art will appreciate how to implement a shape reconstruction of any optical fiber in accordance with the fiber segmentation technique of the present invention for numerous medical procedures utilizing any type of medical device 20 suitable for supporting optical fiber 30. For example, in an atrial fibrillation ablation, a portion of the optical fiber is in the heart and moves with user manipulation of the medical device as well as patient cardiac and respiratory motion, but a remaining portion of the optical fiber is in the inferior vena cava and is relatively stable. The inferior vena cava portion of the optical fiber provides a good candidate for locating the anchor point during high spatiotemporal shape sampling of the optical fiber.

Also by example, a stent balloon positioning and deployment in which the distal portion of the medical device is focused solely around the stent region. In this case, a portion of the optical fiber remote from the stent region provides a good candidate for locating the anchor point during high spatiotemporal shape sampling of the optical fiber.

A description of a more detailed exemplary shape reconstruction in accordance with the fiber segmentation technique of the present invention as shown in FIGS. 6-9 will now be provided herein to facilitate a further understanding of the present invention.

FIG. 6 shows a clinical setting having a patient 70 prepared for a medical procedure involving catheter 21 supporting optical fiber 34 and an X-ray device 51 controlling a C-arm 53 and displaying images on a image monitor 52. An optical fiber controller 45 generates and/or receives parameters 46-49 as shown for implementing the fiber segmentation of optical fiber 34 as shown in FIG. 4.

Specifically, a parameter l_{ANCHOR} 46 specifies a sampling location of an anchor point 36 along a length of optical fiber 34. A parameter l_{ACTIVE} 47 specifies a length of active fiber segment 38 from anchor point 36 to distal endpoint 35d or to any point between anchor point 36 and distal endpoint 35d. A parameter t_{ANCHOR} 48 specifies a time interval for which the sampling location of anchor point 36 is to be updated if applicable. And, a parameter t_{ACTIVE} 48 specifies a time interval for which the shape of the active fiber segment 38 is to be updated.

FIG. 7 illustrates a Table 80 representing four (4) embodiments for generating and/or receiving parameters 46-49.

Specifically, an automatic mode 81 during a pre-operative phase of a medical procedure involves optical fiber controller 45 automatically defining parameter l_{ANCHOR} 46, parameter l_{ACTIVE} 47 and parameter t_{ANCHOR} 48 by rules based one or more previously acquired libraries of training data from similar interventions and/or based on one or more preference profiles from physicians with similar approaches/perspectives. Additionally, optical fiber controller 45 automatically defines parameter t_{ACTIVE} 48 based on the maximum reconstruction speed of 45. In alternative embodiments of automatic mode 81, any other combination of three parameters among parameters 45-48 may be defined with the undefined parameter being determined based on the three defined parameters.

For an automatic mode 82 during an intra-operative phase of a medical procedure, optical fiber controller 45 executes an anchor point calibration sampling that involves an analysis of several reconstructions of the shape of the entire optical fiber 34. Specifically, from the shape reconstructions, optical fiber controller 45 works backwards from the distal tip of optical fiber 34 in order to search for a point of optical fiber 34 that experiences minimal, if any, motion and automatically defines that point as anchor point for parameter l_{ANCHOR} 46. Parameters 47-49 may be automatically defined based on real-time processing of additional intra-operative data streams (e.g., fluoroscopy with X-ray device 51), and additional parameters that must be defined for this mode 82 include a duration of the calibration acquisition and a motion threshold used to choose anchor point.

For an interactive mode 83 during a pre-operative phase of the medical procedure, a graphical user interface ("GUI") may be presented to allow a user to interactively choose parameters 46-49, to define additional customized parameters based on imaging or monitoring information, and to see the results of one parameter choice on the other parameter choices or the overall impact of the shape sensing sections on any measured data (e.g., imaging being integrated with the shape sensing fiber).

For example, as shown in FIG. 8, a color coded GUI may be presented having parameter inputs 95-98. Specifically, a parameter input l_{ANCHOR} 95 specifies a sampling location of an anchor point 93 (e.g., a blue colored dot) along a length of the optical fiber for establishing an anchor fiber segment 90 (e.g., a yellow colored segment) and an active fiber segment 91 (e.g., a green colored segment) relative to an anchor point 93. More particularly, anchor fiber segment 90 is inclusive of both the proximal endpoint of the deformation optic sensor array (not shown) and anchor point 93, and active fiber segment 91 is exclusive of anchor point 93 and inclusive of a termination point 94 (e.g., a blue colored dot).

A parameter input l_{ACTIVE} 96 specifies a length of an active fiber segment 91 via termination point 94, which may coincide with a distal endpoint of the deformation optic sensor array (not shown) or alternatively establish an untracked fiber segment 92 (e.g., red colored segment) that is exclusive of termination point 94 and inclusive of the distal endpoint of the deformation optic sensor array.

A parameter input t_{ANCHOR} 97 specifies a time interval for which the sampling location of anchor point 93 is to be updated. And, a parameter input t_{ACTIVE} 98 specifies a time interval for which the shape of the active fiber segment 91 is to be updated.

In practice, the GUI may further allow for user-specified alarms (e.g., audible and/or visual cues) to be defined for indicating any deviation of shape reconstruction from user specific characteristics (e.g., a shape inaccuracy alarm due to undersampling in space or time based on optical sensing in conjunction with real-time fluoroscopic data).

For an interactive mode 84 during an intra-operative phase of the medical procedure, an imaging of the fiber may be presented on imaging monitor 52 whereby a user can graphically select the parameters by visually comparing a location of optical fiber 34 with a medical image in which shape of optical fiber 34 is displayed. For example, as shown in FIG. 9, an anchor point 103 (e.g., a blue colored dot) may be guided along the displayed optical fiber for establishing an anchor fiber segment 100 (e.g., a yellow colored segment) and an active fiber segment 101 (e.g., a green colored segment). Similarly, a termination point 104 may be guided along the displayed optical fiber for extending length of active fiber segment 101 to the distal endpoint of the displayed optical fiber or for establishing an untracked fiber segment 102 (e.g., a red colored segment).

More particularly, anchor fiber segment 100 is inclusive of both a proximal endpoint of the deformation optic sensor array (not shown) and anchor point 103. By comparison, active fiber segment 101 is exclusive of anchor point 103 and inclusive of termination point 104, which may coincide with a distal endpoint of the deformation optic sensor array (not shown) or alternatively establish untracked fiber segment 102 as shown that is exclusive of termination point 104 and inclusive of the distal endpoint of the deformation optic sensor array.

Referring back to FIG. 6, irrespective of which mode(s) 81-84 are utilized for defining all necessary parameter, optical fiber controller 45 executes a movement tracking of catheter 21 via optical fiber 34 in accordance with the state diagram of FIG. 5 or another shape reconstruction in accordance with the fiber segmentation technique of the present invention.

From the description of FIGS. 6-9, those having skill in the art will have a further appreciation on how to implement a shape reconstruction of any optical fiber in accordance with the fiber segmentation technique of the present invention for numerous medical procedures utilizing any type of medical device 20 suitable for supporting optical fiber 30.

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. For example, although the invention is discussed herein with regard to FBGs, it is understood to include fiber optics for shape sensing or localization generally, including, for example, with or without the presence of FBGs or other optics, sensing or localization from detection of variation in one or more sections in a fiber using back scattering, optical fiber force sensing, fiber location sensors or Rayleigh scattering. 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 optical sensing system (10), comprising:

a flexible optical fiber (30) including a deformation optic sensor array (31) having a proximal endpoint (31p) and a distal endpoint (31d),

wherein the optical fiber (30) is operable to be adjoined to a medical device (20) for generating encoded optical signal (32) indicative of a change in a shape of the optical fiber (30) responsive to movement of the medical device (20) within a defined space; and

a optical fiber controller (40) responsive to the encoded optical signal (32) for reconstructing at least a portion of a shape of the optical fiber (30) between the proximal endpoint (31p) and the distal endpoint (31d),

wherein the optical fiber controller (40) selectively segments the optical fiber (30) into an anchor fiber segment and an active fiber segment relative to an anchor point having a fixed sampling location within the defined space as designated by the optical fiber controller (40), the anchor fiber segment extending between the proximal endpoint (31p) and an anchor point, the active fiber segment extending between the anchor point and the distal endpoint (31d),

wherein, for a low spatiotemporal shape sampling of the optical fiber (30), the optical fiber controller (40) sequentially reconstructs a shape of the anchor fiber segment and a shape of the active fiber segment of the optical fiber (30), and

wherein, for a high spatiotemporal shape sampling of the optical fiber (30), the optical fiber controller (40) exclusively reconstructs the shape of the active fiber segment of the optical fiber (30).

2. The optical shape sensing system (10) of claim 1, wherein the optical fiber controller (40) designates the fixed sampling location of the anchor point as being permanently fixed within the defined space for a plurality of spatiotemporal shape samplings of the optical fiber (30).

3. The optical shape sensing system (10) of claim 1, wherein the optical fiber controller (40) designates the fixed sampling location of the anchor point as being temporarily fixed within the defined space for a plurality of spatiotemporal shape samplings of the optical fiber (30).

4. The optical shape sensing system (10) of claim 3, wherein, for an anchor point update sampling between spatiotemporal shape samplings of the optical fiber (30), the optical fiber controller (40) exclusively reconstructs the shape of the anchor fiber segment of the optical fiber (30) and updates the fixed sampling location of the anchor point within the defined space.

5. The optical shape sensing method of claim 1, wherein, based on at least one pre-operative rule associated with the medical device (20), the optical fiber controller (40) derives at least one of the fixed sampling location of the anchor point, a length of the active fiber segment, a time interval for updating the fixed sampling location of the anchor point, and a time interval for updating the length of the active fiber segment.

6. The optical shape sensing method of claim 1, wherein the optical fiber controller (40) includes a graphical user interface for deriving at least one of the fixed sampling location of the anchor point, a length of the active fiber segment, a time interval for updating the fixed sampling location of the anchor point, and a time interval for updating the length of the active fiber segment.

7. The optical shape sensing method of claim 1, wherein the optical fiber controller (40) designates the fixed sampling location of the anchor point as a being a point experiencing minimal motion over a plurality of reconstructions of the shape of the optical fiber (30) by the optical fiber controller (40).

8. The optical shape sensing method of claim 1, wherein the optical fiber controller (40) includes an image overlay of the optical fiber (30) for deriving at least one of the fixed sampling location of the anchor point and a length of the active fiber segment.

9. A medical imaging system, comprising:

a medical device (20);

a flexible optical fiber (30) including a deformation optic sensor array (31) having a proximal endpoint (31p) and a distal endpoint (31d),

wherein the optical fiber (30) is adjoined to the medical device (20) for generating encoded optical signal (32) indicative of a change in a shape of the optical fiber (30) responsive to movement of the medical device (20) within a defined space; and

a optical fiber controller (40) responsive to the encoded optical signal (32) for reconstructing at least a portion of a shape of the optical fiber (30) between the proximal endpoint (31p) and the distal endpoint (31d),

wherein the optical fiber controller (40) selectively segments the optical fiber (30) into an anchor fiber segment and an active fiber segment relative to an anchor point having a fixed sampling location within the defined space as designated by the optical fiber controller (40), the anchor fiber segment extending between the proximal endpoint (31p) and an anchor point, the active fiber segment extending between the anchor point and the distal endpoint (31d), wherein, for a low spatiotemporal shape sampling of the optical fiber (30), the optical fiber controller (40) sequentially reconstructs a shape of the anchor fiber segment and a shape of the active fiber segment of the optical fiber (30), and

wherein, for a high spatiotemporal shape sampling of the optical fiber (30), the optical fiber controller (40) exclusively reconstructs the shape of the active fiber segment of the optical fiber (30); and

an imaging system for displaying a movement tracking of the medical device (20) derived from a plurality of reconstructions of the at least a portion of the shape of the optical fiber (30) between the proximal endpoint (31p) and the distal endpoint (31d).

10. The medical imaging system of claim 9, wherein the optical fiber controller (40) designates the fixed sampling location of the anchor point as being permanently fixed within the defined space for a plurality of spatiotemporal shape samplings of the optical fiber (30).

11. The medical imaging system of claim 9, wherein the optical fiber controller (40) designates the fixed sampling location of the anchor point as being temporarily fixed within the defined space for a plurality of spatiotemporal shape samplings of the optical fiber (30).

12. The medical imaging system of claim 11, wherein, for an anchor point update sampling between spatiotemporal shape samplings of the optical fiber (30), the optical fiber controller (40) exclusively reconstructs the shape of the anchor fiber segment of the optical fiber (30) and updates the fixed sampling location of the anchor point within the defined space.

13. The medical imaging system of claim 9, wherein, based on at least one pre-operative rule associated with the medical device (20), the optical fiber controller (40) derives at least one of the fixed sampling location of the anchor point, a length of the active fiber segment, a time interval for updating the fixed sampling location of the anchor point, and a time interval for updating the length of the active fiber segment.

14. The medical imaging system of claim 9, wherein the optical fiber controller (40) includes a graphical user interface for deriving at least one of the fixed sampling location of the anchor point, a length of the active fiber segment, a time interval for updating the fixed sampling location of the anchor point, and a time interval for updating the length of the active fiber segment.

15. The medical imaging system of claim 9, wherein the optical fiber controller (40) designates the fixed sampling location of the anchor point as a being a point experiencing minimal motion over a plurality of reconstructions of the shape of the optical fiber (30) by the optical fiber controller (40).

16. The medical imaging system of claim 9, wherein the optical fiber controller (40) includes an image overlay of the optical fiber (30) for deriving at least one of the fixed sampling location of the anchor point and a length of the active fiber segment.

17. A method of utilizing an optical fiber (30) adjoined to a medical device (20) for generating an encoded optical signal (32) indicative of each change in a shape of the optical fiber (30) responsive to movement of the medical device (20) within a defined space, the optical fiber (30) including a deformation optic sensor array (31) having a proximal endpoint (31p) and a distal endpoint (31d), the method comprising:

segmenting the optical fiber (30) into an anchor fiber segment and an active fiber segment relative to an anchor point having a fixed sampling location within the defined space, the anchor fiber segment extending between the proximal endpoint (31p) and an anchor point, the active fiber segment extending between the anchor point and the distal endpoint (31d);

for a low spatiotemporal shape sampling of the optical fiber (30), sequentially reconstructing a shape of the anchor fiber segment and a shape of the active fiber segment of the optical fiber (30); and

for a high spatiotemporal shape sampling of the optical fiber (30), exclusively reconstructing the shape of the active fiber segment of the optical fiber (30).

18. The method of claim 17, wherein the fixed sampling location of the anchor point is designated as being permanently fixed within the defined space for a plurality of spatiotemporal shape samplings of the optical fiber (30).

19. The method of claim 17, wherein the fixed sampling location of the anchor point is designated as being temporarily fixed within the defined space for a plurality of spatiotemporal shape samplings of the optical fiber (30).

20. The method of claim 19, further comprising:

for an anchor point update sampling between spatiotemporal shape samplings of the optical fiber (30), exclusively reconstructing the shape of the anchor fiber segment of the optical fiber (30) and updating the fixed sampling location of the anchor point within the defined space.

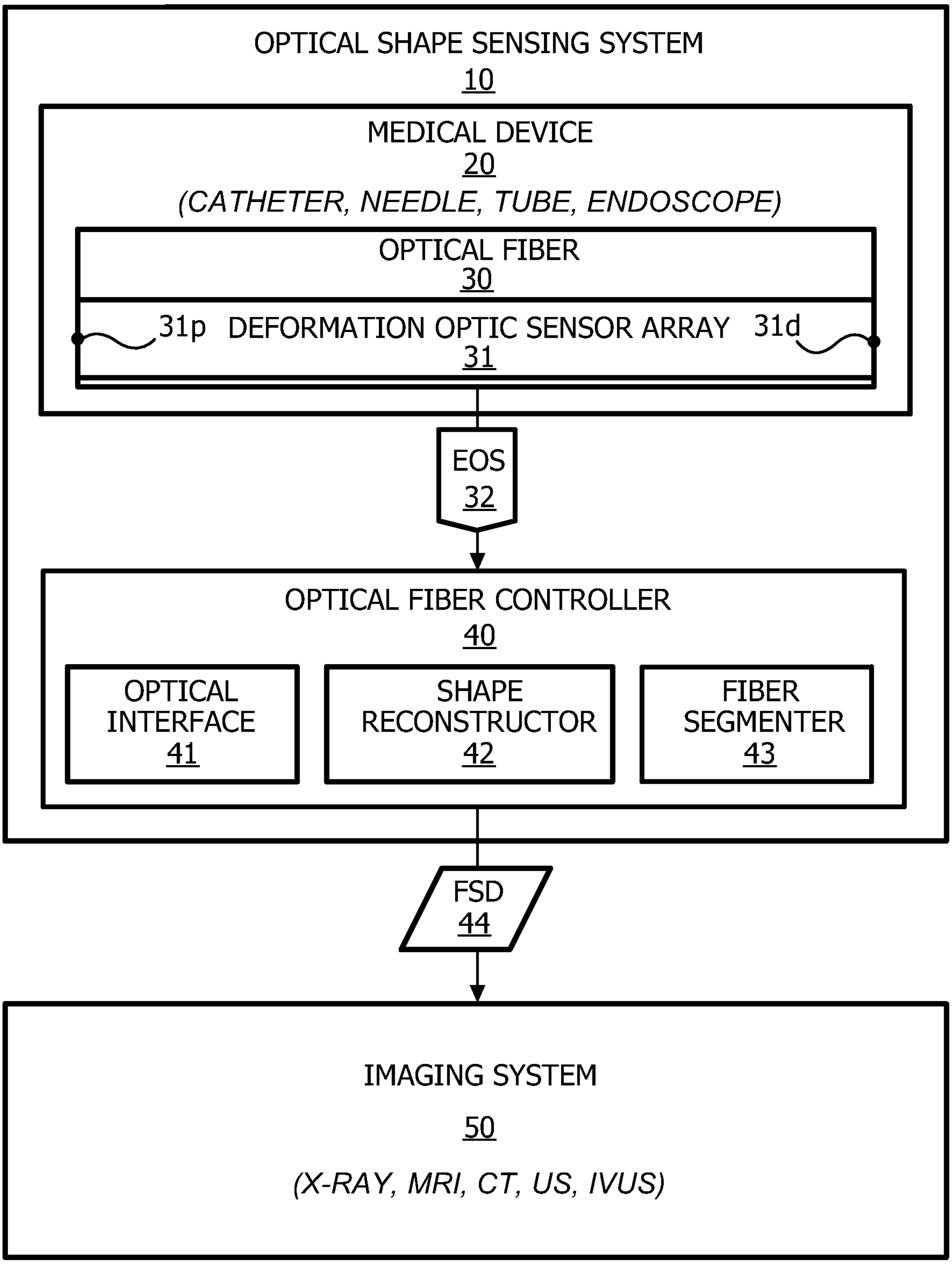
OPTICAL SHAPE SENSING SYSTEM
10
MEDICAL DEVICE
20
(CATHETER, NEEDLE, TUBE, ENDOSCOPE)
OPTICAL FIBER
30
31p
DEFORMATION OPTIC SENSOR ARRAY
31d
31
EOS
32
OPTICAL FIBER CONTROLLER
40
OPTICAL INTERFACE
41
SHAPE RECONSTRUCTOR
42
FIBER SEGMENTER
43
FSD
44
IMAGING SYSTEM
50
(X-RAY, MRI, CT, US, IVUS)

FIG. 1

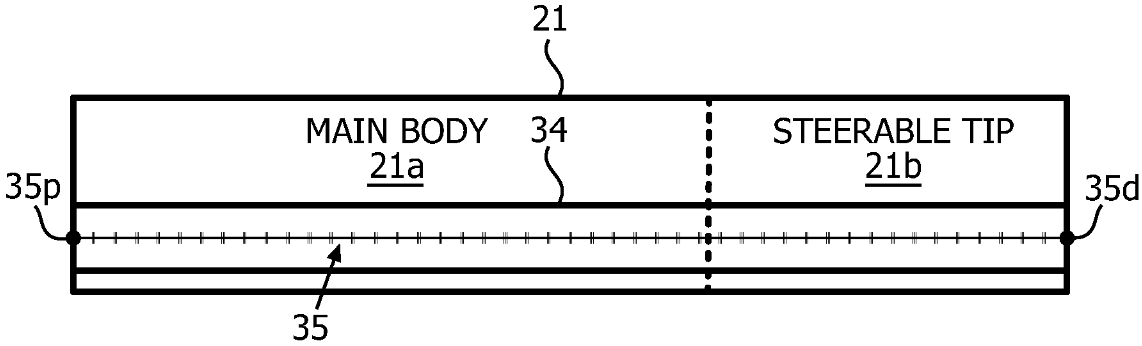

FIG. 2
(PRIOR ART)

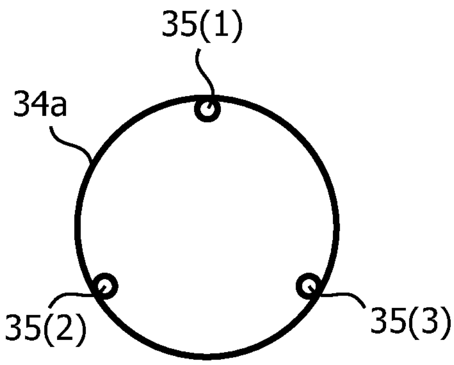

FIG. 3A
(PRIOR ART)

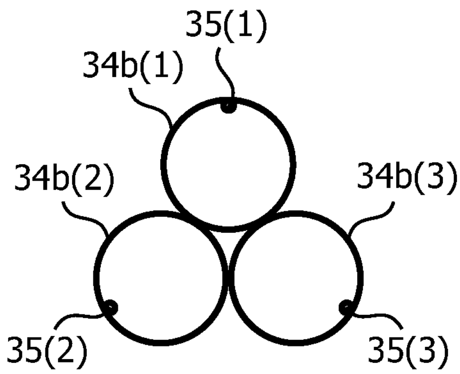

FIG. 3B
(PRIOR ART)

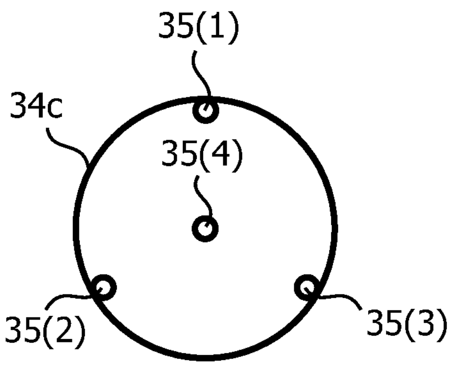

FIG. 3C
(PRIOR ART)

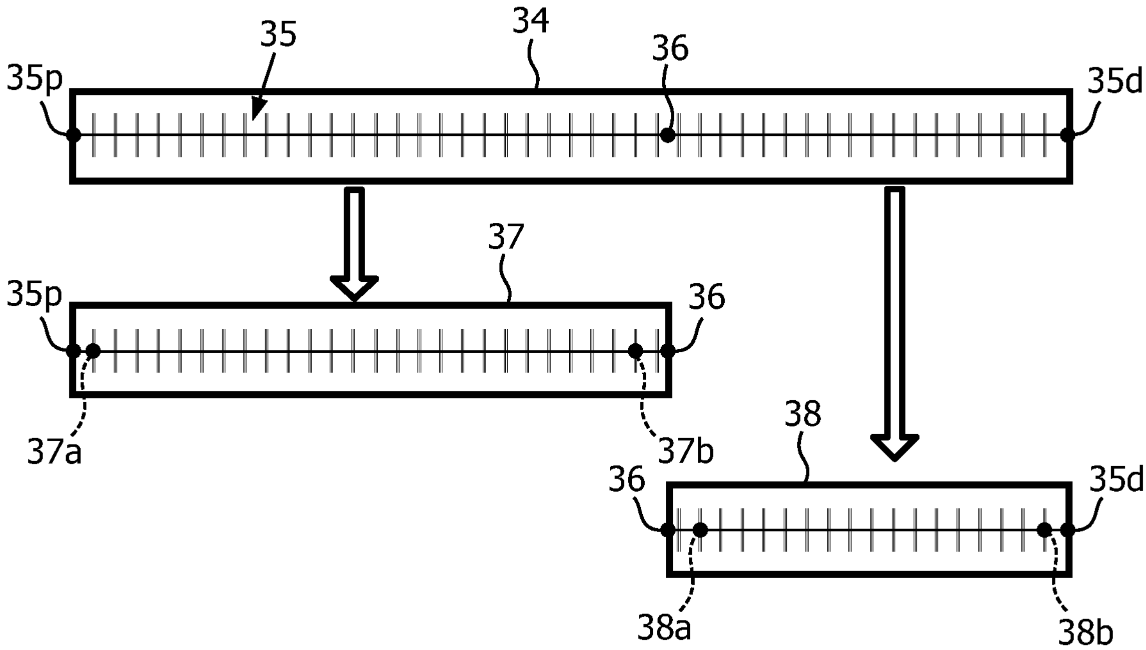
34
35
36
35p
35d
37
35p
36
37a
37b
38
36
35d
38a
38b

FIG. 4

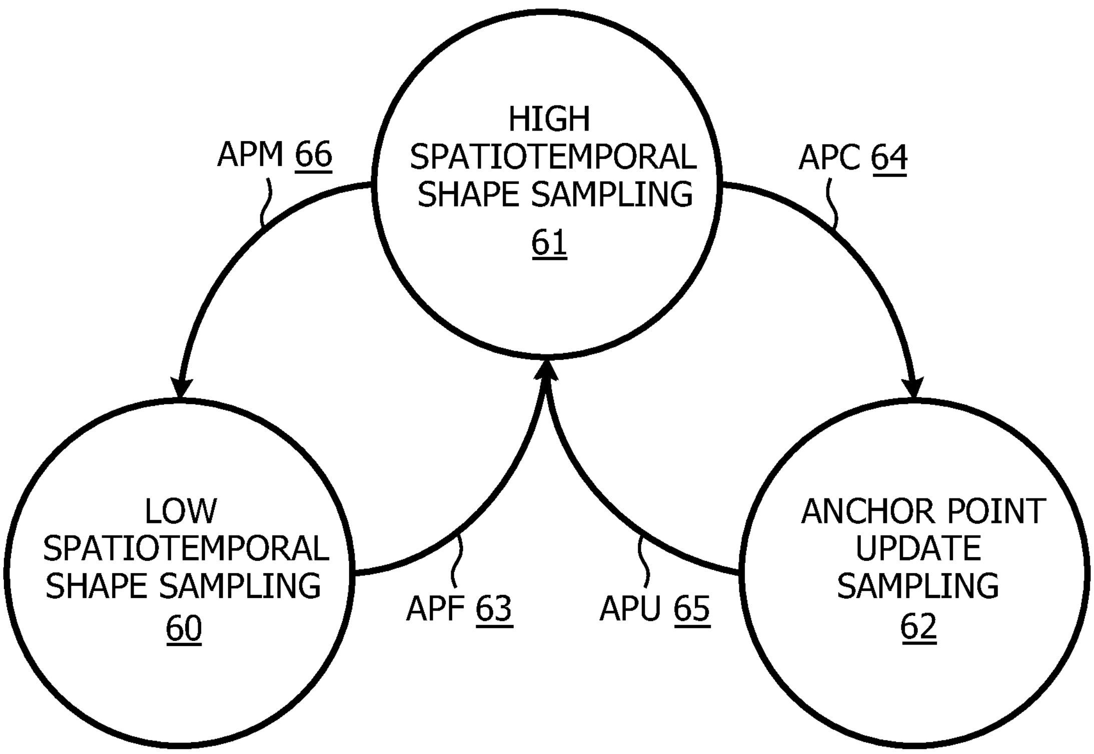
HIGH SPATIOTEMPORAL SHAPE SAMPLING 61
APM 66
APC 64
LOW SPATIOTEMPORAL SHAPE SAMPLING 60
ANCHOR POINT UPDATE SAMPLING 62
APF 63
APU 65

FIG. 5

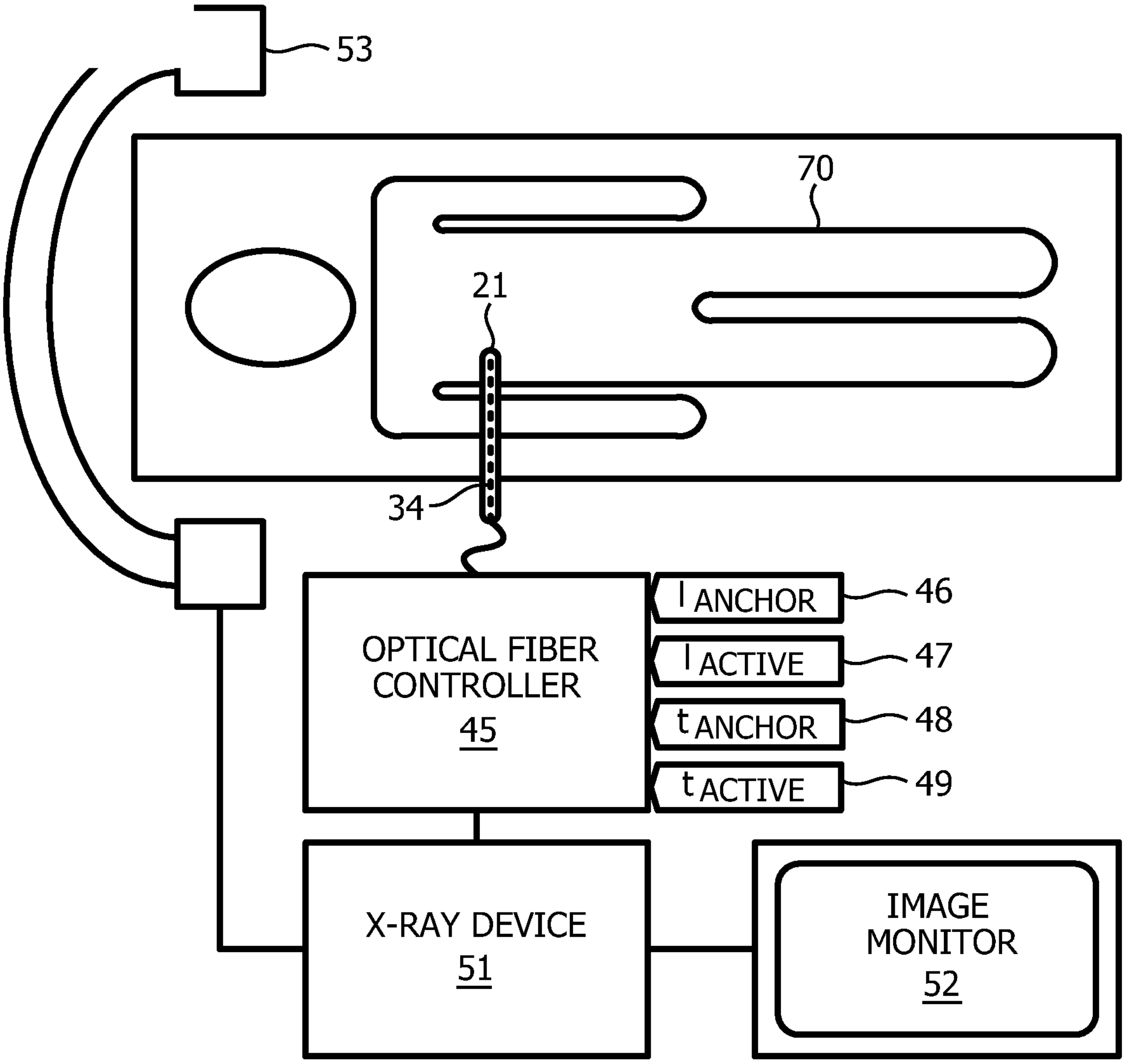

FIG. 6

80

STAGE / MODE	PRE-OPERATIVE	INTRA-OPERATIVE
AUTOMATIC	*81: PARAMETER RULES*	*82: FIBER CALIBRATION*
INTERACTIVE	*83: GRAPHICAL USER INTERFACE (FIG. 8)*	*84: FIBER IMAGING (FIG. 9)*

FIG. 7

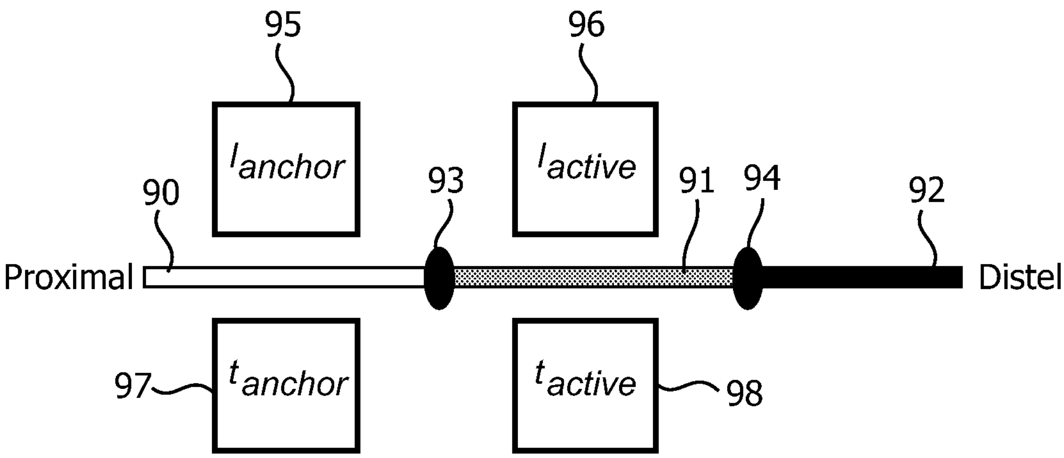
95
96
l_{anchor}
l_{active}
90
93
91
94
92
Proximal
Distel
t_{anchor}
t_{active}
97
98

FIG. 8

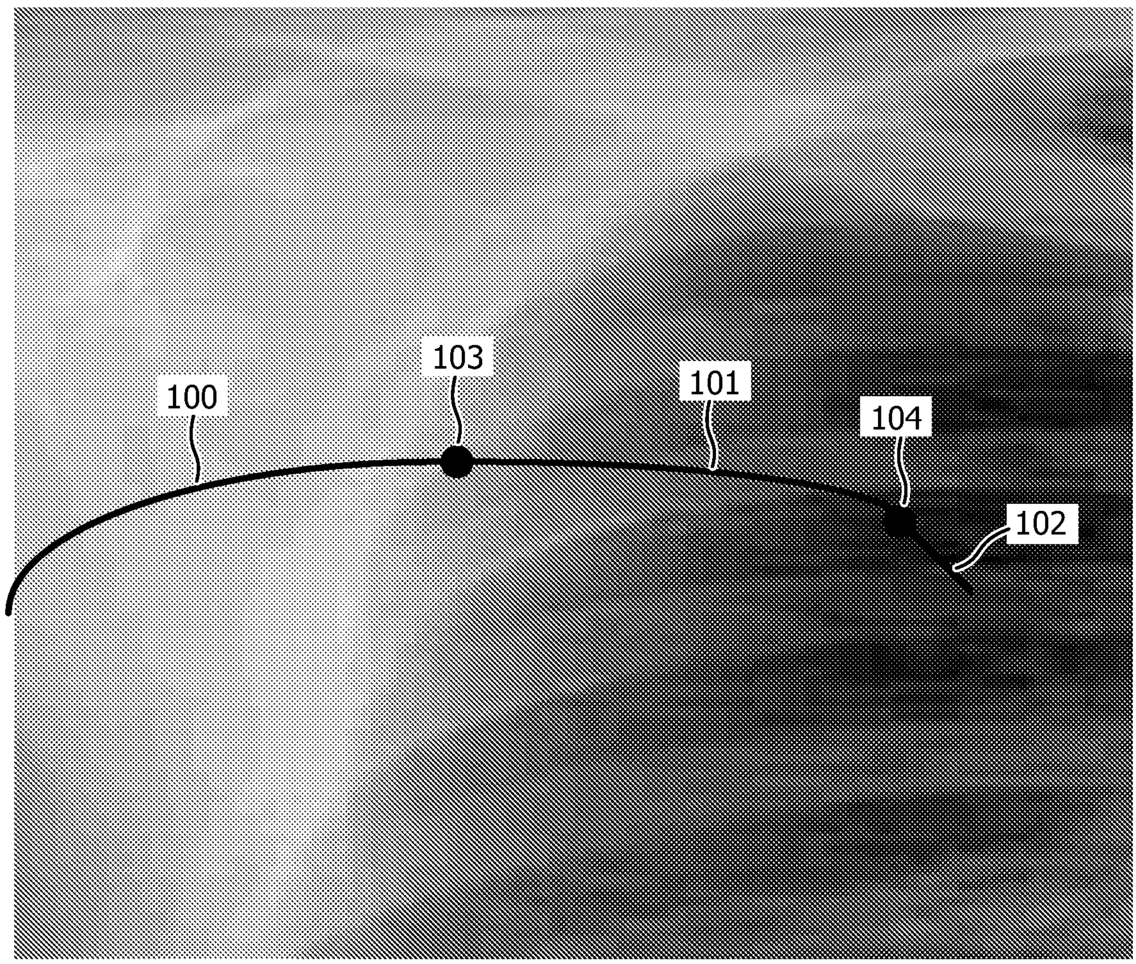
103
100
101
104
102

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/051366

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B1/00 A61B1/005 G01L1/24 G02B6/02 A61B19/00
A61M25/00 A61B5/06
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 G01L G02B A61M

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/023801 A1 (HANSEN MEDICAL INC [US]; RAMAMURTHY BHASKAR S [US]; TANNER NEAL A [US]) 19 February 2009 (2009-02-19) page 15, line 19 - last line page 17, line 22 - page 18, line 7 page 20, lines 12-25 page 21 page 42, lines 8-12 figures 2A, 3A-3C, 22C -----	1-16
A	WO 2009/114689 A1 (UNIV PENNSYLVANIA [US]; LITT BRIAN [US]; VIVENTI JONATHAN [US]) 17 September 2009 (2009-09-17) paragraphs [0037], [0054] figures 10, 11, 13 -----	1-16

-/--

[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
3 August 2011	10/08/2011

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	Gärtner, Andreas

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/051366

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 2006/013523 A1 (CHILDLERS BROOKS A [US] ET AL) 19 January 2006 (2006-01-19) paragraphs [0031] - [0048] -----	1-16
A	US 2004/165810 A1 (FUJITA HIROSHI [JP]) 26 August 2004 (2004-08-26) paragraphs [0028] - [0043] -----	1-16
A	US 2009/324161 A1 (PRISCO GIUSEPPE [US]) 31 December 2009 (2009-12-31) paragraphs [0025] - [0124] -----	1-16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2011/051366

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.: 17-20
because they relate to subject matter not required to be searched by this Authority, namely:

Rule 39.1(iv) PCT - Method for treatment of the human or animal body by surgery

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.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2011/051366

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009023801 A1	19-02-2009	EP 2187830 A1 US 2009137952 A1	26-05-2010 28-05-2009
WO 2009114689 A1	17-09-2009	EP 2265171 A1 JP 2011513038 A US 2011054583 A1	29-12-2010 28-04-2011 03-03-2011
US 2006013523 A1	19-01-2006	US 2007065077 A1	22-03-2007
US 2004165810 A1	26-08-2004	JP 2004251779 A	09-09-2004
US 2009324161 A1	31-12-2009	US 2010202727 A1	12-08-2010