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— *before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments (Rule 48.2(h))*

Published:

— *with international search report (Art. 21(3))*

SYSTEM AND METHOD FOR REGISTERING SHAPE SENSING WITH IMAGING USING AN OPTIMAL PLANE

This disclosure relates to medical instruments and more particularly to increasing the accuracy and reliability of optical fiber shape sensing systems.

Shape sensing based on fiber optics exploits inherent backscatter in a conventional optical fiber. The principle involved makes use of distributed strain measurement in the optical fiber using characteristic Rayleigh backscatter patterns. The physical length and index of refraction of a fiber are intrinsically sensitive to environmental parameters temperature and strain and, to a much lesser extent, pressure, humidity, electromagnetic fields, chemical exposure, etc.

With a four or more core fiber system where one core is located in the center of the cross-section, one is able to separate strain due to bending and temperature effects as long as no axial strain (tension) is applied, or if the tension is known and controllable (or can be calibrated out).

While such a system is capable of delivering accurate reconstructions of shape in three-dimensions, in practice, it is often seen that the accuracy of shape sensing is reduced along one direction when compared to the other two directions.

In accordance with the present principles, a shape sensing system includes a shape sensing device having an optical fiber. A launch console is configured to send and receive optical signals to and from the optical fiber and interpret the optical signals to determine a shape of the device. A calibration module is configured to determine a data reference plane for the optical signals received from the device. The data reference plane is determined based on minimized error, and the calibration module is configured to register the data reference plane with an image reference plane.

Another shape sensing system includes a shape sensing device having at least one optical fiber and a launch console configured to send and receive optical signals to and from the at least one optical fiber and interpret the optical signals to determine a shape of the device. A calibration module is configured to determine a data reference plane for the optical signals received from the device. The data reference plane is determined based on minimized error between a known configuration of the shape sensing device and a measured configuration of the shape sensing device. The calibration module is configured to register the data reference plane with an image reference plane. A calibration instrument is configured to position the shape sensing device in the known configuration for comparison with the measured configuration. A registration and update module is configured to dynamically update the registration between the data reference plane and the image reference plane over time.

A method for improving accuracy of a shape sensing system includes placing a shape sensing device in a known configuration to provide first position data; measuring shape data from the shape sensing device to provide second position data; comparing the first position data and the second position data to determine error differences therebetween; identifying an optimal plane based on a minimum error difference; and registering the optimal plane with an image reference plane to improve accuracy.

These and other objects, features and advantages of the present disclosure will become apparent from the following detailed description of illustrative embodiments thereof, which is to be read in connection with the accompanying drawings.

This disclosure will present in detail the following description of preferred embodiments with reference to the following figures wherein:

FIG. 1 is a block/flow diagram showing a shape sensing system which employs a calibration module in accordance with one embodiment;

FIG. 2 shows a 2D path plate having an optical fiber shape sensing device routed thereon in accordance with one embodiment;

FIG. 3A shows measured XY data for the optical fiber shape sensing device of FIG. 2 in accordance with one embodiment;

FIG. 3B shows measured XZ data for the optical fiber shape sensing device of FIG. 2 showing multiple possible Z planes in accordance with one embodiment;

FIG. 3C shows measured YZ data for the optical fiber shape sensing device of FIG. 2 showing multiple possible Z planes in accordance with one embodiment;

FIG. 4 shows a perspective view of an illustrative launch unit path having optical fiber routed therethrough in accordance with one embodiment;

FIG. 5A is a diagram showing ellipsoid error distributions for a high error projection corresponding to a non-optimal plane in accordance with one embodiment;

FIG. 5B is a diagram showing ellipsoid error distributions for a low error projection corresponding to an optimal plane in accordance with one embodiment; and

FIG. 6 is a flow diagram showing a method for optical shape-sensing in accordance with illustrative embodiments.

In accordance with the present principles, systems and methods for identifying an optimal plane for shape sensing are provided. This optimal plane (with the least amount of errors) is matched to an imaging plane or projection. The imaging plane may include any imaging technology (e.g., X-ray, ultrasound, magnetic resonance, etc.). The optimal plane of the shape sensing is dynamically updated to match an imaging reference as the imaging reference changes.

In accordance with the present principles, identification of a source of accuracy reductions along one direction when compared to the other two directions includes error due to insufficient birefringence correction. As a result, the presence of preferential or optimal

planes for optical shape sensing can be inferred. In these optimal planes, the error (both absolute and relative) is significantly lower when compared to an axis perpendicular to the optimal plane. The poor performance along one direction due to inadequate birefringence correction results in higher overall errors and may show sensed shapes outside features of interest within an image or imaging space.

The present principles address these one-direction errors by determining an optimal or preferential plane of the shape sensing and matching the same to the image. Once identified and matched, the optimal plane can be updated periodically/dynamically to ensure optimal performance of the shape sensing data with respect to the image or images.

In particularly useful embodiments, a module and instruments for performing a calibration of measurements to identify the optimal plane (i.e., the plane that shows least errors for shape sensing) are provided. A true shape of the shape sensing device can be determined by many techniques. For example, one or more 2D path plates may be employed wherein the off-plane error is known since the ground truth shape (or part of the shape) fits a plane. 3D path plates may be employed, wherein the true shape (or sub-segment of the shape) in all three dimensions is known. Robotic grid maps may be employed and include a portion of the shape sensing optical fiber (tip or proximal to the tip), which is moved in a known fashion (translation and/or rotation). Other methods may include the use of imaging or images with standard shapes, etc.

The optical fiber may be moved in a known fashion, position and orientation that best fits the imaging plane, and these configurations are identified. A second optical fiber may also be attached on a grid and connected to a same laser console, and this grid is translated and rotated in 3D space to optimize for the best plane of the first optical fiber.

A processing unit or processor uses the optimal plane information from the calibration to match the plane to a corresponding plane in the imaging frame of reference and/or compute

a transformation matrix to perform the same matching. An update module controls and modifies the optimal plane (its rotation, translation, etc. of a launch point, console, etc.) such that as the image or orientation of an operating table or other platform changes, the optimal plane changes accordingly. For example, during a rotational run in X-ray, a fiber optic shapes sensing launch unit, which contains a fiber launch region, can be rotated appropriately to ensure that the optimal plane matches / lies parallel to the plane of a projection image in the X-ray along each position of the rotational run.

It should be understood that the present invention will be described in terms of medical instruments; however, the teachings of the present invention are much broader and are applicable to any fiber optic or shapes sensing instruments. In some embodiments, the present principles are employed in correcting, tracking, analyzing shape sensing signals collected for complex biological or mechanical systems. In particular, the present principles are applicable to internal tracking procedures of biological systems and procedures in all areas of the body such as the lungs, gastro-intestinal tract, excretory organs, blood vessels, etc. The elements depicted in the FIGS. may be implemented in various combinations of hardware and software and provide functions which may be combined in a single element or multiple elements.

The functions of the various elements shown in the FIGS. can be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions can be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which can be shared. Moreover, explicit use of the term “processor” or “controller” should not be construed to refer exclusively to hardware capable of executing software, and can implicitly include, without limitation, digital signal processor (“DSP”) hardware, read-only memory (“ROM”) for storing software, random access memory (“RAM”), non-volatile storage, etc.

Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future (i.e., any elements developed that perform the same function, regardless of structure). Thus, for example, it will be appreciated by those skilled in the art that the block diagrams presented herein represent conceptual views of illustrative system components and/or circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams and the like represent various processes which may be substantially represented in computer readable storage media and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

Furthermore, embodiments of the present invention can take the form of a computer program product accessible from a computer-usable or computer-readable storage medium providing program code for use by or in connection with a computer or any instruction execution system. For the purposes of this description, a computer-usable or computer readable storage medium can be any apparatus that may include, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium. Examples of a computer-readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk – read only memory (CD-ROM), compact disk – read/write (CD-R/W), Blu-Ray™ and DVD.

Referring now to the drawings in which like numerals represent the same or similar

elements and initially to FIG. 1, a system 100 for identifying and tracking an optimal plane for shape sensing enabled devices is illustratively shown in accordance with one embodiment. System 100 may include a workstation or launch console 112 from which a procedure is supervised and/or managed. Workstation 112 preferably includes one or more processors 114 and memory 116 for storing programs and applications. Memory 116 may store an optical sensing module 115 configured to interpret optical feedback signals from a shape sensing device or system 104. Optical sensing module 115 is configured to use the optical signal feedback (and any other feedback, e.g., electromagnetic (EM) tracking) to reconstruct deformations, deflections and other changes associated with a medical device or instrument 102 and/or its surrounding region. The medical device 102 may include a catheter, a guidewire, a probe, an endoscope, a robot, an electrode, a filter device, a balloon device, or other medical component, etc.

The shape sensing system 104 on device 102 includes one or more optical fibers 126 which are coupled to the device 102 in a set pattern or patterns. The optical fibers 126 connect to the workstation 112 through cabling 127. The cabling 127 may include fiber optics, electrical connections, other instrumentation, etc., as needed.

Shape sensing system 104 with fiber optics may be based on fiber optic Bragg grating sensors. A fiber optic Bragg grating (FBG) 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 can therefore be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector.

A fundamental principle behind the operation of a fiber Bragg grating is Fresnel reflection at each of the interfaces where the refractive index is changing. For some wavelengths, the reflected light of the various periods is in phase so that constructive

interference exists for reflection and, consequently, destructive interference for transmission. The Bragg wavelength is sensitive to strain as well as to temperature. This means that Bragg gratings can be used as sensing elements in fiber optical sensors. In an FBG sensor, the measurand (e.g., strain) causes a shift in the Bragg wavelength.

One advantage of this technique is that various sensor elements can be distributed over the length of a fiber. Incorporating three or more cores with various sensors (gauges) along the length of a fiber that is embedded in a structure permits a three dimensional form of such a structure to be precisely determined, typically with better than 1 mm accuracy. Along the length of the fiber, at various positions, a multitude of FBG sensors can be located (e.g., 3 or more fiber sensing cores). From the strain measurement of each FBG, the curvature of the structure can be inferred at that position. From the multitude of measured positions, the total three-dimensional form is determined.

As an alternative to fiber-optic Bragg gratings, the inherent backscatter in conventional optical fiber can be exploited. One such approach is to use Rayleigh scatter in standard single-mode communications fiber. Rayleigh scatter occurs as a result of random fluctuations of the index of refraction in the fiber core. These random fluctuations can be modeled as a Bragg grating with a random variation of amplitude and phase along the grating length. By using this effect in three or more cores running within a single length of multi-core fiber, the 3D shape and dynamics of the surface of interest can be followed.

In one embodiment, workstation 112 includes an image generation module 148 configured to receive feedback from the shape sensing device 104 and record position data for the sensing device 104 within a volume 131 in a subject 160 (e.g., a patient). An image 134 of the shape sensing device 104 within the space or volume 131 can be displayed on a display device 118 and registered with an image 136 (preoperative or real-time) collected using an imaging system 110. The imaging system 110 may include an X-ray system, a magnetic

resonance system, an ultrasound system or any other imaging system. Workstation 112 includes the display 118 for viewing internal images of the subject (patient) 160 or volume 131 and may include the image 134 of the shape sensing data as an overlay or other rendering on the image 136. Images 134 and 136 may be concurrently viewed.

Display 118 may also permit a user to interact with the workstation 112 and its components and functions, or any other element within the system 100. This is further facilitated by an interface 120 which may include a keyboard, mouse, a joystick, a haptic device, or any other peripheral or control to permit user feedback from and interaction with the workstation 112.

A calibration module 150 may be stored in memory 116 or may be included as a separate system. The calibration module 150 receives feedback from the shape sensing device 104. The calibration module 150 may be employed with instruments 152 for performing a calibration step. The calibration may include measurements to identify an optimal plane (i.e. the plane that shows the least errors for the shape sensing system 104). The instruments 152 may include two-dimensional (2D) path plates, three-dimensional (3D) path plates, robotic grid maps, dynamic launch fixtures, and/or more than one shape sensing fiber connected to a same laser console for calibration or any combination of the above. The instruments 152 provide a known configuration for the shape sensing device 104. In this way, the known shape can be compared to a measured shape to compute error therebetween. Since the data in two of the three dimensions can easily be determined as accurate, the two dimensions which are accurate are employed in seeking a plane in the third dimension space that provides the least error. The plane that provides the least error (in comparison with the known configuration held using the instruments 152) is referred to as the optimal plane.

The instruments 152 for proving known configurations for the shape sensing device 104 may include some of the following. In one embodiment, a 2D path plate may be

employed wherein off-plane error is known since a ground truth shape (or part of the shape) fits or is constrained to a plane. 3D path plates may also be employed where the true shape (or sub-segment of the shape) in all three dimensions is known. Robotic grid maps may be employed where a portion of the fiber (e.g., a tip or proximal portion to the tip) is moved in a known fashion (translation and/or rotation). In another embodiment, the console 112 where a light source 108 is located, a fiber launch region 158 within a launch unit 156, the imaging system 110 or a portion thereof (e.g., a C-arm or other movable mechanism) may be moved in a known fashion, position and orientation to find a best fit (minimized error) for the imaging plane to be identified. For example, after the identification of the optimal plane, the imaging equipment (X-ray C-arm) may be repositioned to the preferred plane and all imaging is performed in that view.

In another embodiment, a second shape sensing optical fiber may be employed and attached on a grid (or plate) and connected to a same laser console. The grid may be translated and rotated in 3D space to provide a second data set for comparison with the data set of the first shape sensing optical fiber. In this way, the best plane (optimal plane) of the first fiber can be determined during a procedure. As will be described in greater detail below, a number of samples at a single point may be collected and statistically analyzed. The optimal plane can be determined by smallest eigenvectors of an ellipsoid formed that encompasses those samples. The ellipsoid may represent one, two, three ... sigma error distributions about a point.

Ellipsoids are employed as an example herein. Other error regions and criteria may also be employed. An ellipsoid is a closed quadratic surface that is a three dimensional analog of an ellipse. The standard equation of an ellipsoid centered at the origin of a Cartesian coordinate system is:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1,$$

The points $(a,0,0)$, $(0,b,0)$ and $(0,0,c)$ lie on the surface of the ellipsoid and the line segments from the origin to these points are called semi-principal axes of length a , b , c . These axes correspond to the semi-major axis and semi-minor axis of the appropriate ellipses.

A three sigma ellipsoid, for example, can be determined by a covariance matrix with a center at the mean of the data. For bare fiber in test plates, if the ellipsoid falls within a sphere with radius of milestone requirements (within an acceptable limit or threshold), the test passes.

A Bland-Altman and linear regression may be performed to characterize measurement error bias and noise versus path characteristics. A statistical significance of measurement differences can be determined, e.g., by paired t-testing, Wilcoxon signed-rank test, Mann-Whitney rank-sum test, or similar methods depending on normal versus non-normal distribution assumptions.

Measurement distributions to compute the ellipsoids may include one or more of the following tests. Other tests may be employed as well. Static shape and end point repeatability can be tested using a same shape to evaluate the fiber inside, e.g., aluminum shape plates. This tests the repeatability of the end point measurement of the fiber within the same metal track. For each shape, the operator will repeat fiber placement within the path a number of times to alter the fiber boundary conditions. For each repeat placement, a number of acquisitions will be performed to characterize repeatability of measurement for static boundary conditions.

Another test may include static end point repeatability through various shapes. This test evaluates the repeatability of the measurement of a known end point, when the path to reach that end point is different. To do this, a fiber is used in a set of shape plates or posts. The end point of the fiber will be fixed down at some known location. The shape of the

center section of the fiber will be varied arbitrarily. For each shape, a number of acquisitions will be performed to characterize repeatability of measurements for the same set of shape boundary conditions.

Another test may include positional accuracy in 3D shapes. This test evaluates the shape measured by the fiber in 3D. For each shape, the operator will repeat fiber placement within the path a number of times to alter the fiber boundary conditions. For each repeat placement, a number of acquisitions are performed to characterize repeatability of measurement for static boundary conditions. Other tests may be employed in addition to or instead of these tests.

Referring to FIG. 2, a 2D path plate 200 is shown for a shape sensing optical fiber 202. The path plate 200 provides fiber paths of known segment length dimensions and angular rotations in two dimensions. During calibration, the fiber 202 is routed along a path on the path plate 200 to generate shape sensing data. The shape sensing data is illustratively depicted in FIGS. 3A-3C.

Referring to FIG. 3A, XY data is represented in a plot 302. The XY data is very accurate and corresponds to the position routed on the path plate 200 in FIG. 2. In FIG. 3B, XZ data is plotted in a plot 304. Plot 304 includes discrepancies in the Z data set as indicated by multiple data traces in the Z-direction. The Z-direction is perpendicular to the plane of the path plate 200. These discrepancies are also pronounced in the YZ data of plot 306 of FIG. 3C. The plane parallel to the Z-direction that provides the least error (in comparison with the known configuration held using the instruments, such as path plate 200) is the optimal plane.

Optical shape sensing (OSS) has the ability to deliver reconstructions of 3D shape. While it shows sub-millimeter accuracy in two directions (X and Y in the example), the overall accuracy of OSS is limited by a third dimension (often off-axis from the fan-out of the console (112) in this case the Z axis). This sometimes leads to high absolute error of, e.g.,

approximately a centimeter at the distal tip of a 1.5m long fiber. While one solution is to understand the source of the error (one possible/major reason is sub-optimal birefringence correction) and perform correction on the optical signal, in accordance with the present principles, the system 100 provides a way to correct these errors despite their origin and matches and displays the plane with optimal shape sensing on a screen in conjunction with images of a subject. In a clinical setting, the shape tracked instrument will be displayed on the screen, overlaid with imaging like a projection X-ray image. A high-error projection may cause the device shape and features in the X-ray (image) to be misaligned, thus reducing the confidence of the clinician in shape sensing. While improved initial registration and online registration schemes like vesselness filters may be helpful, the selection and modification of the optimal shape sensing plane such that it always matches the imaging plane will ensure that the plane with the least error lies parallel with, overlays or corresponds with the image plane (e.g., corresponding to an X-ray detector, etc.) and ensures optimal performance with respect to the imaging setup.

Referring to again FIG. 1, calibration may be performed as needed, e.g., before a procedure is performed using the shape sensing device 104. However, updates and checks may be needed during the procedure to ensure that the optimal plane and imaging plane remain registered. This may be performed as needed during the procedure. The calibration module 150 includes a registration and update module 154. The registration and update module 154 uses the optimal plane information from the calibration step to match this plane to a corresponding plane in a frame of reference in imaging space (e.g., image plane) and/or computes a transformation matrix to perform the same matching. The registration and update module 154 controls and modifies the optimal plane to maintain registration with the imaging reference during use of the system 100. The registration and update module 154 may enable adjustments of hardware to maintain the alignment between the optimal plane and the image

plane, e.g., rotation and translation of the workstation 102, the launch segment or unit 156, etc. such that even as the image changes, the optimal plane changes accordingly.

In one example, during a rotational run using an X-ray machine (110) having a C-arm, the optical fiber shape sensing device 104 may be coupled to the launch unit 156 that can be rotated appropriately to ensure that the optimal plane matches or lies parallel with the plane of the projection image in the X-ray along each position of the rotational run (of the C-arm). The orientation of the launch unit 156 may represent the optimal plane or have a set relationship with the optimal plane. In this way, a visual correspondence may be provided between the optimal plane and an imaging plane, which can be observed from the X-ray source or detector or a position on the C-arm. Other indicia and/or mechanical indicators may be employed.

It should be understood that the launch console 112 may include a separate light source 108 to provide light signals for optical shape sensing measurements. The launch unit 156 is coupled to the console 112 and connects the console 112 with the shape sensing device 104. The console 112 may incorporate the launch unit 156. The optical source 108 provides optical signals to the shape sensing device 104 through the fiber launch unit 156 which connects to optical fiber(s) 126) at a fiber launch region 158.

Referring to FIG. 4, an example of a launch unit 156 is illustratively shown. The launch unit 156 provides a way to introduce the shape sensing fiber 126 into the console 112 connected by a cable 164 or other connection. The launch unit 156 may also include a buffer loop 162 (of optical fiber), to accommodate the path length change of the fiber 126 as the shape of the device 104 changes. The launch unit 156 may include a glass slide 166, a V groove, test tubes forming a tight fit with the fiber 126 or any other fiber optic interface. It should also be understood that the launch unit 156 may also include, in addition to optical fiber, routing for other systems using, e.g., cabling 127). In one embodiment, the launch unit

156 may be adjusted to adjust the optimal plane or to register the optimal plane with images by translating or rotating the launch unit 156 in any direction including those directions illustratively indicated by arrows “A”, “B”, “C”, etc.

In FIG. 1, once the optimal plane is identified, a standard processing unit, e.g., workstation 112 (with a personal computer or dedicated electronics) can be used to perform computations that use the optimal plane information from the calibration step to match the optimal plane to a corresponding plane in the imaging frame of reference and/or compute a transformation matrix to perform this matching. The optimal plane may be physically registered by rotating and/or translating the console 112, the launch segment 156, the fibers 126, etc. such that even as the image changes, the optimal plane changes accordingly. Actuators 144 such as servos or the like may be employed and controlled by the registration and update module 154 to achieve this alignment (e.g., of the launch console 112 or the launch unit 156, etc.). The actuators 144 may provide motorized rotation and translation controlled in a closed loop manner by the registration and update module 154 or in an open loop manner by an operator via an appropriate user interface 120. Alternatively, manual adjustment of the position and orientation of the console 112, launch segment 156, etc. could be achieved using appropriate positioning and clamping components. For example, during a rotational run in X-ray, the launch unit 156 (with source 108) can be rotated appropriately to ensure that the optimal plane matches or lies parallel to the plane of the projection image in X-ray along each position of the rotational run.

In another embodiment, the optimal plane is aligned to the imaging plane using software. For example, the transformation computed during the calibration step may be employed to transform and register the imaging plane with the shape sensing optimal plane. In this way, collected data can be transformed for appropriate alignment and rendered in a display with, e.g., 3D preoperative images of the volume 131.

It should also be noted that while the fiber 126 is shown as part of a medical instrument 102, another separate shape sensing fiber (not shown) may be employed to determine the optimal plane and register the shape sensing with the images collected, while the instrument (with another shape sensing fiber 126) is used for the procedure. In one embodiment, both of these fibers may employ the same launch unit 156.

Referring to FIGS. 5A and 5B, results of a grid mapping of a tip of an optical shape sensing fiber (1.5m long) are shown using three sigma ellipsoids 402. The tip of the shape sensing device was placed at positions on a map, and a corresponding shape-sensed position was compared to the known map location. The errors between these values were mapped as ellipsoids 402. The ellipsoids 402 characterize error at each point. The lengths of each axis of the ellipsoids 402 depict the error along that direction, while the shade and volume/size show the overall error. An image or plot 404 in FIG. 5A illustrates a high-error projection, while an image or plot 406 in FIG. 5B illustrates a low-error projection. The low-error projection 406 corresponds to an optimal plane in that the sizes of the ellipsoids are minimized. This can be measured numerically or graphically using the smallest total volume of ellipsoids 402. These error plots may be employed in computing and updating/ dynamically matching of the optimal plane to a detector of the X-ray during a rotational run or other imaging plane reference.

It should be noted that the grid mapping experiment was performed with different sensors to demonstrate that the error is repeatable across the different sensors. Although the orientation of the low-error projection varies with the sensor as well as the orientation of the launch point, the results were repeatable across the different sensors.

Referring to FIG. 6, methods for improving accuracy of a shape sensing system are illustratively shown. The method may include a calibration step in block 500 and an updating step in block 550. For calibration, in block 502, a shape sensing device is placed in a known configuration to provide first position data. The shape sensing device preferably includes a

fiber optic shape sensing device; however, other sensing technologies may also be employed.

In block 504, a calibration instrument may be employed which is configured to position the shape sensing device in the known configuration. The calibration instrument may include a path plate, a grid map or other patterned device. In one embodiment, the calibration instrument may include at least one other shape sensing optical fiber attached on a same grid as the shape sensing enabled device. In another embodiment, the calibration instrument may include a launch segment in the launch console.

In block 512, shape data is measured from the shape sensing device to provide second position data. In block 520, the first position data and the second position data are compared to determine error differences therebetween.

In block 530, an optimal plane is identified based on a minimum error difference. In block 532, an optimal plane may be identified based on the minimum error difference by moving the grid having the additional shape sensing enabled device (e.g., two shape sensing devices with a same source to determine a common solution for both fibers). In block 534, the launch segment or unit may be adjusted to find a position of the data reference plane that reduces error. This may be performed using an actuator or the like. In block 536, the launch console may include at least one actuator, and the launch segment may be adjusted by moving the launch console with the actuator to reduce error.

In block 538, measured samples may be collected at a single point (or points); and, in block 539, smallest eigenvectors of an ellipsoid are determined that encompass the measured sample. The size/volume of these ellipsoids indicates the amount of error and may be employed in finding the optimal plane.

In block 540, the optimal plane is registered with an image reference plane to improve accuracy.

In the updating step (block 550), in block 552, dynamic updating of the registration between the data reference plane and the image reference plane is maintained over time. This may be performed by checking the error and making adjustments to minimize the error. The same techniques employed for calibration as described in blocks 530-539 may be employed to maintain the registration between the data reference plane and the image reference frame in block 554.

In block 560, shape sensing data associated with the data reference plane and an image associated with the image reference plane may be concurrently rendered on a display. This may be performed through an interventional procedure or other procedure.

In interpreting the appended claims, it should be understood that:

- a) the word "comprising" does not exclude the presence of other elements or acts than those listed in a given claim;
- b) the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements;
- c) any reference signs in the claims do not limit their scope;
- d) several "means" may be represented by the same item or hardware or software implemented structure or function; and
- e) no specific sequence of acts is intended to be required unless specifically indicated.

Having described preferred embodiments for system and method for registering shape sensing with imaging using an optimal plane (which are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons skilled in the art in light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the disclosure disclosed which are within the scope of the embodiments disclosed herein as outlined by the appended claims. Having thus described the

details and particularity required by the patent laws, what is claimed and desired protected by Letters Patent is set forth in the appended claims.

CLAIMS:

1. A shape sensing system, comprising:
a shape sensing enabled device (104) having at least one optical fiber (126);
a launch console (112) configured to send and receive optical signals to and from the at least one optical fiber and interpret the optical signals to determine a shape of the device;
and
a calibration module (150) configured to determine a data reference plane for the optical signals received from the device, the data reference plane being determined based on minimized error, the calibration module being configured to register the data reference plane with an image reference plane.
2. The system as recited in claim 1, wherein the calibration module (150) includes and a registration and update module (154) configured to dynamically update the registration between the data reference plane and the image reference plane.
3. The system as recited in claim 1, wherein the minimized error is computed based upon difference between a known configuration of the shape sensing device (104) and a measured configuration of the shape sensing device.
4. The system as recited in claim 1, further comprising a calibration instrument (152) configured to position the shape sensing device in a known configuration for comparison with a measured configuration.
5. The system as recited in claim 4, wherein the calibration instrument (152) includes at least one of a path plate or a grid map.

6. The system as recited in claim 4, wherein the calibration instrument (152) includes at least one other shape sensing optical fiber attached on a same plane as the shape sensing enabled device.

7. The system as recited in claim 4, wherein the calibration instrument (152) includes a launch segment (156) coupled to the launch console, the launch segment being adjusted to find a position of the data reference plane that matches the image reference plane.

8. The system as recited in claim 1, wherein the data reference plane is identified by collecting measured samples at a single point and determining smallest eigenvectors of an ellipsoid that encompasses the measured samples.

9. The system as recited in claim 1, wherein the launch console (112) includes at least one actuator (144), the actuator configured to adjust the launch console to match the data reference plane to the image reference plane.

10. The system as recited in claim 1, wherein the image reference plane is associated with an image collected by an imaging system (110).

11. The system as recited in claim 1, further comprising a display (118) for concurrently rendering shape sensing data associated with the data reference plane and an image associated with the image reference plane.

12. The system as recited in claim 1, wherein the data reference plane is registered

with the image reference plane by translating or rotating at least one of the optical fiber (126) or hardware employed for imaging.

13. A shape sensing system, comprising:

a shape sensing device (104) having at least one optical fiber;

a launch console (112) configured to send and receive optical signals to and from the at least one optical fiber and interpret the optical signals to determine a shape of the device;

a calibration module (150) configured to determine a data reference plane for the optical signals received from the device, the data reference plane being determined based on minimized error between a known configuration of the shape sensing device and a measured configuration of the shape sensing device, the calibration module being configured to register the data reference plane with an image reference plane;

a calibration instrument (152) configured to position the shape sensing device in the known configuration for comparison with the measured configuration; and

a registration and update module (154) configured to dynamically update the registration between the data reference plane and the image reference plane over time.

14. A method for improving accuracy of a shape sensing system, comprising:

placing (502) a shape sensing device in a known configuration to provide first position data;

measuring (512) shape data from the shape sensing device to provide second position data;

comparing (520) the first position data and the second position data to determine error differences therebetween;

identifying (530) an optimal plane based on a minimum error difference; and

registering (540) the optimal plane with an image reference plane to improve accuracy.

15. The method as recited in claim 14, further comprising dynamically updating (552) a registration between the data reference plane and the image reference plane over time.

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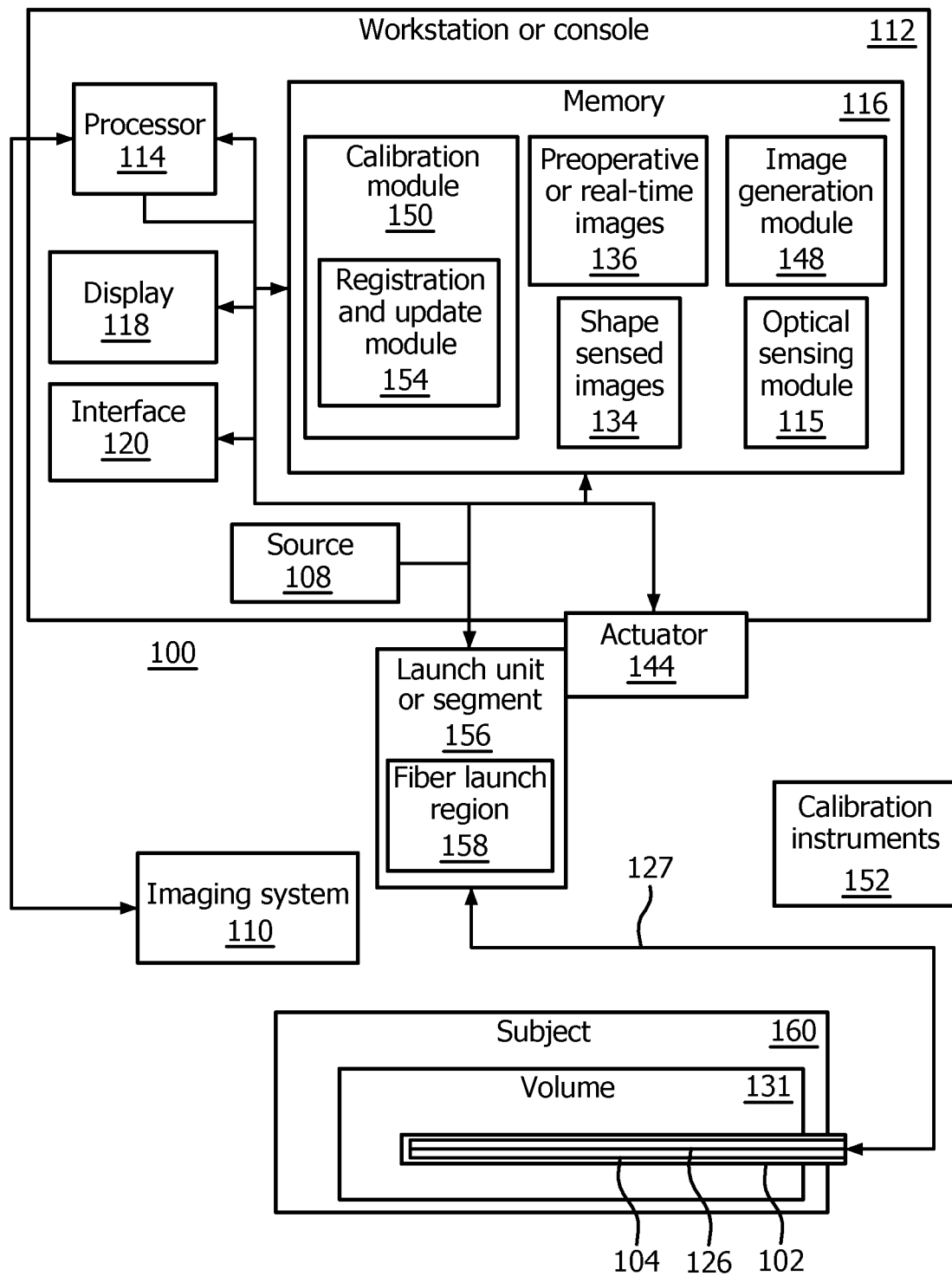


FIG. 1

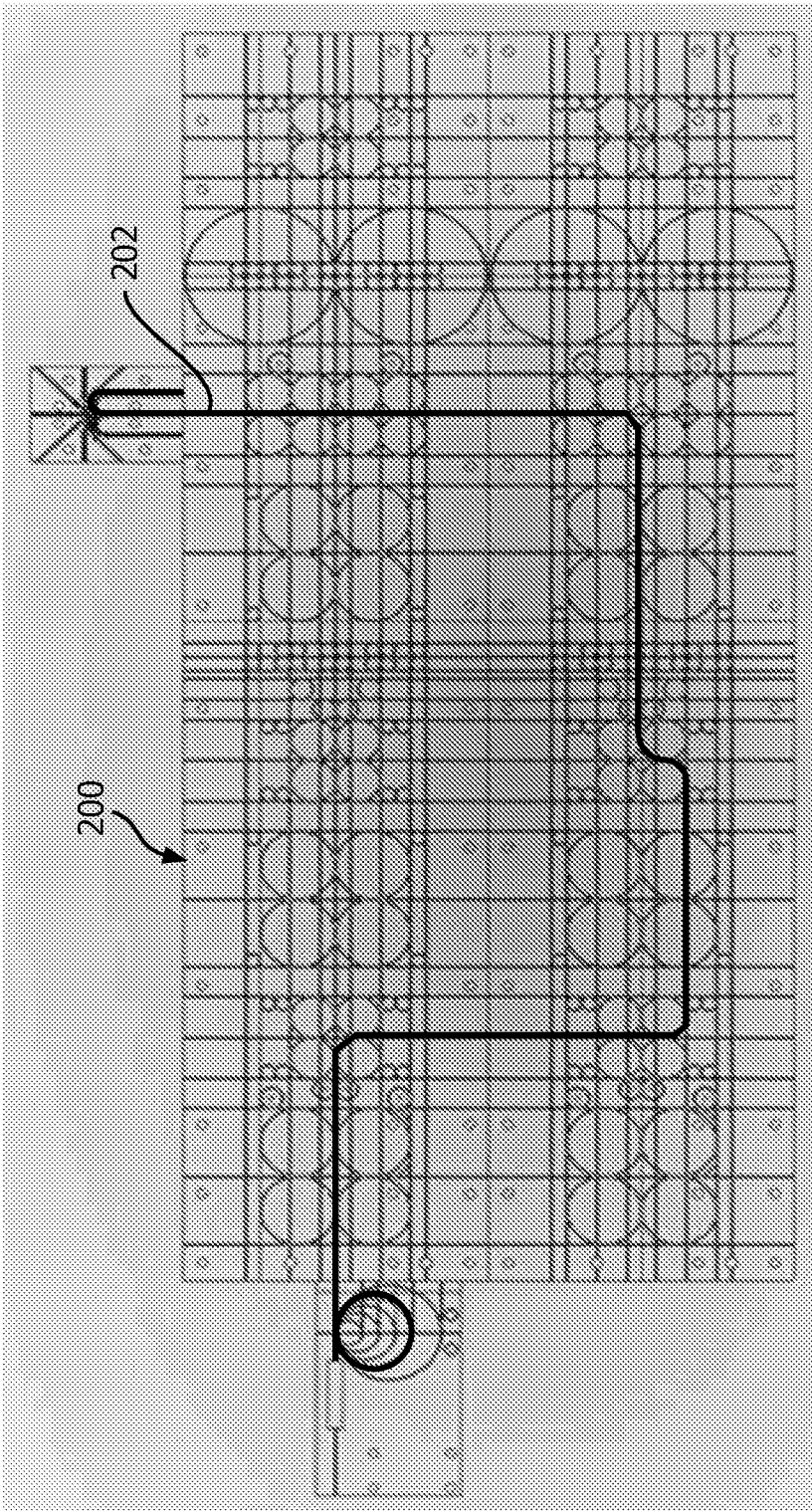
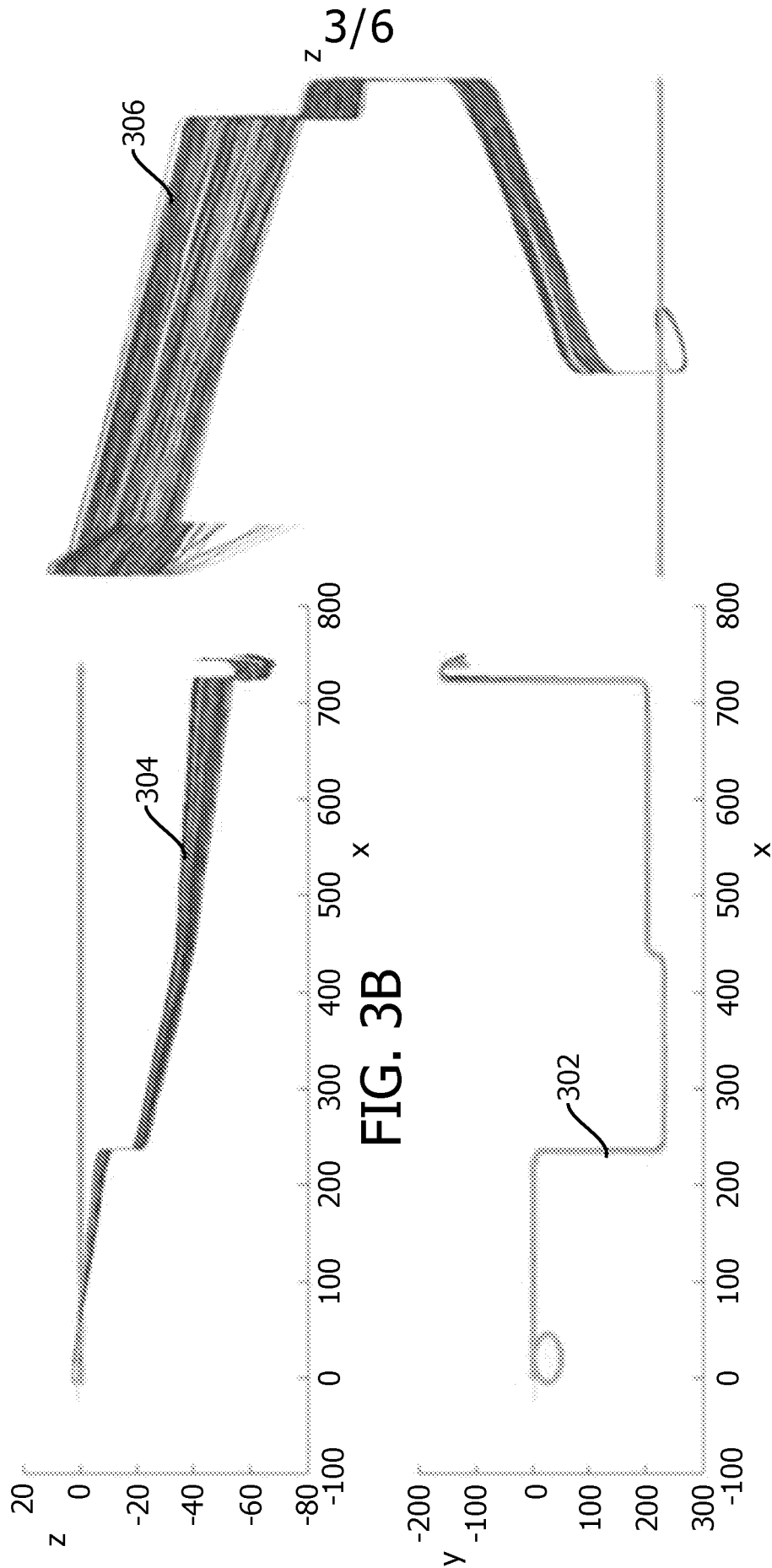


FIG. 2



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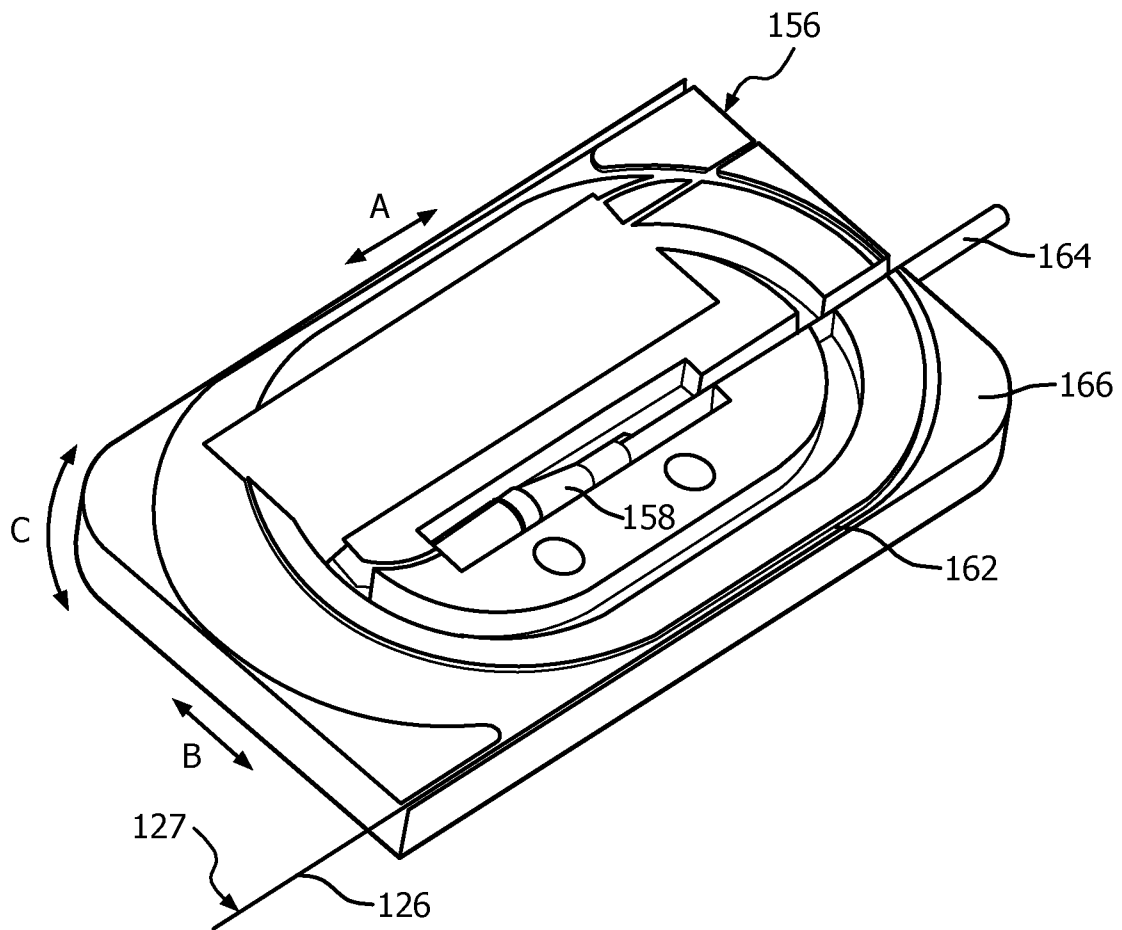


FIG. 4

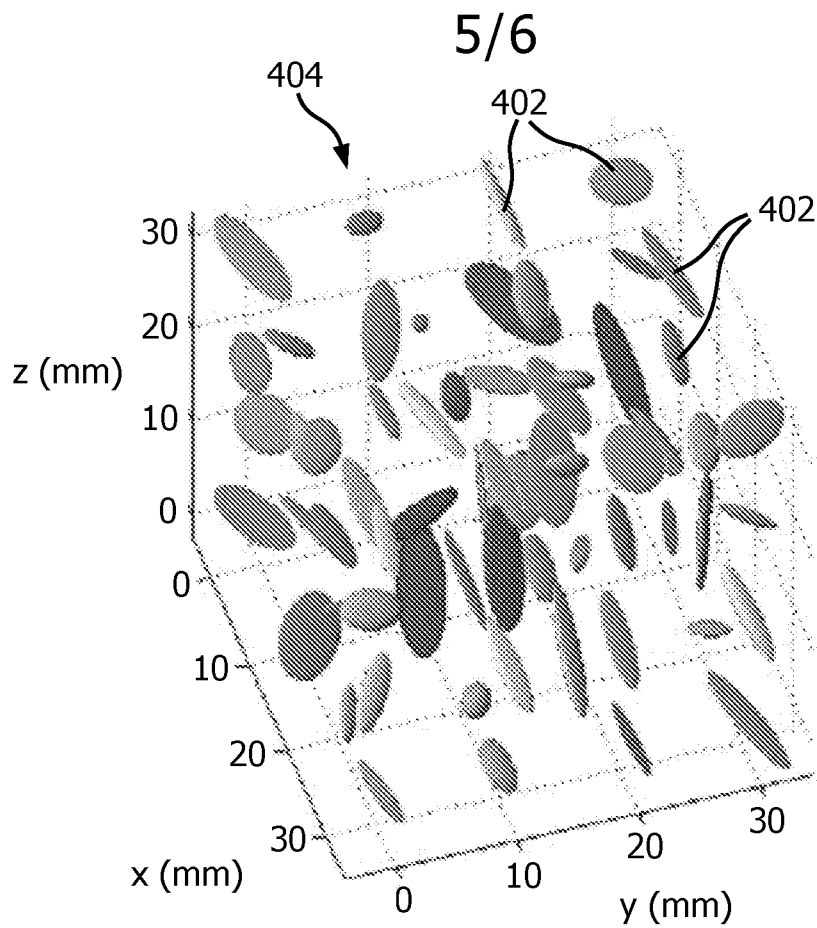


FIG.5A

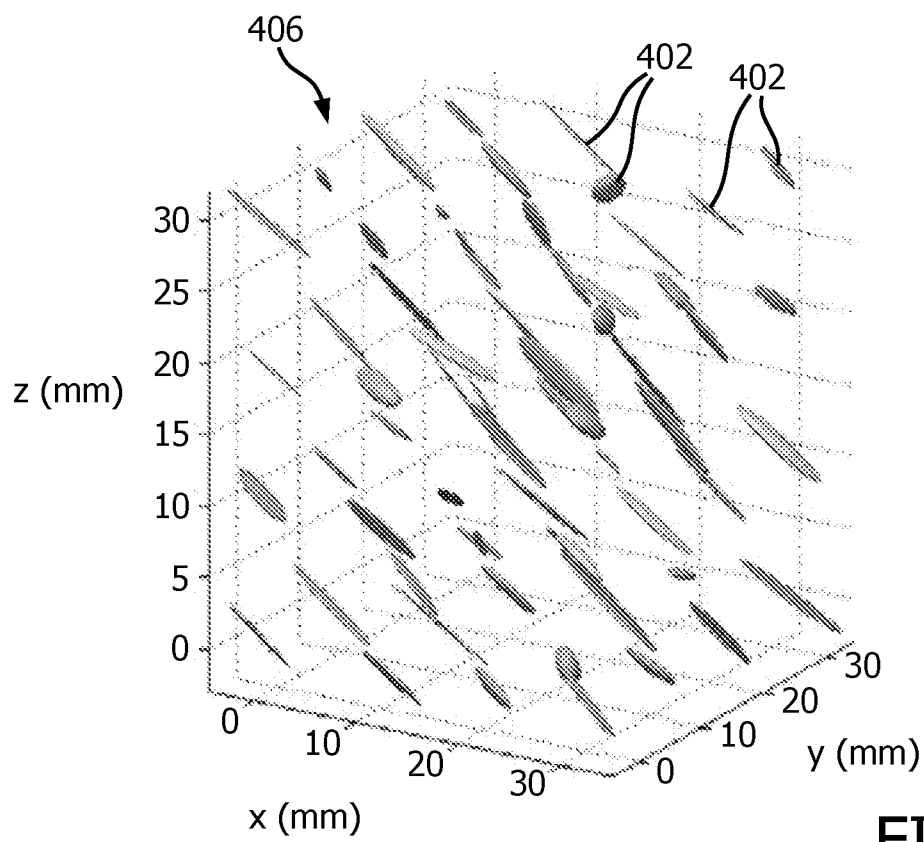


FIG.5B

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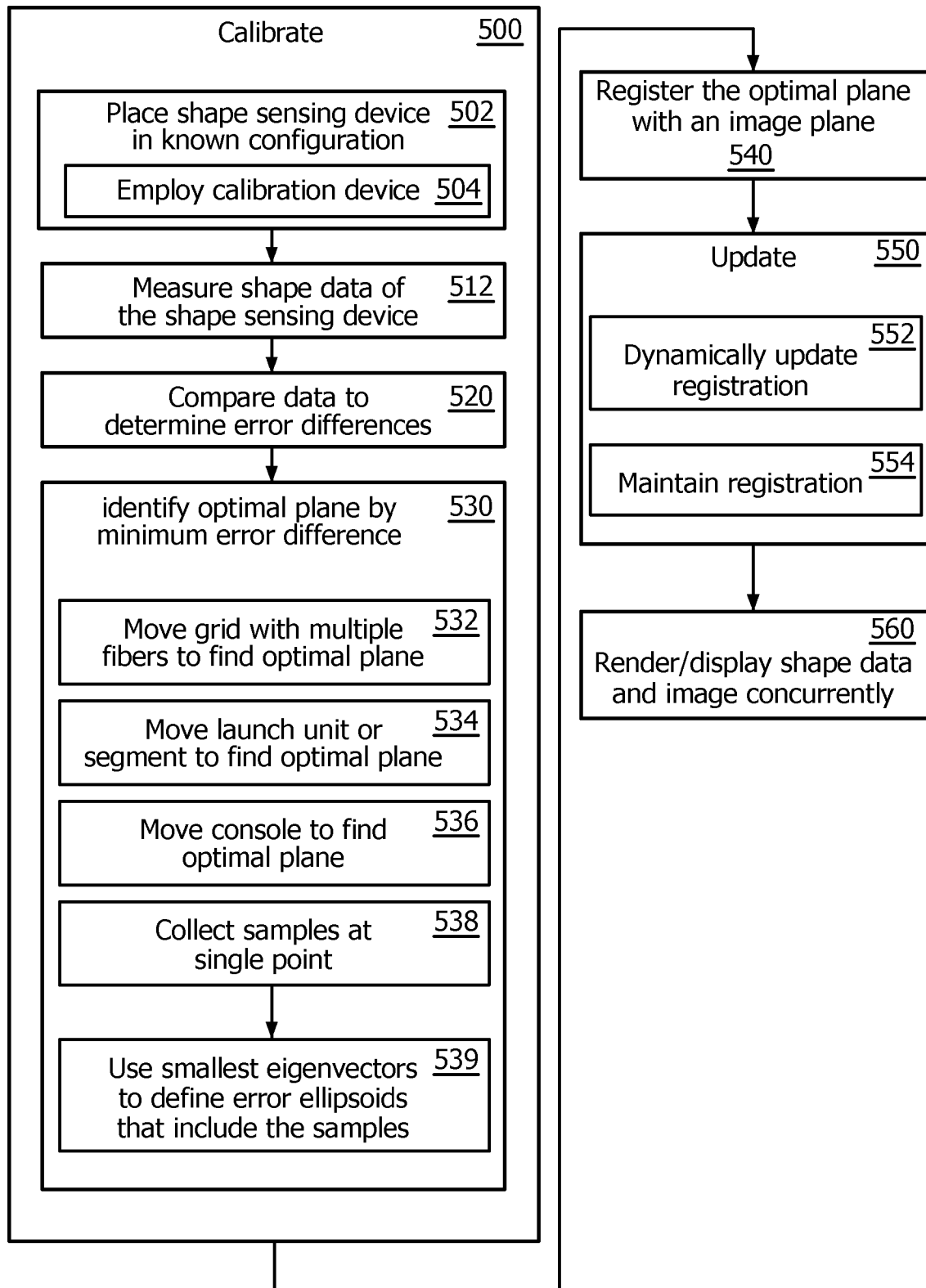


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2013/058569

A. CLASSIFICATION OF SUBJECT MATTER INV. G01B11/16 A61B5/06 G01D5/353 A61B19/00 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) G01B A61B G01D		
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, 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 2012/101563 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; MANZKE ROBERT [US]; CHAN RAYMOND) 2 August 2012 (2012-08-02) page 9, line 13 - page 13, line 20; figures 1,2A,2B -----	1,6,7, 9-11
X	US 2011/113852 A1 (PRISCO GIUSEPPE MARIA [US]) 19 May 2011 (2011-05-19) paragraph [0034] - paragraph [0038]; figures 1-3 paragraph [0046] - paragraph [0068]; figures 5,6 -----	1,6,7, 9-11
X	US 2011/202069 A1 (PRISCO GIUSEPPE M [US] ET AL) 18 August 2011 (2011-08-18) paragraph [0035] - paragraph [0063]; figure 1 paragraphs [0115], [0122] ----- -/-	1,6,7, 9-11
☒ 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 30 January 2014		Date of mailing of the international search report 07/02/2014
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Petelski, Torsten

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/058569

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2012/101551 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; MANZKE ROBERT [US]; RAMACHANDRAN) 2 August 2012 (2012-08-02) page 7, line 1 - page 9, line 16; figures 1,2 -----	1,6,7, 9-11
A	US 2011/109898 A1 (FROGGATT MARK E [US] ET AL) 12 May 2011 (2011-05-12) paragraph [0137] - paragraph [0154]; figures 28-39 -----	1,6,7, 9-11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2013/058569

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. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 2-5, 8, 12-15(completely); 1, 6, 7, 9-11(partially)
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:
see FURTHER INFORMATION sheet PCT/ISA/210
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.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 2-5, 8, 12-15(completely); 1, 6, 7, 9-11(partially)

For the reasoning regarding incomplete search see the Search Opinion

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2013/058569

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012101563 A2	02-08-2012	CN 103347460 A EP 2667815 A2 US 2013308137 A1 WO 2012101563 A2	09-10-2013 04-12-2013 21-11-2013 02-08-2012
US 2011113852 A1	19-05-2011	US 2011113852 A1 WO 2011059888 A2	19-05-2011 19-05-2011
US 2011202069 A1	18-08-2011	CN 102753114 A EP 2533717 A1 JP 2013519432 A KR 20120125575 A US 2011202069 A1 WO 2011100124 A1	24-10-2012 19-12-2012 30-05-2013 15-11-2012 18-08-2011 18-08-2011
WO 2012101551 A1	02-08-2012	EP 2667773 A1 US 2013301031 A1 WO 2012101551 A1	04-12-2013 14-11-2013 02-08-2012
US 2011109898 A1	12-05-2011	CN 102695938 A EP 2478331 A2 JP 2013505441 A RU 2012115444 A US 2011109898 A1 WO 2011034584 A2	26-09-2012 25-07-2012 14-02-2013 27-10-2013 12-05-2011 24-03-2011