



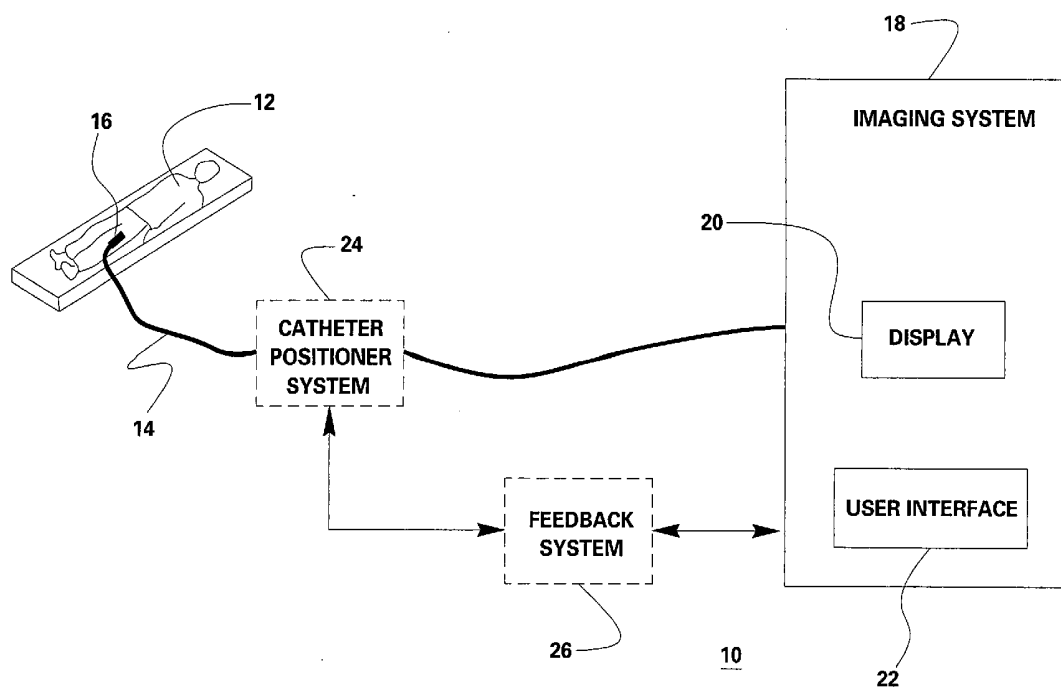
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(19) **United States**(12) **Patent Application Publication** (10) **Pub. No.: US 2007/0167821 A1****Lee et al.**(43) **Pub. Date: Jul. 19, 2007**(54) **ROTATABLE TRANSDUCER ARRAY FOR
VOLUMETRIC ULTRASOUND****Publication Classification**(51) **Int. Cl.****A61B 8/14** (2006.01)(52) **U.S. Cl.** **600/463**(76) **Inventors:** **Warren Lee**, Clifton Park, NY (US);
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NISKAYUNA, NY 12309 (US)**(57) **ABSTRACT**

A rotating transducer assembly and method for use in volumetric ultrasound imaging and catheter-guided procedures are provided. The rotating transducer assembly comprises a transducer array mounted on a drive shaft and the transducer array is rotatable with the drive shaft, a motion controller coupled to the transducer array and the drive shaft for rotating the transducer, and at least one interconnect assembly coupled to the transducer for transmitting signals between the transducer and an imaging device, wherein the interconnection assembly is configured to reduce its respective torque load on the transducer and motion controller due to a rotating motion of the transducer.

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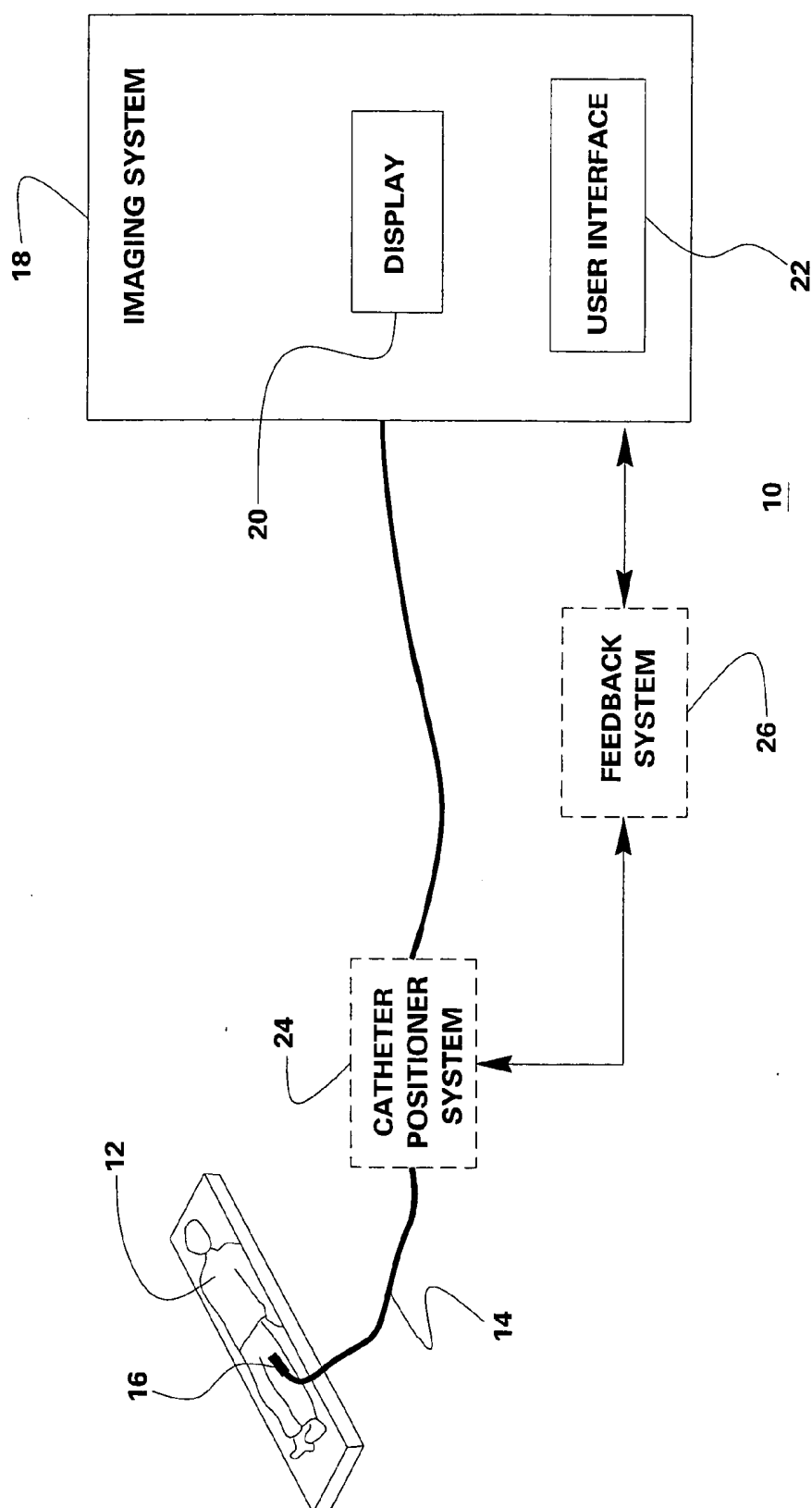


FIG.1

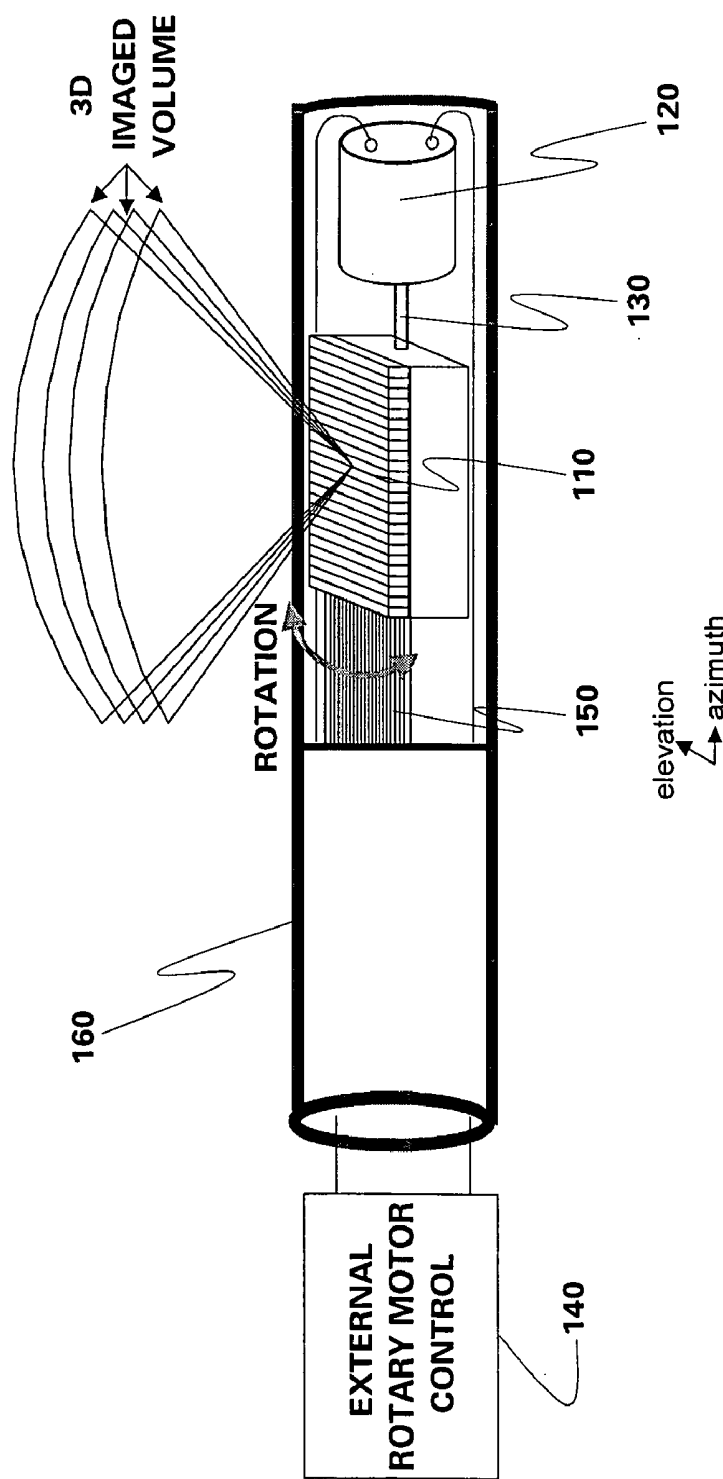


FIG.2

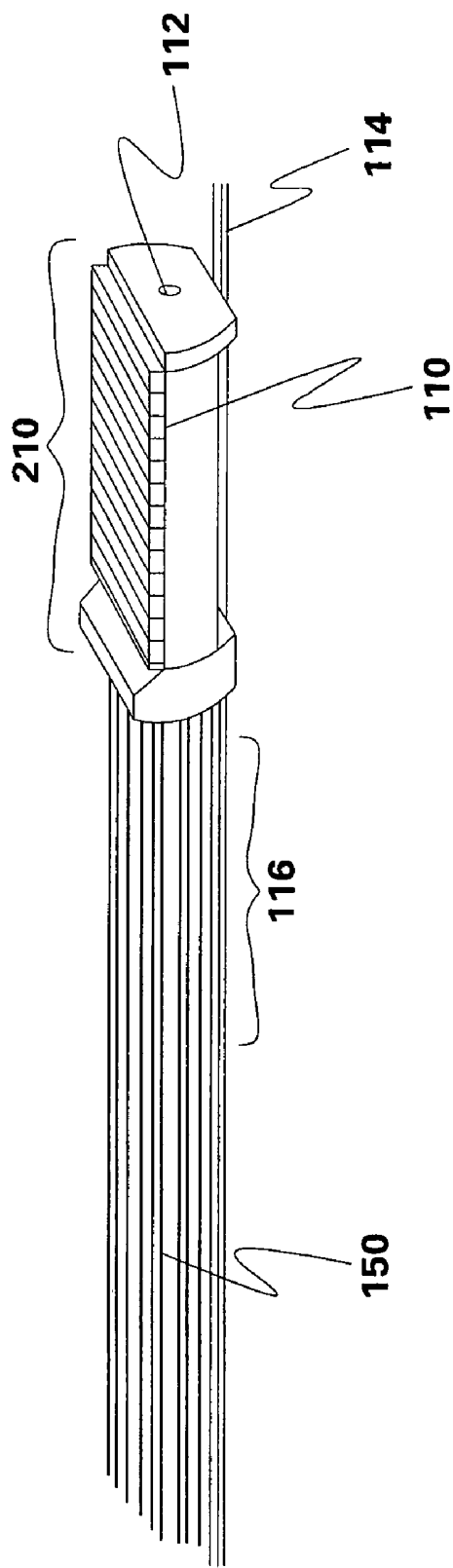


FIG.3

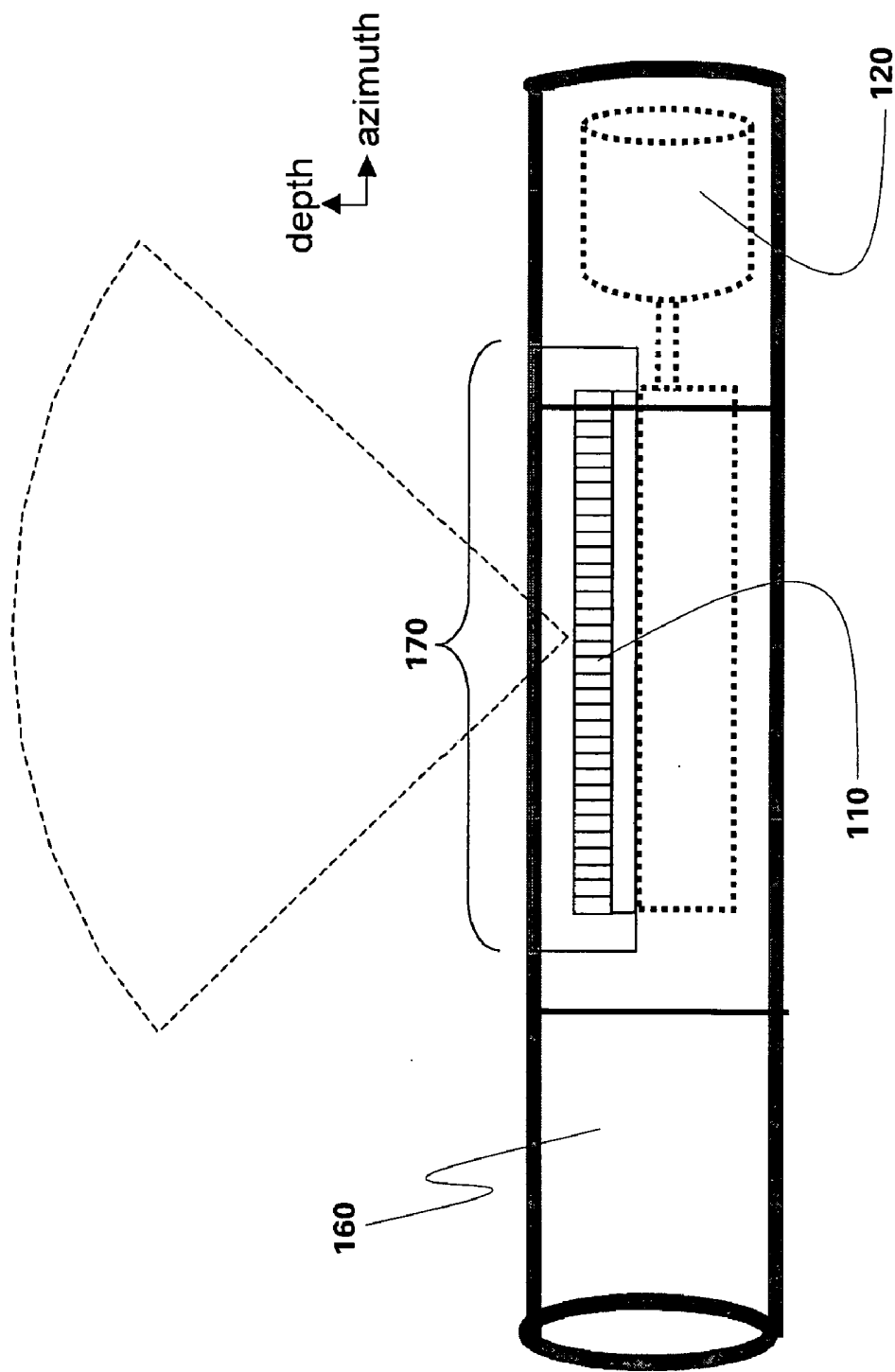


FIG. 4

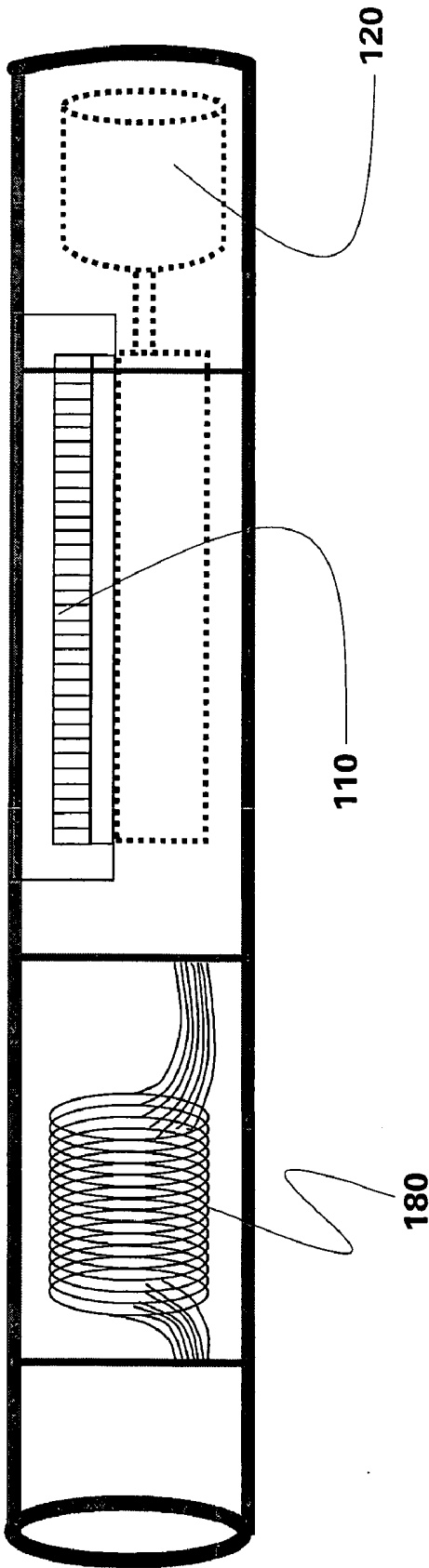


FIG. 5

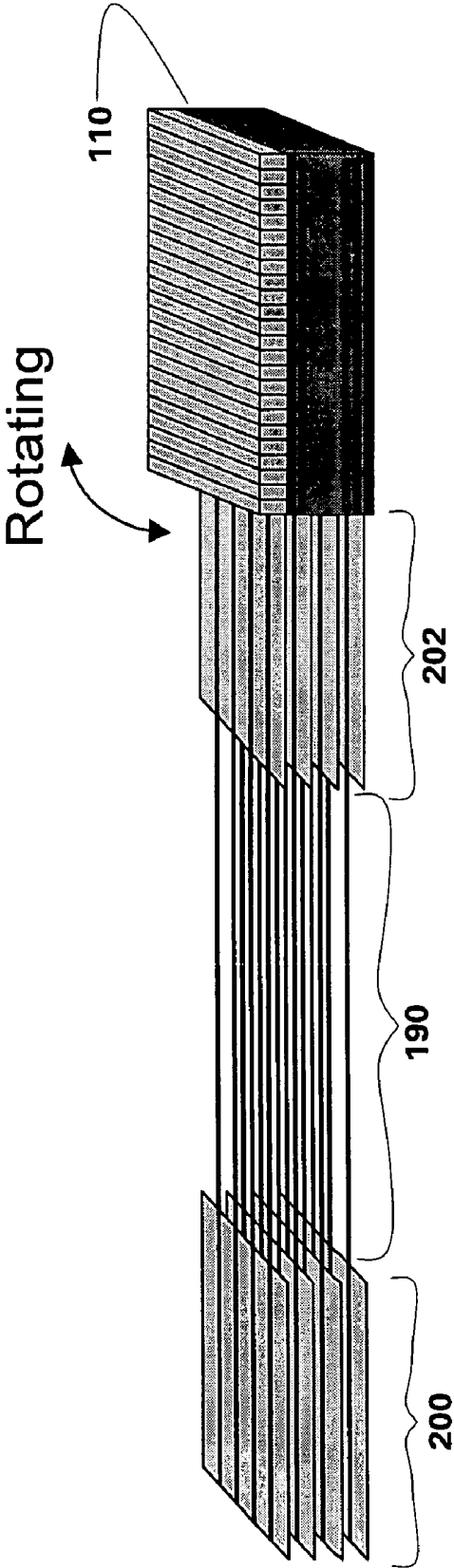


FIG.6

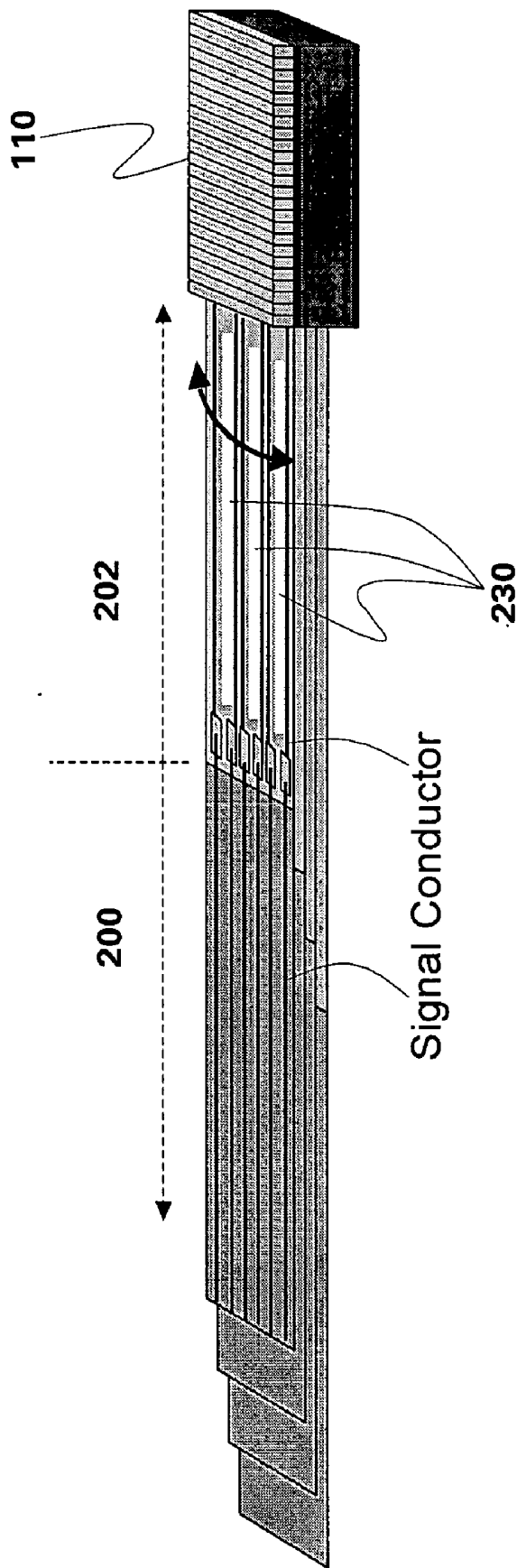


FIG. 7

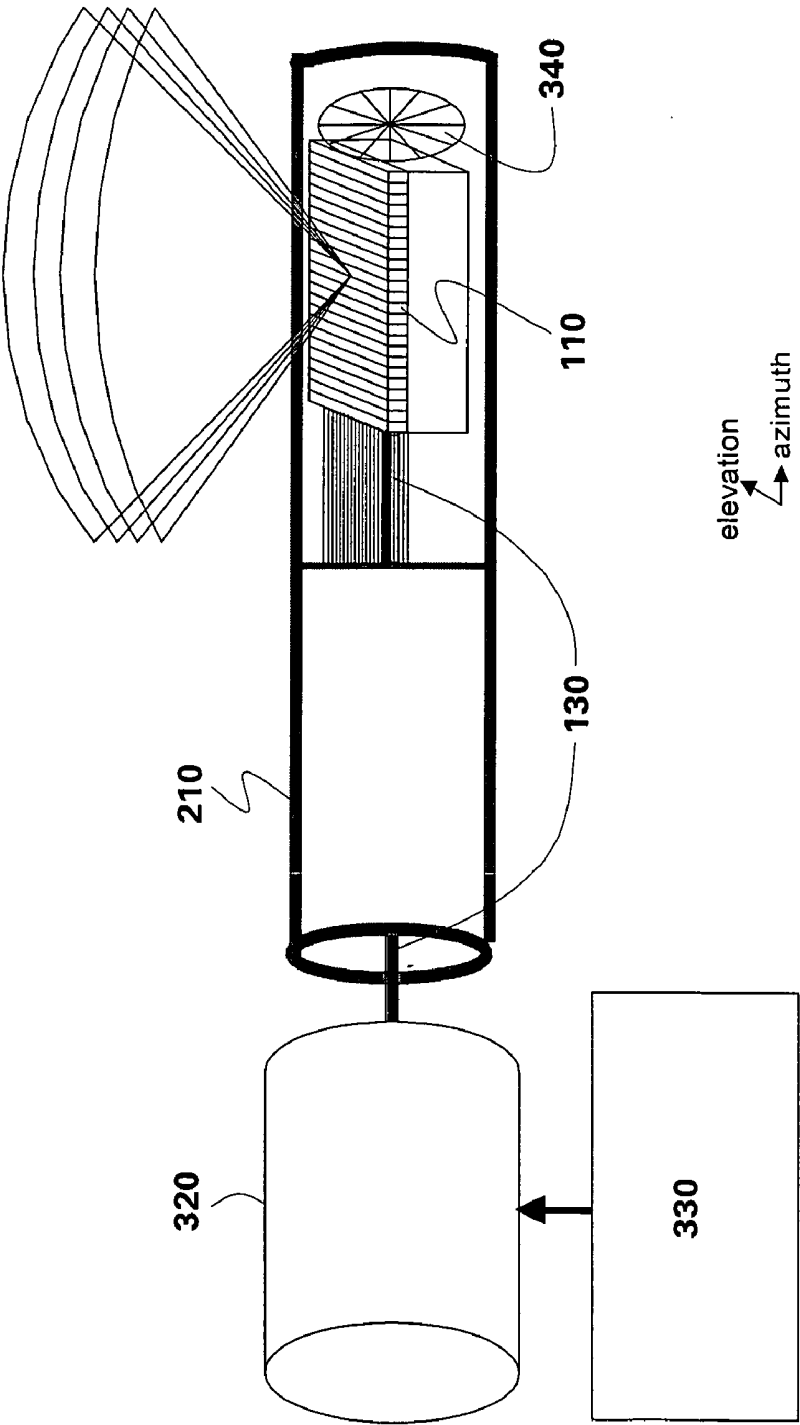
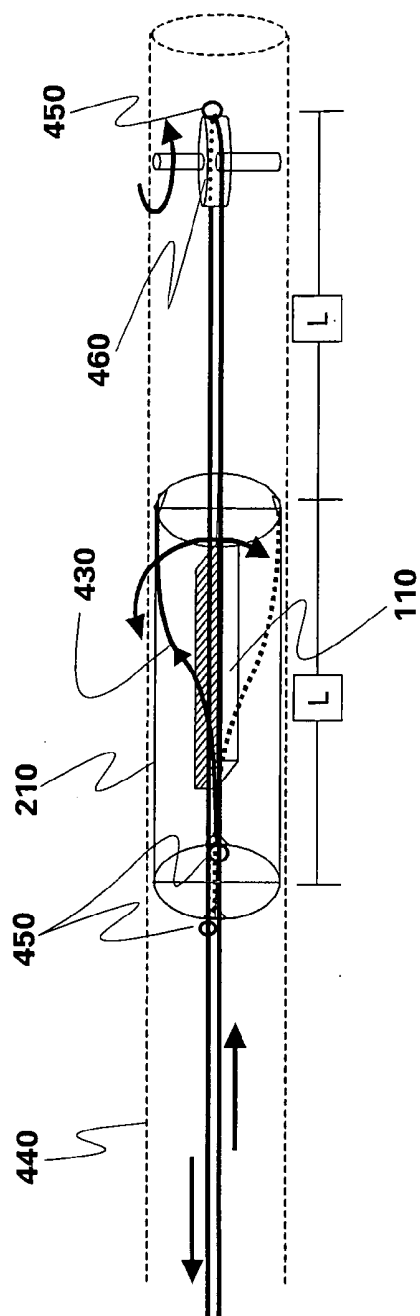
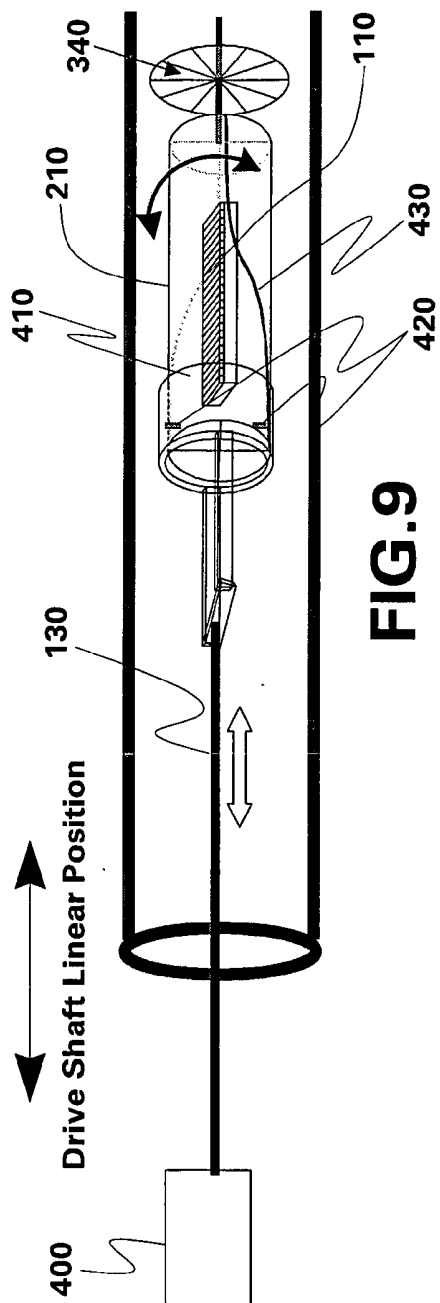


FIG. 8



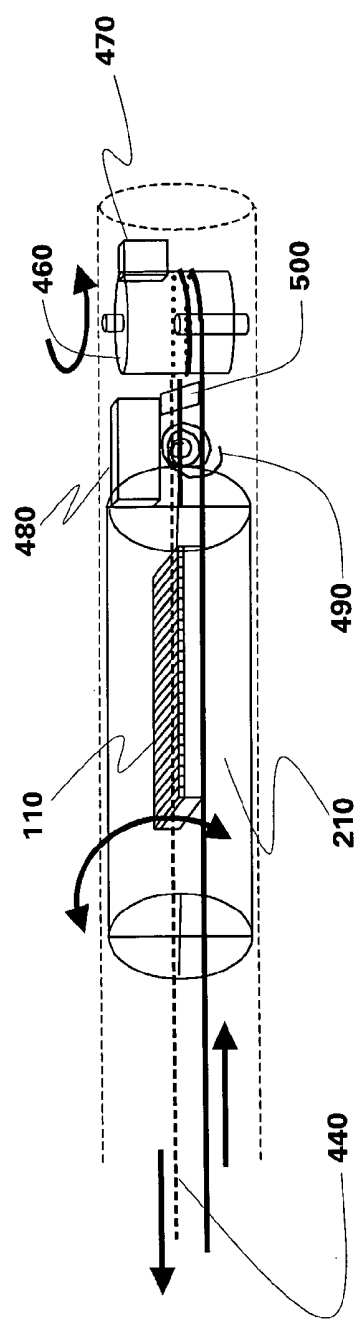


FIG.11

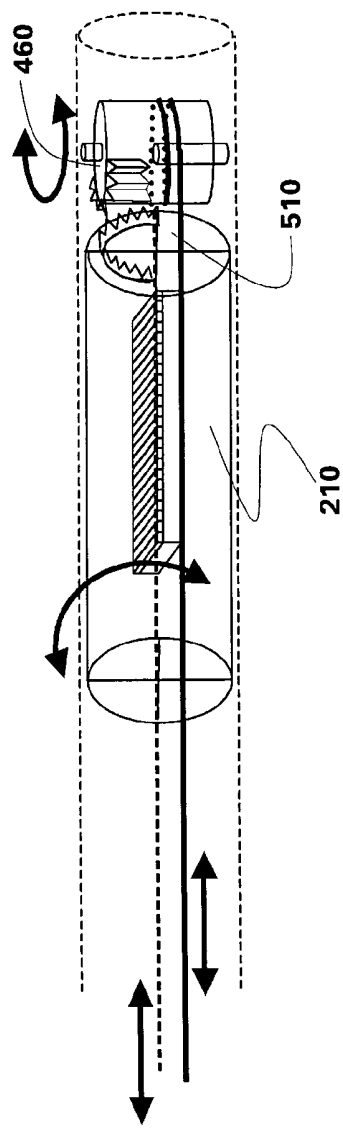


FIG.12

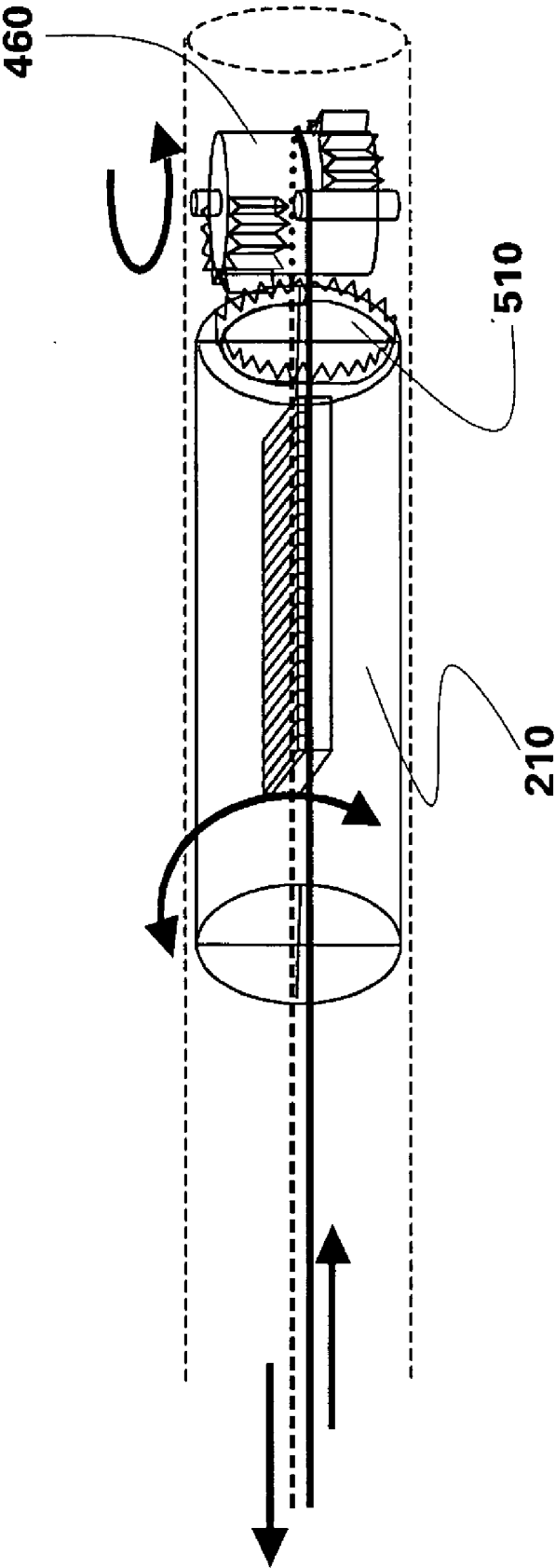
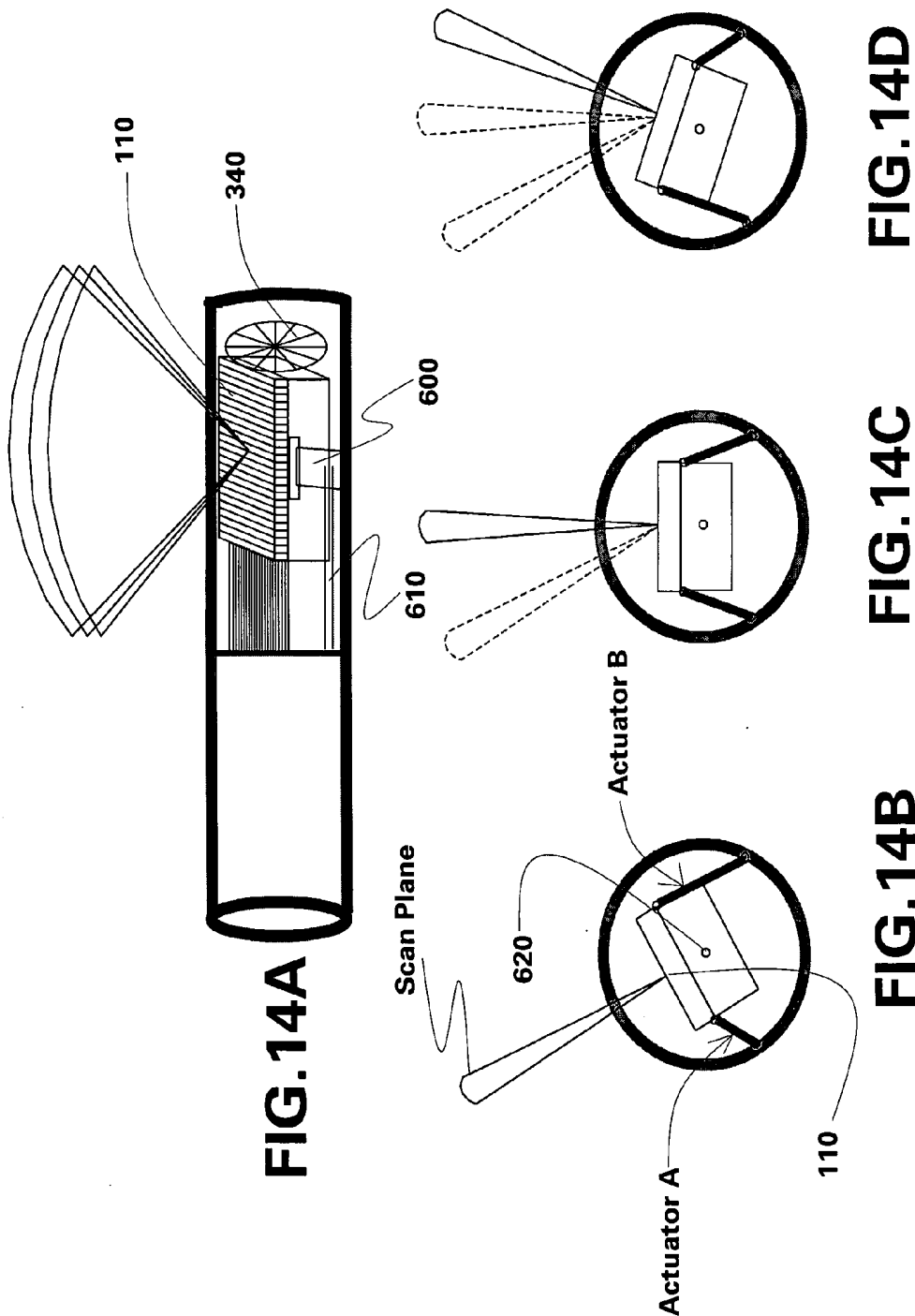
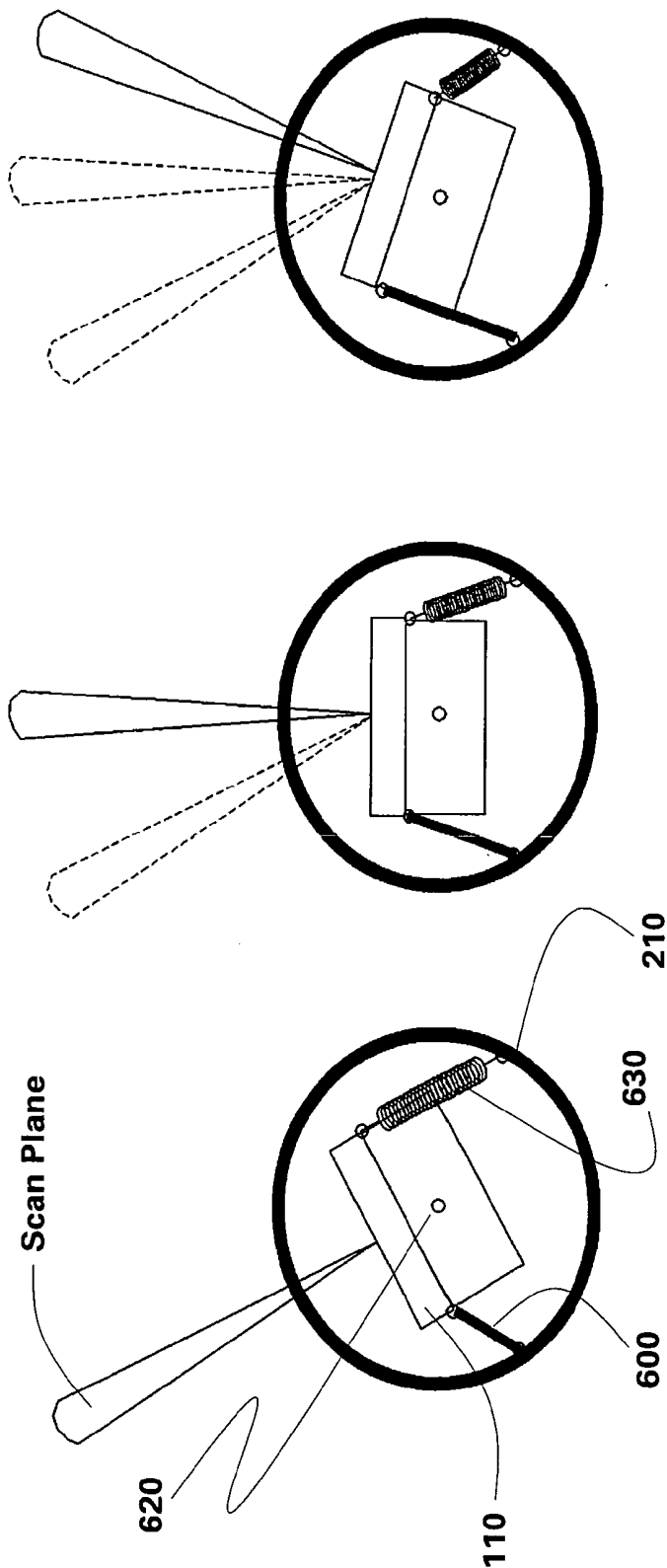


FIG.13





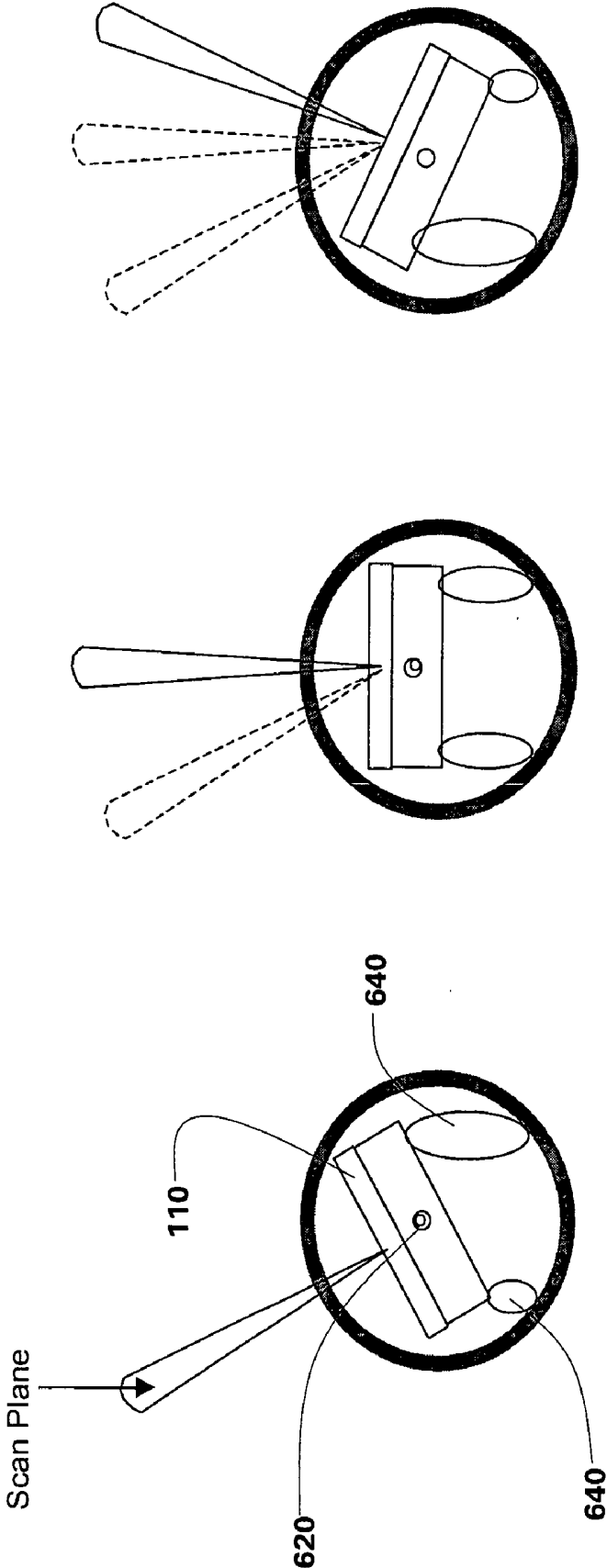


FIG.16

ROTATABLE TRANSDUCER ARRAY FOR VOLUMETRIC ULTRASOUND

BACKGROUND

[0001] The invention relates generally to a rotating transducer array system, and more particularly to a rotatable transducer array assembly for use in volumetric ultrasound imaging and catheter-guided treatment such as cardiac interventional procedures.

[0002] Cardiac interventional procedures such as the ablation of atrial fibrillation are complicated due to the lack of an efficient method to visualize the cardiac anatomy in real-time. Intracardiac echocardiography (ICE) has recently gained interest as a potential method to visualize interventional devices as well as cardiac anatomy in real-time. Current commercially available catheter-based intracardiac probes used for clinical ultrasound B-scan imaging have limitations associated with the monoplanar nature of the B-scan images. Real-time three-dimensional (RT3D) imaging may overcome these limitations. Existing one-dimensional (1D) catheter transducers have been used to make 3D ICE images by rotating the entire catheter, but the resulting images are not real-time. Other available RT3D ICE catheters use a two-dimensional (2D) array transducer to steer and focus the ultrasound beam over a pyramidal-shaped volume. Unfortunately, 2D array transducers require prohibitively large numbers of interconnections in order to adequately sample the acoustic aperture space to achieve sufficient spatial resolution and image quality. In addition, other challenges exist with 2D arrays, such as low sensitivity due to the small element size, and increases in system cost and complexity. Additionally, due to catheter size constraints, 2D arrays have fewer elements than desirable as well as small apertures thereby contributing to poor resolution and contrast and ultimately poor image quality.

[0003] The issue of acquiring three-dimensional volumes has been addressed with the advent of 2D array transducers (e.g., Philips X4 or GE 3V probes), however, their applicability to space-constrained applications such as intracardiac echocardiography is limited due to the unachievable number of signal conductors and/or beamforming electronics that are required in order to adequately sample the aperture space and generate images with sufficient resolution. Further, there are rotating single-element or annular array transducers in catheters (e.g., Boston Scientific), however images are 2D or cone images, not 3D volumes. Mechanically scanning one-dimensional transducer arrays currently exist (e.g., GE Kretz "4D" probes), but have only been applied to much larger abdominal probes, where space constraints do not exist.

[0004] As intracardiac interventional procedures are more commonly used, there is a need to overcome the problems described above. Further, there is a need to enable improved intracardiac imaging and interventional procedures, particularly where there are space constraints.

BRIEF DESCRIPTION

[0005] In a first aspect of the invention, a rotating transducer assembly for use in volumetric ultrasound imaging and catheter-guided procedures is provided. The rotating transducer assembly comprises a transducer array mounted on a drive shaft, a motion controller coupled to the transducer array and the drive shaft for rotating the transducer,

and at least one interconnect assembly coupled to the transducer for transmitting signals between the transducer and an imaging device, wherein the interconnection assembly is configured to reduce its respective torque load on the transducer and motion controller due to a rotating motion of the transducer.

[0006] In a second aspect of the invention, a method for volumetric imaging and catheter-guided procedures is provided. The method comprises obtaining imaging data for at least one region of interest using an imaging catheter and displaying the imaging data for use in at least one of imaging and treatment of a selected region of interest. The imaging catheter comprises a transducer array mounted on a drive shaft, the transducer array rotatable with the drive shaft, a motion controller coupled to the transducer array and the drive shaft for rotating the transducer, and at least one interconnect assembly coupled to the transducer for transmitting signals between the transducer and an imaging device, wherein the interconnection assembly is configured to reduce its respective torque load on the transducer and motion controller due to a rotating motion of the transducer.

DRAWINGS

[0007] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] FIG. 1 is a block diagram of an exemplary ultrasound imaging and therapy system, in accordance with aspects of the present technique;

[0009] FIG. 2 is a side and internal view of an exemplary embodiment of a rotating transducer array assembly for use in the imaging system of FIG. 1;

[0010] FIG. 3 is an illustration of components of a rotating transducer array that are applicable to embodiments of the present invention;

[0011] FIG. 4 is another illustration of a catheter for use in the imaging system of FIG. 1;

[0012] FIG. 5 is an illustration of an interconnect assembly to which embodiments of the present invention are applicable;

[0013] FIG. 6 is an illustration of an interconnect assembly to which embodiments of the present invention are applicable;

[0014] FIG. 7 is an illustration of an interconnect assembly to which embodiments of the present invention are applicable;

[0015] FIG. 8 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable;

[0016] FIG. 9 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable;

[0017] FIG. 10 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable;

[0018] FIG. 11 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable;

[0019] FIG. 12 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable;

[0020] FIG. 13 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable;

[0021] FIG. 14 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable;

[0022] FIG. 15 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable; and,

[0023] FIG. 16 is an illustration of an alternative embodiment of a motion controller to which embodiments of the present invention are applicable.

DETAILED DESCRIPTION

[0024] As will be described in detail hereinafter, a rotating transducer array assembly in accordance with exemplary aspects of the present technique is presented. Based on image data acquired by the rotating transducer array via an imaging and therapy catheter, diagnostic information and/or the need for therapy in an anatomical region may be obtained.

[0025] In accordance with aspects of the present invention, the aforementioned limitations are overcome by using a mechanically rotating, one-dimensional transducer array that sweeps out a three-dimensional volume. The elements of the transducer array are electronically phased in order to acquire a sector image parallel to the long axis of the catheter, and the array is mechanically rotated around the catheter axis in order to acquire the three-dimensional volume through assembly of two-dimensional images. This method results in a spatial resolution and contrast resolution far superior to what may be achieved using a two-dimensional array transducer and current interconnection technology. In addition, problems associated with 2D arrays such as sensitivity and system cost and complexity are avoided using this method. It is to be appreciated that transducer arrays other than 1D arrays may be used, but then complexity is added

[0026] FIG. 1 is a block diagram of an exemplary system 10 for use in imaging and providing therapy to one or more regions of interest in accordance with aspects of the present technique. The system 10 may be configured to acquire image data from a patient 12 via a catheter 14. As used herein, "catheter" is broadly used to include conventional catheters, endoscopes, laparoscopes, transducers, probes or devices adapted for imaging as well as adapted for applying therapy. Further, as used herein, "imaging" is broadly used to include two-dimensional imaging, three-dimensional imaging, or preferably, real-time three-dimensional imaging. Reference numeral 16 is representative of a portion of the catheter 14 disposed inside the body of the patient 12.

[0027] In certain embodiments, an imaging orientation of the imaging and therapy catheter 14 may include a forward viewing catheter or a side viewing catheter. However, a

combination of forward viewing and side viewing catheters may also be employed as the catheter 14. Catheter 14 may include a real-time imaging and therapy transducer (not shown). According to aspects of the present technique, the imaging and therapy transducer may include integrated imaging and therapy components. Alternatively, the imaging and therapy transducer may include separate imaging and therapy components. The transducer in an exemplary embodiment is a one-dimensional (1D) transducer array and will be described further with reference to FIG. 2. It should be noted that although the embodiments illustrated are described in the context of a catheter-based transducer, other types of transducers such as transesophageal transducers or transthoracic transducers are also contemplated.

[0028] In accordance with aspects of the present technique, the catheter 14 may be configured to image an anatomical region to facilitate assessing need for therapy in one or more regions of interest within the anatomical region of the patient 12 being imaged. Additionally, the catheter 14 may also be configured to deliver therapy to the identified one or more regions of interest. As used herein, "therapy" is representative of ablation, percutaneous ethanol injection (PEI), cryotherapy, and laser-induced thermotherapy. Additionally, "therapy" may also include delivery of tools, such as needles for delivering gene therapy, for example. Additionally, as used herein, "delivering" may include various means of guiding and/or providing therapy to the one or more regions of interest, such as conveying therapy to the one or more regions of interest or directing therapy towards the one or more regions of interest. As will be appreciated, in certain embodiments the delivery of therapy, such as RF ablation, may necessitate physical contact with the one or more regions of interest requiring therapy. However, in certain other embodiments, the delivery of therapy, such as high intensity focused ultrasound (HIFU) energy, may not require physical contact with the one or more regions of interest requiring therapy.

[0029] The system 10 may also include a medical imaging system 18 that is in operative association with the catheter 14 and configured to image one or more regions of interest. The imaging system 10 may also be configured to provide feedback for therapy delivered by the catheter or separate therapy device (not shown). Accordingly, in one embodiment, the medical imaging system 18 may be configured to provide control signals to the catheter 14 to excite a therapy component of the imaging and therapy transducer and deliver therapy to the one or more regions of interest. In addition, the medical imaging system 18 may be configured to acquire image data representative of the anatomical region of the patient 12 via the catheter 14. As used herein, "adapted to", "configured" and the like refer to mechanical, electrical or structural connections between elements to allow the elements to cooperate to provide a described effect; these terms also refer to operation capabilities of electrical elements such as analog or digital computers or application specific devices (such as an application specific integrated circuit (ASIC)) that are programmed to perform a sequel to provide an output in response to given input signals.

[0030] As illustrated in FIG. 1, the imaging system 18 may include a display area 20 and a user interface area 22. However, in certain embodiments, such as in a touch screen, the display area 20 and the user interface area 22 may

overlap. Also, in some embodiments, the display area **20** and the user interface area **22** may include a common area. In accordance with aspects of the present technique, the display area **20** of the medical imaging system **18** may be configured to display an image generated by the medical imaging system **18** based on the image data acquired via the catheter **14**. Additionally, the display area **20** may be configured to aid the user in defining and visualizing a user-defined therapy pathway. It should be noted that the display area **20** may include a three-dimensional display area. In one embodiment, the three-dimensional display may be configured to aid in identifying and visualizing three-dimensional shapes. It should be noted that the display area **20** and respective controls could be remote from the patient, for example a control station and a boom display disposed over the patient and/or a control station and display in a separate room, e.g. the control area for an EP suite or catheterization lab.

[0031] Further, the user interface area **22** of the medical imaging system **18** may include a human interface device (not shown) configured to facilitate the identification of one or more regions of interest for delivering therapy using the image of the anatomical region displayed on the display area **20**. The human interface device may include a mouse-type device, a trackball, a joystick, a stylus, or a touch screen configured to assist the user to identify the one or more regions of interest requiring therapy for display on the display area **20**.

[0032] As depicted in FIG. 1, the system **10** may include an optional catheter positioning system **24** configured to reposition the catheter **14** within the patient **12** in response to input from the user. Moreover, the system **10** may also include an optional feedback system **26** that is in operative association with the catheter positioning system **24** and the medical imaging system **18**. The feedback system **26** may be configured to facilitate communication between the catheter positioning system **24** and the medical imaging system **18**.

[0033] FIG. 2 is an illustration of an exemplary embodiment of a rotating transducer array assembly **100** for use in the imaging system of FIG. 1. As shown, the transducer array assembly **100** comprises a transducer array **110**, a micromotor **120**, which may be internal or external to the space-critical environment, a drive shaft **130** or other mechanical connections between motor controller **140** and the transducer array **110**. The assembly further includes interconnect **150**, which will be described in greater detail with reference to FIG. 3. The assembly **100** further includes a catheter housing **160** for enclosing the transducer array **110**, micromotor **120**, interconnect **150** and drive shaft **130**. In this embodiment, the transducer array **110** is mounted on drive shaft **130** and the transducer array **110** is rotatable with the drive shaft **130**. Further in this embodiment, the rotation motion of the transducer array **110** is controlled by motor controller **140** and micromotor **120**. Motor controller **140** and micromotor **120** control the motion of transducer array **100** for rotating the transducer. In an embodiment, the micromotor is placed in proximity to the transducer array for rotating the transducer and drive shaft and the motor controller is used to control and send signals to the micromotor **120**. Interconnect **150** refers to, for example, cables and other connections coupled between the transducer array **110** and the imaging system shown in FIG. 1 for use in receiving/transmitting signals between the transducer and the imaging

system. In an embodiment, interconnect **150** is configured to reduce its respective torque load on the transducer and motion controller due to a rotating motion of the transducer which will be described in greater detail with reference to FIG. 3 below. Catheter housing **160** is of a material, size and shape adaptable for internal imaging applications and insertion into regions of interest. The catheter further includes a fluid-filled acoustic window **170** shown in FIG. 4. Fluid-filled acoustic window **170** is provided to allow coupling of acoustic energy from the rotating transducer array to the region or medium of interest. In embodiments, catheter housing **160** is acoustically transparent, e.g. low attenuation and scattering, acoustic impedance near that of blood and tissue ($Z \sim 1.5 \text{ M Rayl}$) in the acoustic window region. Further, in embodiments, the space between the transducer and the housing is filled with an acoustic coupling fluid, e.g., water, with acoustic impedance and sound velocity near those of blood and tissue ($Z \sim 1.5 \text{ M Rayl}$, $V \sim 1540 \text{ m/sec}$).

[0034] In an embodiment, the motor controller is external to the catheter housing as shown in FIG. 2. In another embodiment, the motor controller is internal to the catheter housing. It is to be appreciated that as micromotors and motor controllers are becoming available in miniaturized configurations that may be applicable to embodiments of the present invention. Micromotor and motor controller dimensions are selected to be compatible with the desired application, for example to fit within the catheter for a particular intracavity or intravascular clinical application. For example, in ICE applications, the catheter housing and components contained therein may be in the range of about 1 mm to about 4 mm in diameter. As is well-known, most catheters include a disposable and non-disposable component if there is an opportunity to re-use a portion of the catheter. Motion controller and/or motor may be enclosed in the disposable or non-disposable portion of the probe in embodiments.

[0035] Referring to FIG. 3, an internal view of the catheter assembly **14** of FIG. 1 is illustrated showing the internal components and arrangement of transducer **110** and interconnect **150**. In an exemplary embodiment, transducer array **110** is a 64-element 1D array having .110 mm azimuth pitch, 2.5 mm elevation and 6.5 MHz frequency. A cylindrical transducer assembly **210** is adapted to fit and rotate effectively within a cylinder of about 2.8 mm inner diameter which would be an appropriate inner dimension of catheter housing **160** (shown in FIG. 2) for intracardiac applications such as ICE. Interconnect **150** is coupled to the transducer **110** and comprises the necessary cables and conductors for transmitting image information between the transducer **110** and imaging system **18** (FIG. 1). As used herein, the terms "cables" and "conductors" are used interchangeably to refer to the cables and conductor assemblies within the catheter. Additionally, the catheter may include one or more wires **114** that may be used at the insertion end of the catheter and pass by the transducer **110** to the tip of the catheter and these wires **114** may be used for, including but not limited to motor control power, position sensing, thermistors, catheter position sensors (e.g. electromagnetic coils), transducer rotation sensors (optical or magnetic encoder), EP sensor or ablation electrodes, and so forth. Further in this embodiment, within the catheter **14** of FIG. 1, there is a flexible region **116** of the interconnect **150**. The length of the flexible region **116** is desirably selected such that during rotation or oscillation of transducer **110** the conductors **180** exert torque

that will not interfere or hamper rotation of the transducer, drive shaft or motor. As used herein, the term “rotate” will refer to oscillatory or rotary motion or movement between a selected $\pm$ degrees of angular range. Oscillatory or rotary motion includes but is not limited to full or partial motion in a clock-wise or counter-clockwise direction or motion between a positive and negative range of angular degrees. Further embodiments for interconnect **150** will be described with reference to FIG. 5-7.

[0036] In an embodiment, transducer array **110** is a one-dimensional (1D) transducer array. Rotation of a 1D transducer array provides improved three-dimensional (3D) image resolution for the following reasons: the ultrasound beam profile and image resolution depend on the active aperture size; relative to 2D arrays, the active aperture for a 1D array is not as restricted by available system channels, nor by interconnect requirements. Using a 1D transducer array in the rotating configuration enables generation of high-quality real-time three-dimensional ultrasound images. Thus, limitations associated with the monoplanar nature of the current commercially available ICE catheters are overcome, and the guidance of cardiac interventional procedures may be substantially simplified.

[0037] Referring to FIG. 5-7, embodiments for interconnect **150** are further illustrated. The signal and ground electrical connections from the transducer array through a catheter to the imaging system may be implemented with either 1) flex circuits, 2) coax cables (one coax per signal), or 3) ribbon cable (e.g., Gore microFlat). The bundle of electrical connections can be quite stiff in torsion and will create a substantial spring or drag force opposing rotation of the transducer array. In accordance with embodiments of the present invention, interconnect **150** is configured to reduce the torque or drag force exerted by the interconnect against the rotation of the transducer and/or drive shaft. Referring to FIG. 5, in one embodiment, a section of the interconnect (conductors **180**) is coiled to reduce torque. Referring to FIG. 6, in one embodiment, in order to reduce the stiffness of the connections, a region of conductors near the transducer may be de-ribbonized (use, e.g. a laser, to remove any common substrate, ground plane, or other connection between adjacent conductors; perhaps reduce the dielectric or shield layers around individual conductors or coaxes) to create a loose group of conductors **190**. During assembly of the catheter, this group of loose conductors **190** should be left slack, not taut, to further facilitate movement of the conductors relative to each other and rotation of the transducer array **110**. Referring to FIG. 6, a section of conductors **200** and **202** adjacent to the loose section **190** may be left ribbonized as a ribbonized section, to facilitate termination of the conductors on ribbonized section **202** to the transducer **110** or to the transducer flex circuit(s) and the conductors on ribbonized section **200** to a non-rotating cable through the catheter. The majority of the length of the conductors in the catheter, beyond the loose section, may be ribbonized, for ease of assembly, or may be loose insulated wires, for maximum flexibility of the catheter, or the conductors may be coaxial conductors for control of impedance and crosstalk. Alternatively, referring to FIG. 7, a rotating section **202** of conductors terminated at the transducer array **110** may be constructed or modified to ease the torque requirements necessary for rotation. For example, the rotational stiffness may be reduced by cutting slits **230** into the ribbon or flex circuit and by making this section of the

interconnect thinner relative to the non-rotating section **200** coupled to the cable end of the catheter. In additional embodiments utilizing ribbon-based cables, the substrate on which the conductors lie may be thinned or removed in the rotating section of the interconnect **150**. In further embodiments utilizing ribbon-based cables having ground planes, the ground planes may be thinned or removed in the rotating section. It is to be appreciated that combinations of the techniques described above may be used to reduce the torque requirements of the interconnect **150** under rotating conditions.

[0038] Referring now to FIG. 8, an alternative embodiment for a rotating transducer array assembly comprises an external motor **320** used to rotate the drive shaft **130** and an external motor controller **330** for driving motor **320**. A rotary encoder or position sensor **340** provides feedback to compensate for any wind-up in the drive shaft. In this embodiment the drive shaft **130** would desirably be made of torsionally rigid material, e.g. steel wire, to minimize wind-up or twisting of the drive shaft due to torque applied by the motor and friction of components rotating within the catheter and to further enable effective rotation of the transducer.

[0039] Referring now to FIG. 9-13, various alternative embodiments for the motion controller for rotating the transducer array assembly are provided. In these embodiments, the motion controller converts internal or external linear motion to oscillatory rotary motion of the transducer array instead of using the micromotor **120** and motor controller **140** of FIG. 2. Similar components common to FIG. 2 and subsequent figures will have the same reference numbers.

[0040] Referring first to FIG. 9, an embodiment for the motion controller comprises an actuator **400**, which can be internal or external to the catheter, used to effect oscillation and/or rotation of the transducer array. The actuator **400** creates a linear motion of the drive shaft **130** which is converted to an oscillatory rotary motion. A sleeve **410** is slidable over transducer cylinder **210** which encloses transducer array **110**. The sleeve **410** includes small pins **420** which engage in spiral guide tracks **430**. In operation, as the sleeve **420** moves along the length of the cylinder/encapsulation, the cylinder/encapsulation rotates a given amount determined by the spiral guide tracks **430**. The reciprocating linear motion of the sleeve creates an oscillatory motion of the cylinder/encapsulation housing the transducer array **110**, allowing the transducer array to rotate and acquire a 3D pyramidal volume. The linear motion part that engages the spiral guide track **430** may be partially constrained for one degree of freedom along the axis of the catheter. A rotary encoder or position sensor **340** may provide feedback to compensate for flexibilities in the system, e.g. the drive shaft, linear-rotary converter, and the like.

[0041] Referring now to FIG. 10, another exemplary embodiment for the motion controller comprises an actuator, either external or internal (not shown), for driving a cable **440** for effecting rotation of transducer array **110**. Cable **440** is a beaded or studded cable including beads **450** placed along the length of cable **440** to engage in spiral guide track **430**. In one embodiment, as bead **450** engages the spiral guide track **430** and travels the length of cylinder **210** terminating at drive pulley **460**, the cylinder **210** rotates 90 degrees. After a quarter revolution, another bead **450**

engages the spiral guide track on the opposite side of the cylinder (shown by dashed lines) and causes the cylinder to rotate 90 degrees in the opposite direction. Thus the cylinder 210 containing the transducer array 110 oscillates 90 degrees total or ± 45 degrees. The oscillation described herein is for exemplary purposes. It is to be appreciated that other angles may be used to effect oscillation in the manners described in this embodiment. In a further embodiment, a rotary encoder or position sensor (not shown) such as one described with reference to FIG. 9 may be included to provide feedback to compensate for flexibilities and errors in the system. Alternative embodiments are also contemplated. For example, in another embodiment, only two beads are needed and spaced to allow motion of cable the full length of cylinder 210. After one bead moves the length of the cylinder, the cable is driven in the opposite direction and pulled back, thereby allowing the cylinder housing containing the transducer array to oscillate ± 90 degrees. In a further embodiment, a variety of angular ranges could be used.

[0042] Referring to FIG. 11-13, various alternative embodiments for motion control comprise cable and pulley systems for effecting oscillatory rotary motion of the transducer array. In FIG. 11, cables 440 engage with drive pulley 460. An actuator (not shown) drives a cable and pulley 460 in a fixed direction with a continuous motion. Attached to the drive pulley 460, which is rotating, is an extension or flapper 470 which impacts a catch 480 attached to the transducer array 110 once per revolution. The flapper 470 forces the rotation of the array cylinder 210 along the long axis. Once the flapper 470 clears the catch 480, the cylinder 210 returns to a nominal position with the aid of a torsion spring 490 and the velocity is limited by a rotary vane damper 500. By driving the pulley 460 with flapper 470 at a constant rate, the cylinder 210 containing the transducer array 110 will undergo an oscillatory motion. Thus the transducer array 110 will oscillate such that the acquisition of a 3D pyramidal volume can be obtained. The torsion spring 490 and rotary vane damper 500 may be adjusted for appropriate timing of the motion of the cylinder 210. A rotary encoder or position sensor (not shown) may also be used in further embodiments to provide feedback to compensate for flexibilities and errors in the system.

[0043] Referring to FIG. 12 and 13, alternative embodiments to FIG. 11 are provided wherein the cylinder 210 further comprises a gear interface 510 to engage with a gear portion of drive pulley 460. In FIG. 12, the pulley 460 and cylinder housing 210 are connected using a bevel gear interface or approximation thereof. In FIG. 13, pulley 460 and cylinder 210 are connected using a bevel gear interface and pulley 460 further comprises two different gear sections, one on an upper section of pulley 460 and one on a lower section, such that the gear sections of the pulley alternately interface with the cylinder housing and drive motion in a fixed direction. In both embodiments, the drive and pulley motion effects rotation of the transducer array 110 in order to acquire a 3D pyramidal imaging volume.

[0044] Referring now to FIG. 14-16, additional embodiments for the motion controller are provided. Referring to FIG. 14A, a side view shows one or more actuators 600 are attached to each side of the transducer array 110 at a first end and fixed to the catheter tube at the other end. Actuator control lines 610 are used to control activation of the

actuator. The actuators on either side of the array are alternatively activated, which causes the array to oscillate about pivot point 620. Actuators 600 may include electro-active polymers. A rotary encoder 340 may provide positional information as has been described in previous embodiments. FIG. 14B-D are end views of this embodiment in operation to effect rotation of transducer 110. In FIG. 14B, a first actuator A is fully activated and actuator B is fully deactivated. In FIG. 14C, actuator A is partially activated and actuator B is partially activated. In FIG. 14D, actuator A is fully deactivated and actuator B is fully activated.

[0045] Referring to FIG. 15, a similar embodiment is shown but rather than using two actuators, one actuator 600 is provided and attached to the transducer array 110 at one end and a spring 630 is attached at the other end and to the catheter cylinder 210. Movement of the actuator extends or contracts the spring as shown in FIG. 15A-C to effect rotation of transducer array 110. The actuator and/or spring may also be torsional, as well as linear.

[0046] Referring to FIG. 16, a further embodiment for motion control is provided. In this embodiment, two bladders 640 are in contact with the transducer array 110. The bladders may be filled with a gas or liquid. The inflation and deflation of the bladders is controlled in such a way as to oscillate the transducer 110 about pivot point 620. In this manner, a 3D volume may be acquired.

[0047] In operation, in accordance with embodiments of the present invention a miniature transducer array with elements along an azimuth dimension (long axis of catheter), preferably capable of operating at high frequencies for improved resolution is coupled to a mechanical system that rotates the array along its elevation dimension. The ultrasound beam is electronically scanned in the azimuth dimension, creating a two-dimensional image, and mechanically scanned in the elevation dimension. The two-dimensional images may then be assembled into a full three-dimensional volume by the ultrasound system. The transducer may take on a variety of shapes, including (but not limited to): (1) linear sector phased arrays which would result in two-dimensional image in the shape of a sector, and a three-dimensional volume in the shape of a pyramidal volume; (2) linear sequential arrays which would result in a two-dimensional image in the shape of a rectangle or trapezoid, and a three-dimensional volume in the shape of an angular portion of a cylinder; and, (3) multi-row arrays. A motion control system is provided to accurately control the array rotation, and to enable more accurate reconstruction of 3D images from the 2D image planes. The acoustic energy is coupled between the transducer array and the imaging medium (patient) through an acoustic window. The acoustic window comprises a section of the catheter wall and may comprise a coupling fluid between the array and the catheter wall. The catheter wall preferably has an acoustic impedance and sound velocity similar to that of the body (1.5 MRayl), to minimize reflections. The coupling fluid preferably has an acoustic impedance similar to that of the body and low viscosity, to minimize drag on the array and motor. Portions of the transducer array may be cylindrical in cross-section (the ends of the array; the sides and back; the entire array assembly) to keep the array centered and rotating smoothly within the catheter and/or to control the fluid flow and viscous drag between the array and the catheter wall. The

transducer itself may be made of a variety of materials, including, but not limited to, PZT, micromachined ultrasound transducers (MUTs), PVDF. In addition to the transduction material, other components (acoustic matching layers; acoustic absorber/backing; electrical interconnect; acoustic focusing lens) may be included in the array assembly.

[0048] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

1. A rotating transducer array assembly for use in volumetric ultrasound imaging procedures, the assembly comprising:

a transducer array;

a motion controller coupled to the transducer array for rotating the transducer array;

at least one interconnect assembly coupled to the transducer array for transmitting signals between the transducer and an imaging device, wherein the interconnection assembly is configured to reduce its respective torque load on the transducer and motion controller due to a rotating motion of the transducer.

2. The rotating transducer array assembly of claim 1 wherein the transducer array is mounted on a drive shaft and the transducer array is rotatable with the drive shaft.

3. The rotating transducer array assembly of claim 1 further comprising a catheter housing for enclosing the rotating transducer assembly.

4. The rotating transducer array assembly of claim 3 wherein the catheter housing further comprises an acoustic window to allow for coupling of acoustic energy from the transducer array to a region of interest.

5. The rotating transducer array assembly of claim 3 wherein the motion controller comprises:

a micromotor coupled to the drive shaft for rotating the transducer; and,

a motor controller for controlling the micromotor.

6. The rotating transducer array assembly of claim 5 wherein the motor controller is contained internal to the catheter housing.

7. The rotating transducer array assembly of claim 5 wherein the motor controller is external to the catheter housing.

8. The rotating transducer array assembly of claim 1 wherein the interconnect comprises a plurality of conductors for transmitting image data acquired by the transducer to an imaging device.

9. The rotating transducer array assembly of claim 1 wherein the interconnect assembly is adapted to reduce rotational stiffness of at least a rotating portion of the interconnect assembly.

10. The rotating transducer array assembly of claim 9 wherein the interconnect assembly comprises flexible cable that is de-ribbonized in the rotating portion.

11. The rotating transducer array assembly of claim 10 wherein the flexible cable is de-ribbonized by at least one of the following methods: removal of any common substrate, ground plane, or other connection between adjacent con-

ductors of the flexible cable or reducing dielectric or shield layers around individual conductors or coaxes of the flexible cable.

12. The rotating transducer array assembly of claim 9 wherein the interconnect cable comprises slits in non-conducting portions of the flexible cable.

13. The rotating transducer array assembly of claim 1 wherein the transducer array comprises a one-dimensional (1D) transducer array.

14. The rotating transducer array assembly of claim 1 wherein the motion controller comprises one or more actuators attached to the transducer array and used to effect rotation of the transducer array.

15. The rotating transducer array assembly of claim 1 wherein the motion controller comprises one or more actuators and springs attached to the transducer array and used to effect rotation of the transducer array

16. The rotating transducer array assembly of claim 1 wherein the motion controller comprises at least one bladder in contact with the transducer array wherein the bladders are controlled to effect rotation of the transducer array about a pivot point.

17. The rotating transducer array assembly of claim 16 wherein the bladders are filled with at least one of a gas and liquid and the bladders are controlled by inflation and deflation of the bladders.

18. The rotating transducer array assembly of claim 14 wherein the motion controller further comprises a cable and pulley assembly coupled to the transducer for effecting rotation of the transducer array.

19. The rotating transducer array assembly of claim 14 wherein the motion controller further comprises a gear interface coupled to the transducer for effecting rotation of the transducer array.

20. A method for performing volumetric ultrasound imaging, the method comprising:

obtaining imaging data for at least one region of interest using an imaging catheter, wherein the imaging catheter comprises:

a transducer array;

a motion controller coupled to the transducer array for rotating the transducer;

at least one interconnect assembly coupled to the transducer for transmitting signals between the transducer and an imaging device, wherein the interconnection assembly is configured to reduce its respective torque load on the transducer and motion controller due to a rotating motion of the transducer; and

displaying the imaging data for use in at least one of imaging and treatment of a selected region of interest.

21. The method of claim 20 wherein the transducer array is mounted on a drive shaft and the transducer array is rotatable with the drive shaft.

22. The method of claim 20 wherein the transducer array is used to scan an ultrasound beam in an azimuth direction and the motion controller is used to rotate the transducer array in an elevation dimension in order to obtain three-

dimensional (3D) volumetric imaging data of the region of interest.

23. The method of claim 20 wherein the imaging catheter further comprises a fluid-filled acoustic window to allow for coupling of acoustic energy from the transducer array to the region of interest.

24. The method of claim 20 wherein the interconnect assembly is adapted to reduce rotational stiffness of at least a rotating portion of the interconnect assembly.

25. The method of claim 20 wherein the motion controller comprises at least one of motors, actuators and mechanical devices coupled to the transducer array for effecting at least one of oscillation and rotation of the transducer array for obtaining volumetric imaging data of the region of interest.

26. The method of claim 20 further comprising the step of delivering treatment to the selected regions of interest.

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专利名称(译)	用于体积超声的可旋转换能器阵列		
公开(公告)号	US20070167821A1	公开(公告)日	2007-07-19
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[标]申请(专利权)人(译)	LEE WARREN 王尔德DOUGLAS摹 AL KHALIDY ABDULRAHMAN一个 GRIFFIN维斯顿乙		
申请(专利权)人(译)	LEE WARREN 王尔德DOUGLAS摹 AL-KHALIDY ABDULRAHMAN一个 GRIFFIN维斯顿乙		
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摘要(译)

提供了一种用于体积超声成像和导管引导程序的旋转换能器组件和方法。旋转换能器组件包括安装在驱动轴上的换能器阵列，换能器阵列可与驱动轴一起旋转，运动控制器耦合到换能器阵列和驱动轴以旋转换能器，并且至少一个互连组件耦合到驱动轴。用于在换能器和成像装置之间传输信号的换能器，其中互连组件被配置成由于换能器的旋转运动而减小其在换能器和运动控制器上的相应扭矩负载。

