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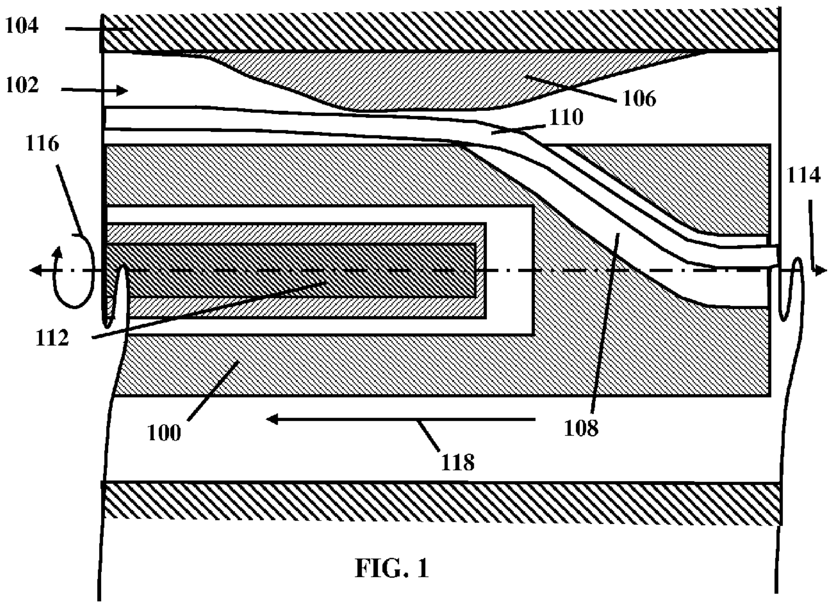

FIG. 1

(57) Abstract: The invention generally relates to systems and methods for producing an electronically displayable medical image. In certain embodiments, methods of the invention involve acquiring electronic image data produced from a rotational imaging apparatus, wherein the data comprises frame-to -frame variability in A-scan density, applying a scan conversion process that can account for frame-to-frame variability in A-scan density to the image data in order to produce an electronically displayable medical image.

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TITLE

VARIABLE SCAN CONVERSION SYSTEMS AND METHODS OF USE

RELATED APPLICATION

[001] The present application claims the benefit of and priority to U.S. provisional application serial number 61/529,744, filed August 31, 2011, the content of which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[002] The invention generally relates to imaging systems and more particularly to image conversion.

BACKGROUND

[003] Imaging from rotational images systems (e.g., OCT and IVUS images) are acquired in the polar domain with coordinates of radius and angle (r, theta) but need to be converted to Cartesian coordinates (x, y) for display or rendering on a screen with rectangularly oriented pixels (e.g. a computer monitor). Scan conversion algorithms generally convert (r, theta) input coordinates into corresponding (x, y) output coordinates by accessing an index or coefficient in a lookup table that is pre-calculated and stored in computer memory for every x and y in the display screen or output array.

[004] If the rotational speed of the imaging probe is not synchronized precisely with the A-line capture rate, a significant variation in the number of A-lines captured per frame ("A-scan density") can occur on a frame-to-frame basis. This complicates the scan conversion process during image streaming because the values in the pre-calculated lookup table are specific to a single A-scan density value (e.g. 500 A-scans/frame is common for OCT). Since precise synchronization with motor/catheter rotational speed is not always possible, it is important to have a scan conversion approach that is flexible enough to process input images having frame-to-frame variation in A-scan density.

SUMMARY OF THE INVENTION

[005] The invention provides numerous scan conversion processes that can account for frame-to-frame variability in A-scan density for acquired image data, thus providing methods for producing an electronically displayable medical image from acquired raw image data.

[006] One scan conversion process involves calculating a plurality of lookup tables including a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates, wherein each lookup table is associated with an A-scan density; storing the plurality of lookup tables in computer memory; receiving a polar domain frame having an A-scan density; locating a lookup table associated with the A-scan density of the frame; and applying the coefficients of the lookup table to the frame. In this process, the plurality of coefficients include pairings of coefficients, where each pair includes a radial coefficient and an angular coefficient. Generally, each pair of radial and angular coefficients is associated with a single pixel on a display. The angular coefficient may be calculated using an ARCTAN approximation. In certain embodiments, the plurality of lookup tables include a lookup table for A-scan densities ranging from 490 A-lines per frame and 510 A-lines per frame.

[007] Another scan conversion method involves receiving a polar domain frame having an A-scan density; calculating a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates based upon the A-scan density of the frame; and applying the plurality of coefficients to the frame.

[008] Another aspect of the invention provides methods for imaging inside a lumen that involve introducing a rotational imaging apparatus inside a lumen to be imaged, acquiring electronic image data produced from the rotational imaging apparatus, in which the data includes frame-to-frame variability in A-scan density, and applying a scan conversion process that can account for frame-to-frame variability in A-scan density to the image data in order to produce an electronically displayable image of the inside of the lumen. The method may further involve axially moving the imaging apparatus through the lumen. In certain embodiments, the image data includes a data discontinuity artifact and a guidewire shaft artifact. In those embodiments, methods of the invention further involve segmenting the image data to form a frame where the data discontinuity artifact overlaps the guidewire shaft artifact.

BRIEF DESCRIPTION OF THE DRAWINGS

[009] In the accompanying figures, like elements are identified by like reference numerals among the several preferred embodiments of the present invention.

[010] **FIG. 1** is a partial cross-sectional view of an imaging catheter suitable for use with a rotational imaging system.

[011] **FIG. 2** illustrates a helical scanning pattern for a rotational imaging system.

[012] **FIG. 3** is illustrates the geometry of a data stream acquired using the helical scanning pattern of **FIG. 2.**

[013] **FIG. 4** illustrates data acquisition of the data stream via a series of fixed data acquisition angles.

[014] **FIG. 5** illustrates segmenting the acquired data stream.

[015] **FIG. 6A** illustrates a display frame that combines the data discontinuity artifact and the guidewire shadow artifact of into a single artifact; **FIG. 6B** illustrates a rotationally registered display frame that combines the data discontinuity artifact and the guidewire shadow artifact.

[016] **FIG. 7** is a flow chart of one embodiment of the first variable scan conversion.

[017] **FIG. 8** is a flow chart of one embodiment of the second variable scan conversion

[018] **FIG. 9** is a flow chart of one embodiment of the variable scan conversion

[019] **FIG. 10** is a flow chart of one embodiment of the variable scan conversion

DETAILED DESCRIPTION OF THE INVENTION

[020] The foregoing and other features and advantages of the invention are apparent from the following detailed description of exemplary embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

[021] Language indicative of a relative geometric relationship between components includes use of the terms "proximal" and "distal" herein. In this context, "proximal" refers to an end of a component nearest to the medical practitioner during use and "distal" refers to the end of the component furthest from the medical practitioner during use. FIGS. herein are line drawings representative of data acquired by a rotational imaging modality and may be representative of negative images of the actual acquired data. Darker areas in the line drawings represent typically brighter areas as would be displayed, for example, on a video monitor. Likewise, lighter areas in the line drawings represent typically darker areas as would be displayed; thus, a shadow is displayed as white space.

[022] The systems and methods of use described herein may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Accordingly, the systems and methods of use described herein may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. The systems and methods of use described herein can be performed using any type of computing device, such as a computer, that includes a processor or any combination of computing devices where each device performs at least part of the process or method.

[023] Suitable computing devices typically include mass memory and typically include communication between devices. The mass memory illustrates a type of computer-readable media, namely computer storage media. Computer storage media may include volatile, nonvolatile, removable, and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data. Examples of computer storage media include RAM, ROM, EEPROM, flash memory, or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, Radiofrequency Identification tags or chips, or any other medium which can be used to store the desired information and which can be accessed by a computing device.

[024] Methods of communication between devices or components of a system can include both wired and wireless (e.g., RF, optical, or infrared) communications methods and such methods provide another type of computer readable media; namely communication media. Communication media typically embodies computer-readable instructions, data structures, program modules, or other data in a modulated data signal such as a carrier wave, data signal, or other transport mechanism and include any information delivery media. The terms "modulated data signal," and "carrier-wave signal" includes a signal that has one or more of its characteristics set or changed in such a manner as to encode information, instructions, data, and the like, in the signal. By way of example, communication media includes wired media such as twisted pair, coaxial cable, fiber optics, wave guides, and other wired media and wireless media such as acoustic, RF, infrared, and other wireless media.

[025] A method for managing artifacts in a rotational imaging system is disclosed herein. The rotational imaging system may be suitable for insertion into a lumen of any anatomical or mechanical conduit, vessel, tube, or the like. The rotational imaging system may comprise an Optical Coherence Tomography ("OCT") system, or may comprise another type of imaging system, including by way of example and not limitation, Intravascular Ultrasound ("IVUS"), spectroscopy, RAMAN, alternative interferometric techniques, therapeutic or diagnostic delivery devices, pressure wires, etc. In the case of an optical imaging system, light sources can be any laser source, broadband source, superluminescent diode, tunable source, and the like. Communication between any proximal and distal end of any of the rotational imaging systems noted hereinabove may be by any communication devices, such as wires, optics, including fiberoptics and/or lens systems, wireless, RF, etc.

[026] **FIG. 1** illustrates an exemplary catheter 100 for rotational imaging inside a lumen of any anatomical or mechanical conduit, vessel, or tube. The exemplary catheter 100 is suitable for in vivo imaging, particularly for imaging of an anatomical lumen or passageway, such as a cardiovascular, neurovascular, gastrointestinal, genitor-urinary tract, or other anatomical luminal structure. For example, **FIG. 1** illustrates a vascular lumen 102 within a vessel 104 including a plaque buildup 106. The exemplary catheter 100 may include a rapid access lumen 108 suitable for guiding the catheter 100 over a guidewire 110.

[027] The exemplary catheter 100 is disposed over an exemplary rotational imaging modality 112 that rotates about a longitudinal axis 114 thereof as indicated by arrow 116. The exemplary rotational imaging modality 112 may comprise, in one embodiment, an OCT system. OCT is an optical interferometric technique for imaging subsurface tissue structure with micrometer-scale resolution. In another embodiment, the exemplary rotational imaging modality 112 may comprise an ultrasound imaging modality, such as an IVUS system, either alone or in combination with an OCT imaging system. The OCT system may include a tunable laser or broadband light source or multiple tunable laser sources with corresponding detectors, and may be a spectrometer based OCT system or a Fourier Domain OCT system, as disclosed in U.S. Patent Application Publication No. 2009/0046295, herein incorporated by reference. The exemplary catheter 100 may be integrated with IVUS by an OCT-IVUS system for concurrent imaging, as described in, for example, Castella et al. U.S. Patent Application Publication No. 2009/0043191 and Dick et al. U.S. Patent Application Publication No. 2009/0018393, both incorporated by reference in their entirety herein.

[028] Referring to **FIGS. 1** and **2,** the rotational imaging modality 112 may be longitudinally translated during rotation, as indicated by line 118 in **FIG. 1.** Thus, the rotational imaging modality 112 acquires data along a path 120 that includes a combination of rotation and/or longitudinal translation of the rotational imaging modality 112. **FIG. 2** illustrates an exemplary path 120, which is a helical scanning pattern 120, resulting from such a combination. Because **FIG. 2** is a cross-sectional view, the helical scanning pattern 120 is illustrated as would be traced on a rear half of a luminal surface 122 of the scanned vessel 104. The helical scanning pattern 120 facilitates scanning a three-dimensional space within and beneath the luminal surface 122 longitudinally as desired, but also introduces a data artifact commonly known as a seam line artifact during reconstruction of the data into a display frame, as will be further discussed herein below.

[029] Referring to **FIGS. 1** and **2,** the longitudinal axis 114 is illustrated as linear for simplicity and clarity. However, the longitudinal axis 114 is not necessarily linear as illustrated. The longitudinal axis 114 may be curvilinear having a curvature following a tortuosity of the vessel 104. It will be understood that vessel 104 need not be linear, but may in fact have a curvilinear longitudinal axis 104 following the vessel 104 along a tortuous geometry, and that the present invention equally applicable to an imaging modality 112 longitudinally translated along the vessel 104 having a longitudinally linear and/or tortuous geometry.

[030] Referring to **FIG. 3,** a portion of the three dimensional space within and beneath the luminal surface 122 scanned within a single rotational period is projected into a planar (2D) format. In this format, line 126 represents a circumferential axis plotted horizontally. The geometry of a data stream acquired utilizing the above-described helical scan pattern 120 relative to the geometry of the luminal surface 122 may be represented by the parallelogram 124 disposed over the horizontal line 126 in **FIG. 3.** Starting at a fixed data acquisition angle 200 (hereinafter a "FDAA 200") conveniently denoted as zero degrees (0°) in **FIG. 3,** the rotational imaging modality 112 acquires data following a rotational path indicated by line 128 (parallel to the line 126) in **FIG. 3.** However, because the rotational imaging modality 112 may also be translated longitudinally, as indicated by line 130 in **FIG. 3,** the two-dimensional representation of the scanned three dimensional space within and beneath the luminal surface 122 comprises the shape of the parallelogram 124. This means that at the end of one full rotation of the rotational imaging modality 112 as denoted in **FIG. 3** by the FDAA 200 having a value of 360 degrees, the rotational imaging modality 112 has translated longitudinally by a distance Z. Still referring to **FIG. 3,** data represented in polar form (r, Θ) within the parallelogram 124 includes a radial dimension, r, represented on a vertical axis and a circumferential or angular dimension, Θ, represented on the bottom edge of the parallelogram 124. The parallelogram 124 may be thought of as a sequence of thin three-dimensional slices of data taken along FDAA's as the rotational imaging modality 112 rotates within the lumen 120 (See **FIGS. 5-6).** Thus, the radial dimension, labeled r, represents radial distance from the longitudinal axis 114 (See **FIG. 1)** so that a smooth circular luminal surface 122 of the vessel 104 would be represented as a straight line parallel to a bottom edge of the parallelogram 124. Fluctuations in radius of the luminal surface 122 would be represented as peaks or valleys varying from the straight line.

[031] Note that the radial dimension r within the acquired rotational period of data as represented by the parallelogram 124 should not be confused with the distance Z that the rotational imaging modality 112 longitudinally translates in one rotation. The radial dimension r applies to the radius of data acquired within each of the three-dimensional slices of data taken along FDAA's, and the distance Z illustrates where that acquired data is acquired longitudinally relative to a fixed point on the lumen 120.

[032] One or more of embodiments of methods for managing artifacts described hereinabove with regard to **FIGS. 4** and **5** and applied to segment the acquired data stream into a k=l data frame, the acquired data is further processed to produce data frames k=2, 3, 4, . . . N-l. Each of the thus segmented data frames can then be scan-converted into Cartesian coordinates for displaying as a display frame in a format representative of true physical space, as described in further detail hereinbelow. The segmented data thus gets displayed, archived, analyzed, etc. similar to segmented data frames that are conventionally segmented, i.e., with a rotational sensor on a drive motor or other rotational timing mechanism.

[033] Once the acquired data has been segmented into properly bounded data frames, a next step may be to normalize the segmented data frames to 360 degrees to create display frames and, if desired, to rotationally register either artifact 202, 204 to the same angle in each of the display frames. For example, in one embodiment, referring to **FIG. 6A,** a data frame illustrated in **FIG. 5,** for example, k=l, has been scan-converted to a Cartesian view display frame that shows the actual shape of the luminal surface 122, for example between FDAAs 214 and 216, as the luminal contour 122d. **FIG. 6A** is a simplified line drawing of what an actual display frame would look like. Note that the acquired data stream segmented as described hereinabove with regard to **FIGS. 5** and **6A** overlaps the gap 206 caused by the guidewire shadow artifact 204 and the data discontinuity artifact 132. Such overlap provides a better image than an image lacking such overlap for analysis by a medical professional.

[034] The embodiments disclosed herein may be used with OCT, rotational IVUS, FL.IVUS, Intravascular Spectroscopy (NIRS, fluorescence, etc.), CT, MRI, and other imaging technologies which use rotating or circularly-oriented sensors or transducers.

[035] Generally speaking, the variable scan conversion includes a frame-to-frame variability in the A-scan density in several different embodiments. The variable scan conversion system and methods enables scan conversion of frames with variable A-scan density (rotational asynchrony); allows zoom/scale, rotation, pan/scroll, and variable display size functionality directly built-in to scan conversion process; and ARCTAN approximation speeds up the calculation of scan conversion coefficients for real time frame processing and display.

[036] In one embodiment, as shown in **FIG. 7**, a first variable scan conversion method 700 comprises pre-calculating a plurality of lookup tables 710, which contain scan conversion coefficients/indexes for some finite range of A-scan densities that are expected to occur in the input data. The input data for A-scan densities may include, but are not limited to about 490, 491, 492, 493, ... 500, 501, 502, ... 509, 510, and the like. The variable scan conversion method 700 then stores the plurality of lookup tables including the scan conversion coefficients/indexes in accessible memory at step 720. Next, the method 700 determines the appropriate lookup table at step 730 based on the incoming A-scan density for any given frame in the image stream. Finally, the method 700 applies the appropriate lookup table to the incoming frame at step 740. The first variable scan conversion method 700 has the advantage of reducing the computational cost of converting the A-scan data into Cartesian coordinates, as the necessary calculations are pre-performed and the results stored in the lookup tables. However, the first variable scan conversion method 700 can take large amounts of computer memory/RAM to store a wide range of possible input A-scan densities, and there is always a chance that the pre-determined range was insufficient to capture all possible A-scan densities.

[037] In another embodiment, as shown in **FIG. 8**, a second variable scan conversion system and method 800 comprises calculating a plurality of scan conversion coefficients in real time and applying the scan conversion coefficients immediately. Method 800 first receives an A-scan density for a given frame in the image stream in step 810. Based upon that A-scan density, method 800 calculates a plurality of conversion coefficients/indexes in real time in step 820. Finally, the conversion coefficients/indexes are applied in step 820, thereby producing Cartesian coordinates for the frame. The calculated coefficients/indexes are always appropriate for the A-scan density of the specific input frame and a pre-determined estimate of the finite range of possible A-scan densities is not needed. The second variable scan conversion system and method 800 uses minimal storage/RAM but is computationally expensive (mathematical computations) and also inefficient because the same coefficients/indexes are re-calculated for every subsequent frame, even if these same coefficients had been previously calculated for an earlier frame.

[038] The second variable scan conversion system and method 800 has the additional advantage of providing image scaling/zoom, rotation, and panning/scrolling functionality directly as part of the scan conversion process (built-in to the coefficient calculation), rather than as an image processing process that follows the Polar-to-Cartesian scan conversion in a distinctly separate step, as shown in **FIG. 9.** There, a third variable scan conversion system and method 900 first receives the A-scan density for a given frame in the image stream at step 910. Next, method 400 receives the display parameters from a display operated by the user. Based upon both the A-scan density and the display parameters, method 900 calculates the scan conversion coefficients in real time. Finally, method 900 applies the scan conversion coefficients to the frame, producing Cartesian coordinates for the frame. As the user/viewer of the image desires to adjust the zoom/scale, rotation, and pan/scroll state of the displayed image, the equations used for calculation of the scan conversion coefficients can be updated in real time to provide these functions. In addition, on-the-fly calculation of scan conversion coefficients allows the display size (number of pixels in the output image window) to be changed in real time without the re-calculation of a lookup table which would be necessary in prior approaches.

[039] The second variable scan conversion system and method 800 is one preferred approach, because of its flexibility (no a priori need to define range of A-scan densities) and its additional functionality (concurrent zoom/scale, rotation, and pan/scroll; display size changes). Computer processing requirements (especially using graphics processing units and ARCTAN approximation methods) enables "real-time" or "on-the-fly" scan conversion coefficient calculation needed for the second variable scan conversion system and method 800 at frame rates that are much faster than standard display video rate (about 30 frames/sec) and are thus practical for medical imaging system products.

[040] In another embodiment, as shown in **FIG. 10,** a hybrid method 1000 generally comprises the second variable scan conversion method 800 and the third variable scan conversion method 900. In the hybrid method 1000, there are no pre-determined lookup tables of conversion coefficients/indexes calculated. At step 1010, the hybrid method 1000 receives an A-scan density from a given frame in the image stream. Once the A-scan density has been received, the hybrid method 1000 will query whether a lookup table for the A-scan density has previously been calculated and stored in memory at step 1020.

[041] If a lookup table for the A-scan density is not stored in memory, the hybrid method 1000 will calculate the scan conversion coefficients/indexes at step 1030 and apply the scan conversion coefficients to the frame at step 1040. Finally, the conversion coefficients for the instant A-scan density are stored as a lookup table in memory at step 1050. If a lookup table for the A-scan density is stored in memory, the hybrid method 1000 will apply the appropriate lookup table to the frame at step 1060.

[042] The hybrid method 1000 combines aspects of the second variable scan conversion method 800 and the third variable scan conversion method 900. First, the conversion coefficients for a given A-scan density when a frame with that density is received, and then the coefficients are preserved in a lookup table for reuse if subsequent frames having the same A-scan density are received from the image stream, thereby preventing repeatedly recalculating the same coefficients. Second, the coefficients for any A-scan density can be calculated on the fly, eliminating the need of estimating the range of A-scan densities that will be encountered as well as the risk of not anticipating every A-scan density. However, the third variable scan conversion method 900 does require increasingly complex software when compared to the first and second variable scan conversion methods 700 and 800, as the space requirements for the lookup tables is not predetermined, requiring the software to allocate more memory as necessary during the process. Additionally, the greater the variance in A-scan density, the third variable scan conversion method 900 will require a greater amount of memory to store lookup tables for each density calculated, thereby creating the same space issue presented by first variable scan conversion method 700. In an alternative embodiment, lookup tables based upon both A-scan densities as well as display parameters could be calculated and stored.

[043] Image zoom/scale, rotation, and pan/scroll functionality built into scan conversion coefficient calculation. Storage of multiple scan conversion coefficient lookup tables for processing frames that could contain varying A-scan density on a frame-to-frame basis (the first variable scan conversion method 700). ARCTAN approximation for scan conversion coefficient calculation makes the approach computationally feasible on present-day computing hardware.

[044] Once scan conversion coefficients are calculated, the converted (x,y) pixel intensity values can be constructed using any known interpolation method (nearest neighbor, bilinear, bicubic, trilinear, spline, lanczos, and the like). Interpolation is a method of constructing new data points within the range of a discrete set of known data points. Nearest-neighbor interpolation (also known as proximal interpolation or point sampling in some contexts) is a multivariate interpolation in 1 or more dimensions. The nearest neighbor algorithm simply selects the value of the nearest point, and does not consider the values of other neighboring points at all, yielding a piecewise-constant interpolant. Bilinear interpolation is an extension of linear interpolation for interpolating functions of two variables (e.g, x and y) on a regular grid. The interpolated function should not use the term of x^2 or y^2, but xy, which is the bilinear form of x and y. Bicubic interpolation is an extension of cubic interpolation for interpolating data points on a two dimensional regular grid. The interpolated surface is smoother than corresponding surfaces obtained by bilinear interpolation or nearest-neighbor interpolation. Bicubic interpolation can be accomplished using either Lagrange polynomials, cubic splines, or cubic convolution algorithm. Trilinear interpolation is a method of multivariate interpolation on a 3-dimensional regular grid. It approximates the value of an intermediate point (x,y,z) within the local axial rectangular prism linearly, using data on the lattice points. For an arbitrary, unstructured mesh (as used in finite element analysis), other methods of interpolation must be used; if all the mesh elements are tetrahedra (3D simplices), then barycentric coordinates provide a straightforward procedure. Spline interpolation is a form of interpolation where the interpolant is a special type of piecewise polynomial called a spline. Spline interpolation is preferred over polynomial interpolation because the interpolation error can be made small even when using low degree polynomials for the spline. Thus, spline interpolation avoids the problem of Runge's phenomenon which occurs when using high degree polynomials. Lanczos resampling is an interpolation method used to compute new values for sampled data. It is often used multivariate interpolation, for example for image scaling (to resize digital images), but could be used for any other digital signal. The Lanczos kernel indicates which samples in the original data, and in what proportion, make up each sample of the final data.

[045] Accommodation of longitudinal translation.

[046] **Examples**

[047] The basic equations for Cartesian-to-Polar scan conversion are:

[048] $r = \sqrt{y^2 + x^2}$, (1)

[049] where the two Cartesian coordinates x and y can be converted to polar coordinate r, and

[050] $\theta = \arctan\left(\frac{y}{x}\right)$, (2)

[051] where Θ (theta) is the angular coordinate. Theta values must be converted to array indexes that reference the 2D input image array. The input A-scan indexes have rotational angle (Θ) values mapped from 0° to 360° in (usually) a linear fashion.

[052] Lookup tables are generated by calculating r and theta for every possible input value for x and y in a displayed image (for example, if periodicity of the angle is not used, a 768x768 image would store 768^2 = 589824 radius (r) coefficients and 589824 angle (theta) coefficients).

[053] When the number of A-scans in a frame is different, the new array of A-scans is no longer mapped from 0° to 360° in the same fashion and the original lookup table is no longer valid for this input image. The second variable scan conversion method 800 recalculates the appropriate mapping on-the-fly. The first variable scan conversion method 700 depends on a different lookup table preexisting in storage which is appropriate for the A-scan density in the input image/array.

[054] Rotation is achieved by adding an angular bias to arctan(y/x); zoom/scale is achieved by multiplying the square root argument by a scaling factor; and scrolling/panning in the x and y directions are achieved by adding a translational bias to x and y:

[055] $r = scale \times \sqrt{(x + xpan)^2 + (y + ypan)^2}$, (3)

and,

[056] $\Theta = \arctan\left(\frac{y + y_{pan}}{x + x_{pan}}\right) + \theta_{rotation}$. (4)

[057] The hybrid method 1000 uses stored lookup tables of r and theta (prior to array indexing) and then on-the-fly recalculation of the array indexes (distribution of array elements from 0° to 360°). This provides means for flexibility in frame-to-frame A-scan density without the need to store lookup tables for every possible A-scan density value. However, this approach does not provide the means to pan/scroll the image during the scan conversion coefficient calculation process.

[058] It will be understood that each block of the flowchart illustrations, and combinations of blocks in the flowchart illustrations, as well any portion of the module, systems and methods disclosed herein, can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions, which execute on the processor, create means for implementing the actions specified in the flowchart block or blocks or described for the tissue classifier, imager, control module, systems and methods disclosed herein. The computer program instructions may be executed by a processor to cause a series of operational steps to be performed by the processor to produce a computer implemented process. The computer program instructions may also cause at least some of the operational steps to be performed in parallel. Moreover, some of the steps may also be performed across more than one processor, such as might arise in a multi-processor computer system. In addition, one or more processes may also be performed concurrently with other processes or even in a different sequence than illustrated without departing from the scope or spirit of the invention.

[059] The computer program instructions can be, stored on any suitable computer-readable medium including, but not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by a computing device.

[060] It will be understood that the catheter pullback may be performed by pulling the catheter from a proximal end to a distal end of the region being imaged. It will also be understood that the intravascular imaging techniques described above can also be used with other types of imaging techniques that use a catheter insertable into patient vasculature. For example, the intravascular imaging techniques can be used with any imaging techniques configured and arranged to assess one or more measurable characteristics of patient tissue (e.g., intravascular magnetic resonance imaging, spectroscopy, temperature mapping, or the like).

[061] While the invention has been described in connection with various embodiments, it will be understood that the invention is capable of further modifications. This application is intended to cover any variations, uses or adaptations of the invention following, in general, the principles of the invention, and including such departures from the present disclosure as, within the known and customary practice within the art to which the invention pertains

CLAIMS

What is claimed is:

1. A method for producing an electronically displayable medical image, the method comprising:

acquiring electronic image data produced from a rotational imaging apparatus, wherein the data comprises frame-to-frame variability in A-scan density; and

applying a scan conversion process that accounts for frame-to-frame variability in A-scan density to the image data in order to produce an electronically displayable medical image.

2. The method according to claim 1, wherein the scan conversion process comprises:

calculating a plurality of lookup tables comprising a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates, wherein each lookup table is associated with an A-scan density;

storing the plurality of lookup tables in computer memory;

receiving a polar domain frame having an A-scan density;

locating a lookup table associated with the A-scan density of the frame; and

applying the coefficients of the lookup table to the frame.

3. The method of claim 2, wherein the plurality of coefficients comprises pairings of coefficients, where each pair comprises a radial coefficient and an angular coefficient.

4. The method of claim 3, wherein each pair of radial and angular coefficients is associated with a single pixel on a display.

5. The method of claim 3, wherein the angular coefficient is calculated using an ARCTAN approximation.

6. The method of claim 2, wherein the plurality of lookup tables comprises a lookup table for A-scan densities ranging from 490 A-lines per frame and 510 A-lines per frame.

7. The method according to claim 1, wherein the scan conversion process comprises:

receiving a polar domain frame having an A-scan density;

calculating a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates based upon the A-scan density of the frame; and applying the plurality of coefficients to the frame.

8. The method of claim 7, wherein the plurality of coefficients comprises pairings of coefficients, where each pair comprises a radial coefficient and an angular coefficient.

9. The method of claim 8, wherein each pair of radial and angular coefficients is associated with a single pixel on a display.

10. The method of claim 8, wherein the angular coefficient is calculated using an ARCTAN approximation.

11. The method of claim 7, further comprising the step of incorporating a rotational offset to the plurality of coefficients.

12. The method of claim 7, further comprising the step of incorporating a translational offset to the plurality of coefficients.

13. The method of claim 7, further comprising the step of incorporating a scaling factor to the plurality of coefficients.

14. The method of claim 7, further comprising the steps of:

creating a lookup table comprised of the plurality of coefficients, the lookup table being associated with the A-scan density of the frame;

storing the lookup table in computer memory;

receiving a second polar domain frame having an A-scan density;

determining whether a lookup table associated with the A-scan density of the second frame is stored in computer memory.

15. The method of claim 14, wherein a lookup table associated with the A-scan density of the

second frame is stored in computer memory, further comprising the step of applying the lookup table associated with the A-scan density of the second frame to the second frame.

16. The method of claim 14, wherein a lookup table associated with the A-scan density of the second frame is not stored in computer memory, further comprising the steps of:

calculating a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates based upon the A-scan density of the frame;

applying the plurality of coefficients to the frame;

creating a lookup table comprised of the plurality of coefficients, the lookup table being associated with the A-scan density of the frame; and

storing the lookup table in computer memory.

17. The method according to claim 1, wherein the imaging apparatus is selected from the group consisting of: an optical coherence tomography apparatus, an intravascular ultrasound apparatus, a near infrared spectroscopy apparatus, and a combination thereof.

18. A method for imaging inside a lumen, the method comprising:

introducing a rotational imaging apparatus inside a lumen to be imaged;

acquiring electronic image data produced from the rotational imaging apparatus, wherein the data comprises frame-to-frame variability in A-scan density;

applying a scan conversion process that can account for frame-to-frame variability in A-scan density to the image data in order to produce an electronically displayable image of the inside of the lumen.

19. The method of claim 18, further comprising axially moving the imaging apparatus through the lumen.

20. The method of claim 18, wherein the image data comprises a data discontinuity artifact and a guidewire shaft artifact.

21. The method of claim 20, further comprising the step of segmenting the image data to form a

frame where the data discontinuity artifact overlaps the guidewire shaft artifact.

22. The method according to claim 18, wherein the imaging system is selected from the group consisting of: an optical coherence tomography apparatus, an intravascular ultrasound apparatus, a near infrared spectroscopy apparatus, and a combination thereof.

23. A system, the system comprising a central processing unit (CPU) and storage coupled to the CPU for storing instructions that configure the CPU to:

acquire electronic image data produced from a rotational imaging apparatus, wherein the data comprises frame-to-frame variability in A-scan density; and

apply a scan conversion process that accounts for frame-to-frame variability in A-scan density to the image data in order to produce an electronically displayable medical image.

24. The system according to claim 23, further comprising the rotational imaging apparatus.

25. The system according to claim 24, wherein the imaging apparatus is selected from the group consisting of: an optical coherence tomography apparatus, an intravascular ultrasound apparatus, a near infrared spectroscopy apparatus, and a combination thereof.

26. The system according to claim 23, wherein the scan conversion process comprises:

calculating a plurality of lookup tables comprising a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates, wherein each lookup table is associated with an A-scan density;

storing the plurality of lookup tables in computer memory;

receiving a polar domain frame having an A-scan density;

locating a lookup table associated with the A-scan density of the frame; and

applying the coefficients of the lookup table to the frame.

27. The system of claim 26, wherein the plurality of coefficients comprises pairings of coefficients, where each pair comprises a radial coefficient and an angular coefficient.

28. The system of claim 27, wherein each pair of radial and angular coefficients is associated with a single pixel on a display.

29. The system of claim 27, wherein the angular coefficient is calculated using an ARCTAN approximation.

30. The system of claim 26, wherein the plurality of lookup tables comprises a lookup table for A-scan densities ranging from 490 A-lines per frame and 510 A-lines per frame.

31. The system according to claim 23, wherein the scan conversion process comprises:

receiving a polar domain frame having an A-scan density;

calculating a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates based upon the A-scan density of the frame; and

applying the plurality of coefficients to the frame.

32. The system of claim 31, wherein the plurality of coefficients comprises pairings of coefficients, where each pair comprises a radial coefficient and an angular coefficient.

33. The system of claim 32, wherein each pair of radial and angular coefficients is associated with a single pixel on a display.

34. The system of claim 32, wherein the angular coefficient is calculated using an ARCTAN approximation.

35. The system of claim 31, further comprising the step of incorporating a rotational offset to the plurality of coefficients.

36. The system of claim 31, further comprising the step of incorporating a translational offset to the plurality of coefficients.

37. The system of claim 31, further comprising the step of incorporating a scaling factor to the

plurality of coefficients.

38. The system of claim 31, further comprising the steps of:

creating a lookup table comprised of the plurality of coefficients, the lookup table being associated with the A-scan density of the frame;

storing the lookup table in computer memory;

receiving a second polar domain frame having an A-scan density;

determining whether a lookup table associated with the A-scan density of the second frame is stored in computer memory.

39. The system of claim 38, wherein a lookup table associated with the A-scan density of the second frame is stored in computer memory, further comprising the step of applying the lookup table associated with the A-scan density of the second frame to the second frame.

40. The system of claim 38, wherein a lookup table associated with the A-scan density of the second frame is not stored in computer memory, further comprising the steps of:

calculating a plurality of coefficients for converting polar domain coordinates of radius and angle into Cartesian coordinates based upon the A-scan density of the frame;

applying the plurality of coefficients to the frame;

creating a lookup table comprised of the plurality of coefficients, the lookup table being associated with the A-scan density of the frame; and

storing the lookup table in computer memory.

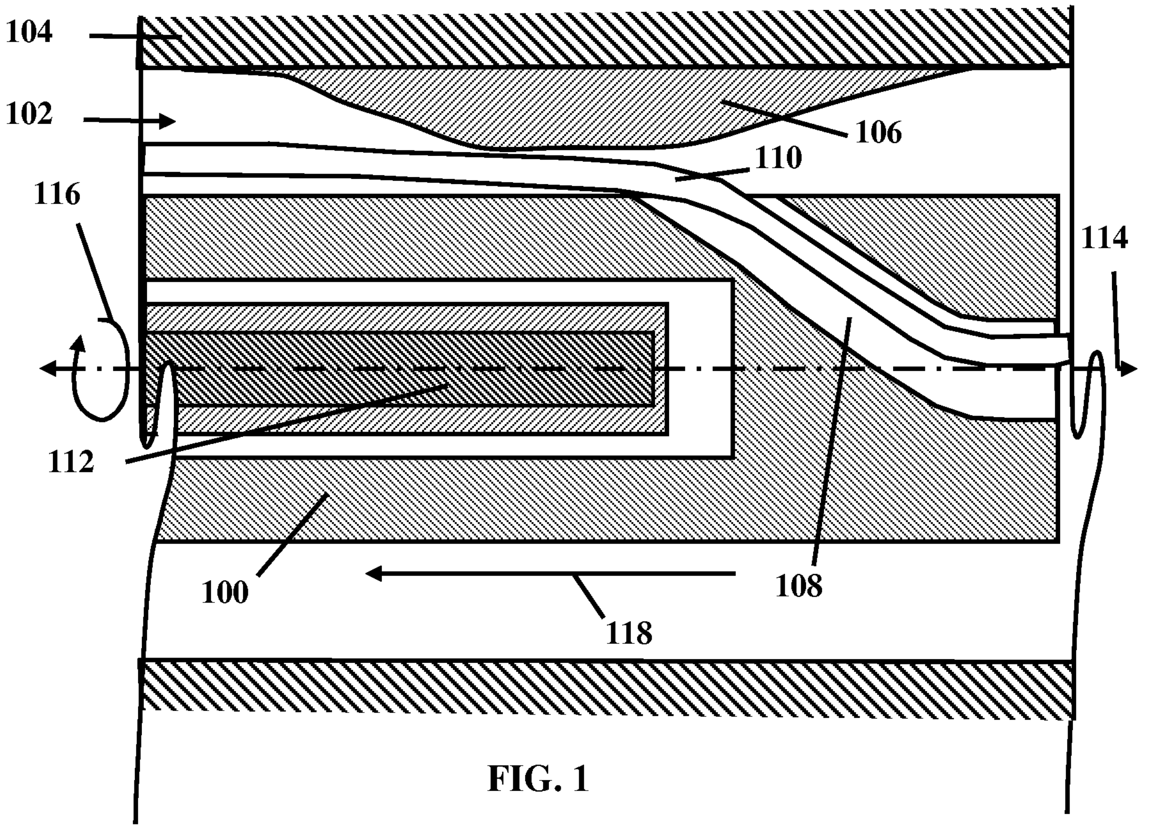
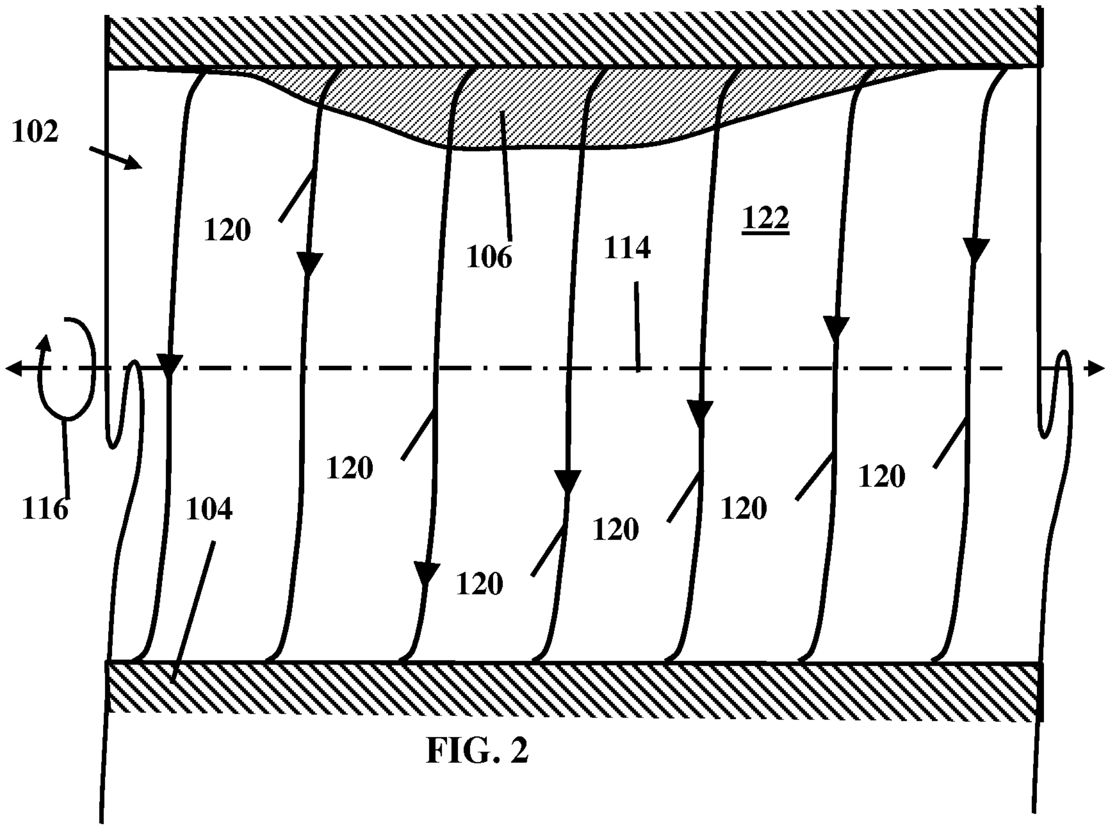

104
102
106
110
116
114
112
100
118
108

FIG. 1


102
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104
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120
120
120

FIG. 2

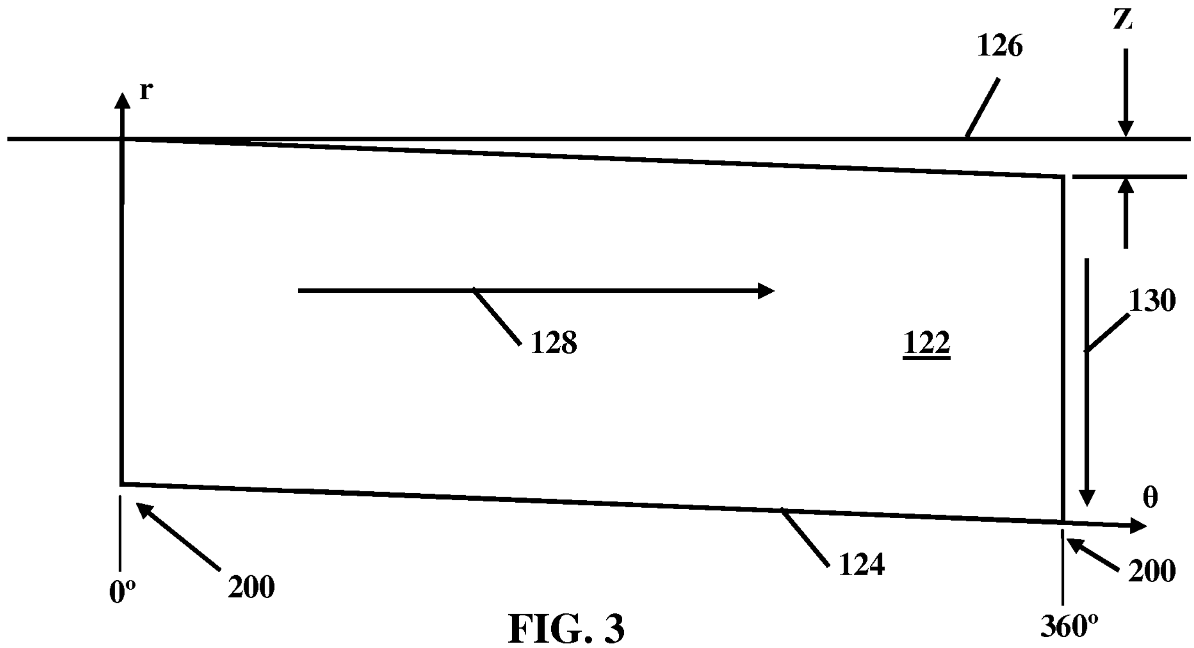
Z
126
r
128
122
130
θ
200
124
200
0º
360º

FIG. 3

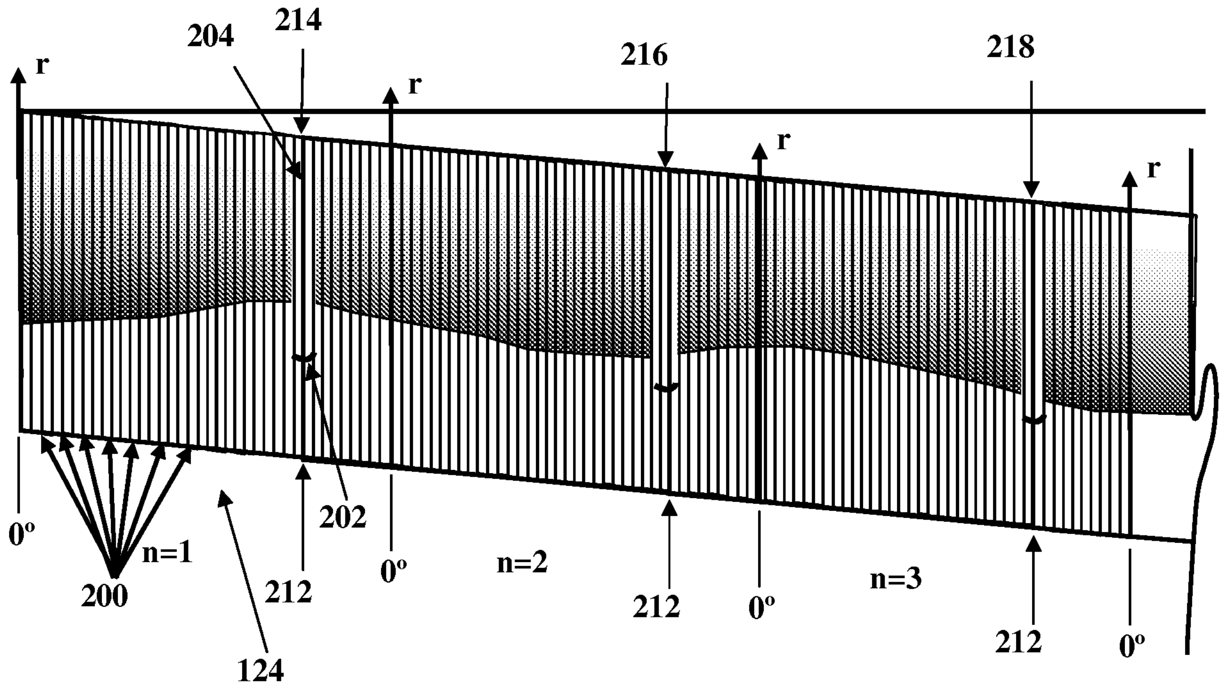
204
214
216
218
r
r
r
r
202
0º
n=1
200
212
124
0º
n=2
212
0º
n=3
212
0º

FIG. 4

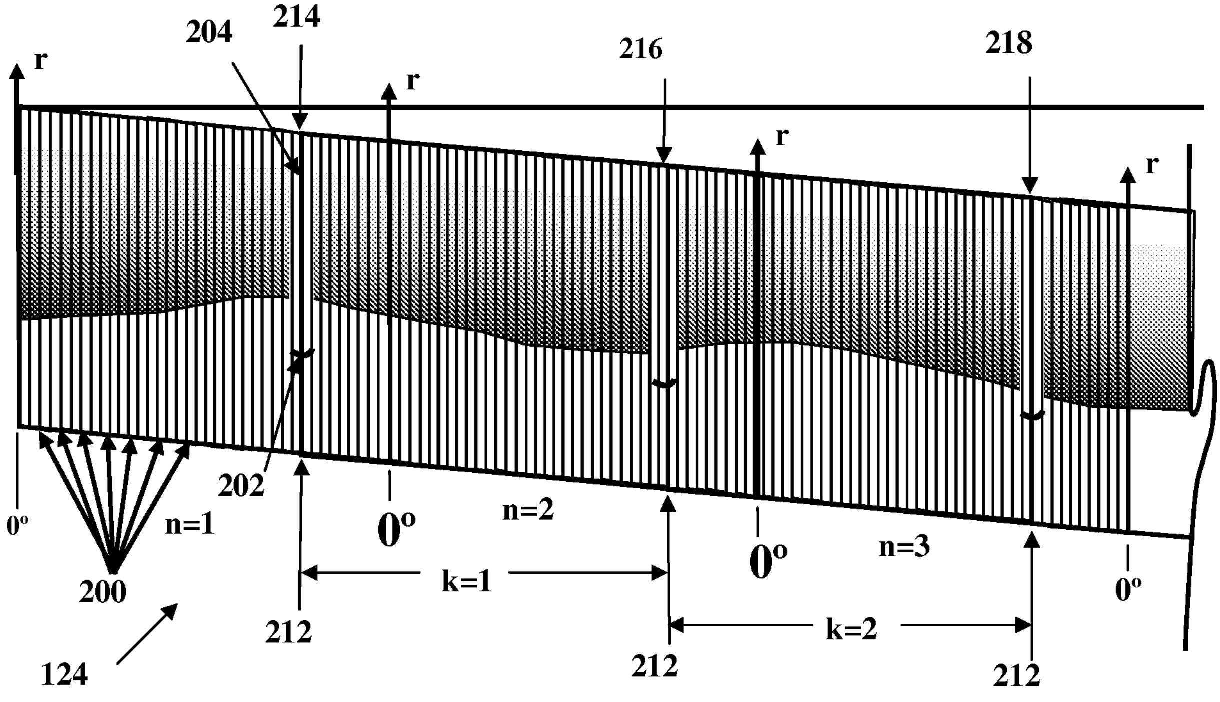

FIG. 5

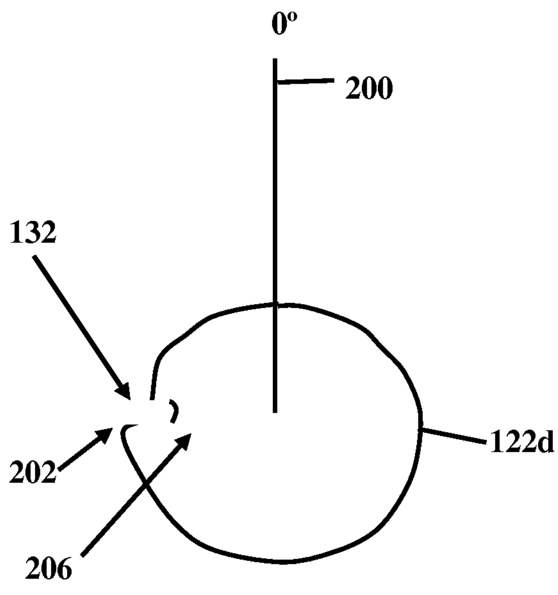

FIG. 6A

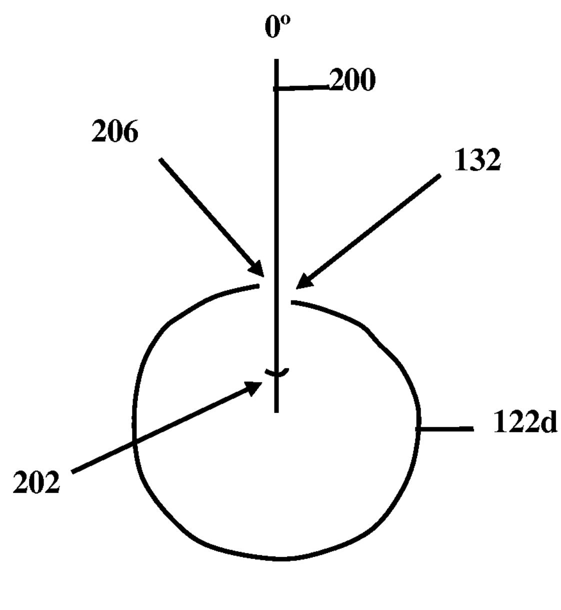

FIG. 6B

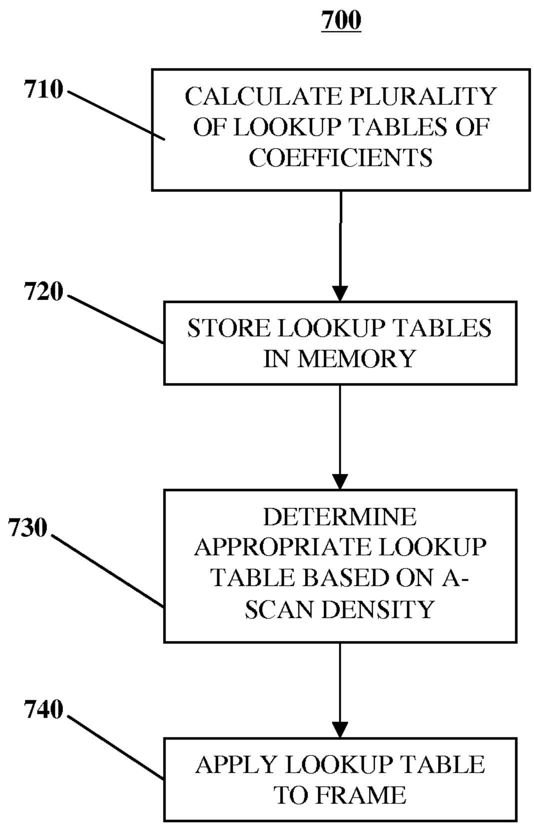
700
710
CALCULATE PLURALITY OF LOOKUP TABLES OF COEFFICIENTS
720
STORE LOOKUP TABLES IN MEMORY
730
DETERMINE APPROPRIATE LOOKUP TABLE BASED ON A-SCAN DENSITY
740
APPLY LOOKUP TABLE TO FRAME

FIG. 7

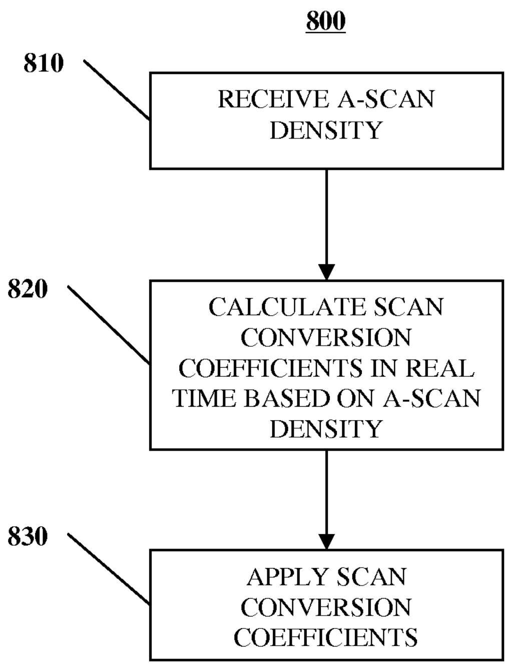
800
810
RECEIVE A-SCAN DENSITY
820
CALCULATE SCAN CONVERSION COEFFICIENTS IN REAL TIME BASED ON A-SCAN DENSITY
830
APPLY SCAN CONVERSION COEFFICIENTS

FIG. 8

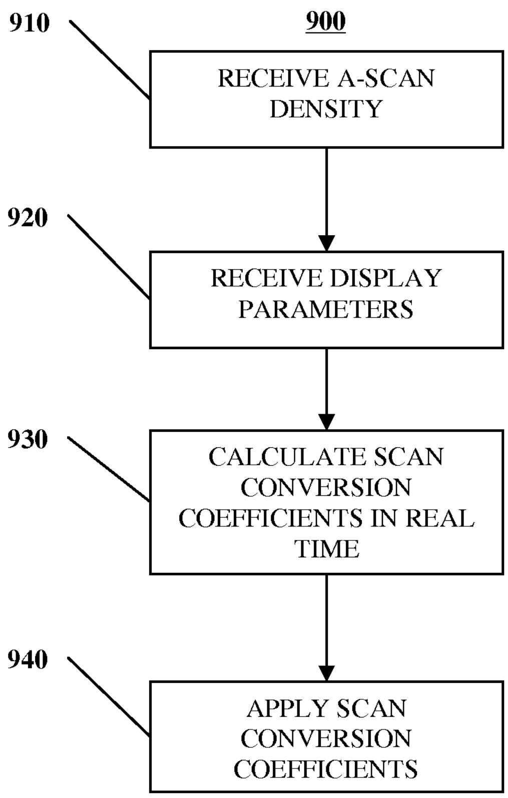
910
900
RECEIVE A-SCAN DENSITY
920
RECEIVE DISPLAY PARAMETERS
930
CALCULATE SCAN CONVERSION COEFFICIENTS IN REAL TIME
940
APPLY SCAN CONVERSION COEFFICIENTS

FIG. 9

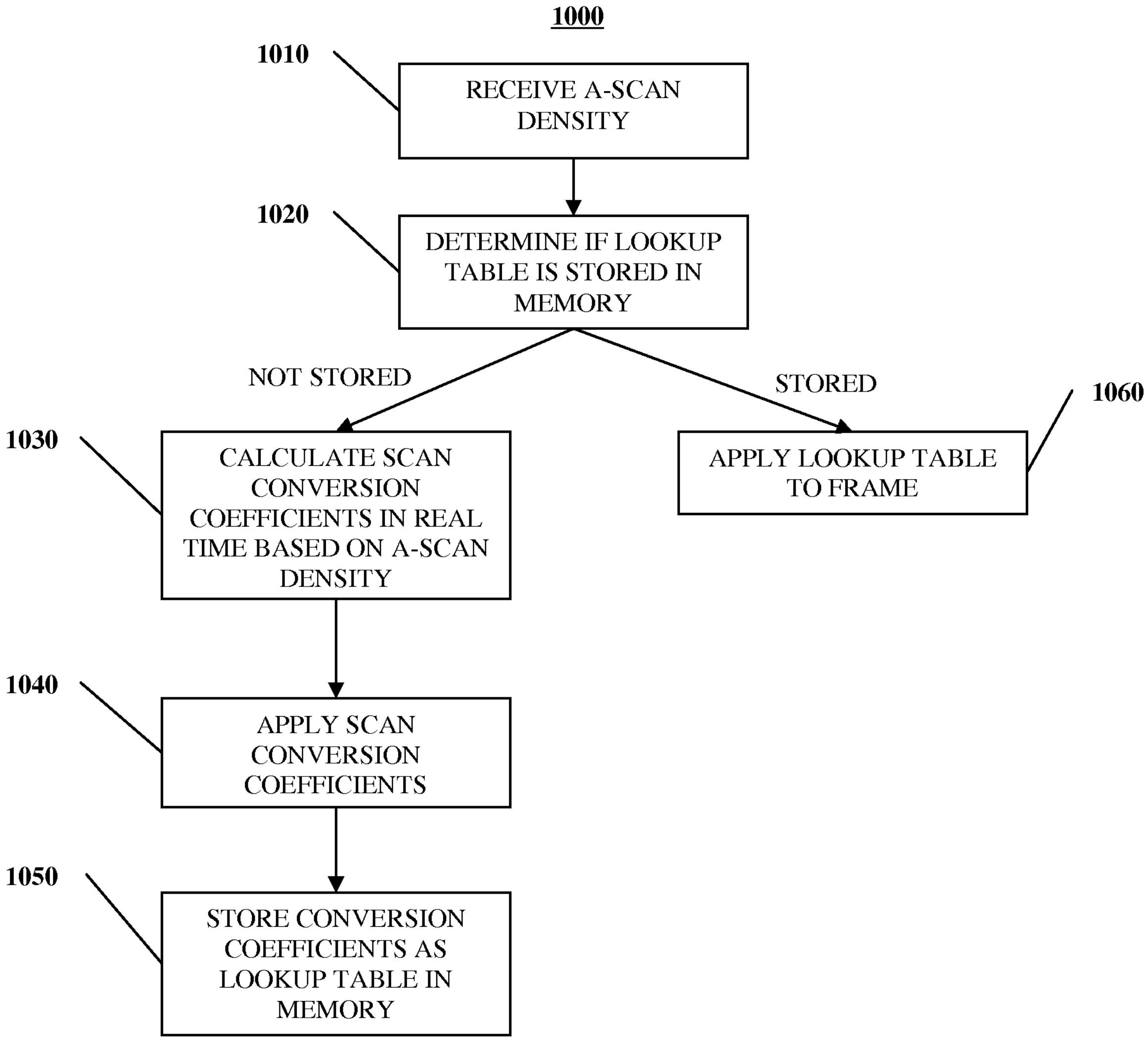
1000
1010
RECEIVE A-SCAN DENSITY
1020
DETERMINE IF LOOKUP TABLE IS STORED IN MEMORY
NOT STORED
STORED
1030
CALCULATE SCAN CONVERSION COEFFICIENTS IN REAL TIME BASED ON A-SCAN DENSITY
1060
APPLY LOOKUP TABLE TO FRAME
1040
APPLY SCAN CONVERSION COEFFICIENTS
1050
STORE CONVERSION COEFFICIENTS AS LOOKUP TABLE IN MEMORY

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 12/53167

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01B 9/02 (2012.01)
USPC - 356/479
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)
USPC: 356/479

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 600/109; 600/425 (keyword limited - see search terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase (FullText); Google; Google Scholar
Terms: image, coordinates, polar, cartesian, conversion, translation, transform, coefficient, multiplier, frame, rotate, turn, circular, scan, a-scan, offset, angle, radial, tomography, tangent.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/0087104 A1 (Moore et al.) 14 April 2011 (14.04.2011), entire document, especially abstract, para [0010], [0012], [0046], [0048], [0052], [0082], [0098].	1-40
Y	US 2011/0032533 A1 (Izatt et al.) 10 February 2011 (10.02.2011), entire document, especially abstract, para [0005], [0006], [0044], [0051], [0057], [0097], [0099], [0102], [0116], [0117], [0145].	1-40
A	US 2003/0228039 A1 (Green) 11 December 2003 (11.12.2003), entire document, especially abstract, para [0028], [0041], [0049], [0051]	1-40
A	US 2007/0238957 A1 (Yared) 11 October 2007 (11.10.2007), entire document, especially abstract, para [0134], [0149], [0157], [0250].	1-40

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 October 2012 (19.10.2012)	06 NOV 2012

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774