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(54) PROCESSING AND DISPLAYING BREAST ULTRASOUND INFORMATION

VERARBEITUNG UND ANZEIGE VON ULTRASCHALLINFORMATIONEN DER BRUST

TRAITEMENT ET AFFICHAGE DES INFORMATIONS D'UNE ÉCHOGRAPHIE OU ULTRASONS DES SEINS

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Description

FIELD

[0001] This patent specification relates to medical ultrasound imaging. More particularly, this patent specification relates to processing and/or display of breast ultrasound information for breast cancer screening and/or diagnosis purposes.

BACKGROUND

[0002] Volumetric ultrasound scanning of the breast can serve as a complementary modality for breast cancer screening as described, for example, in the commonly assigned US 2003/0007598A and US 2003/0212327A1. Whereas a conventional two-dimensional x-ray mammogram only detects a summation of the x-ray opacity of individual slices of breast tissue over the entire breast, ultrasound can separately detect the sonographic properties of individual slices of breast tissue, and therefore may allow detection of breast lesions where x-ray mammography alone fails. Another well-known shortcoming of x-ray mammography practice is found in the case of dense-breasted women, including patients with high content of fibroglandular tissues in their breasts. Because fibroglandular tissues ha+ve higher x-ray absorption than the surrounding fatty tissues, portions of breasts with high fibroglandular tissue content are not well penetrated by x-rays and thus the resulting mammograms contain reduced information in areas where fibroglandular tissues reside. Still another shortcoming of x-ray mammography practice relates to difficulty in imaging near the chest wall, because it is difficult to extend these tissues outward onto the compression plates for proper imaging. A substantial number of cancers are known to occur within 3 cm of the chest wall, which can thereby be missed by x-ray mammography.

[0003] In addition to being useful as a complementary modality to x-ray mammography, ultrasound mammography could well become a sole breast cancer screening modality for at least some patient groups. For example, it is believed that preventive health care policy will progress toward the adoption of regular breast cancer screening procedures for increasingly younger women, *e.g.*, women under the age of 40, and perhaps even under the age of 30 if there is a family history of cancer. Because younger women generally have denser breasts, the shortcomings of conventional two-dimensional x-ray mammography are expected to become especially apparent. Even further, because the dangers of x-ray radiation exposure are cumulative over a lifetime, ultrasound mammography could well become a sole breast cancer screening modality for women in these younger age groups. Other demographics indicating higher breast densities among certain groups, regions, or countries may also lead to the increased adoption of breast ultrasound as a sole or adjunctive screening modality for those groups, regions, or countries.

[0004] Once a thorough set of breast ultrasound scans is obtained, a challenge arises in the context of processing and displaying the breast ultrasound information to a clinician. In general, there is an inherent tension between (i) promoting high sensitivity/specificity in the screening and/or diagnosis process, and (ii) promoting efficient patient throughput to keep costs manageable. Thus, for example, while careful slice-by-slice scrutiny of the raw ultrasound scans by a well-trained radiologist would promote high sensitivity and specificity, the overall workflow efficiency of this method would be low, and therefore costs would be high, in view of the hundreds of individual raw ultrasound slices to be reviewed for each patient.

[0005] Accordingly, it would be desirable to provide an interactive user interface for viewing breast ultrasound information that can be effective for (i) adjunctive ultrasound mammography environments in which the ultrasound information complements x-ray mammogram information, and/or (ii) ultrasound-only mammography environments in which ultrasound is a sole screening modality.

[0006] It would be further desirable to provide processing and display of breast ultrasound information in a manner that promotes high specificity and sensitivity in the breast cancer screening and/or diagnosis process.

[0007] It would be still further desirable to provide such processing and display of breast ultrasound information while also promoting high patient throughput and low per-patient costs in the breast cancer screening and/or diagnosis process.

[0008] It would be even further desirable to provide such processing and display of breast ultrasound information that is effective for a wide variety of breast sizes, including smaller-sized breasts.

[0009] It would be still further desirable to provide an interactive user interface for an ultrasound mammography system that allows the radiologist to quickly and intuitively navigate among different representations of the breast ultrasound information.

[0010] It would be even further desirable to provide such processing and display of breast ultrasound information that is effective in exposing breast abnormalities that are in close proximity to the chest wall of the patient, where a comparatively high percentage of breast abnormalities arise.

[0011] A method for processing a three-dimensional data volume of a sonographic property of a breast as defined in claim 1 is provided.

[0012] Advantageously, the array of coronal thick-slice images includes one or more members corresponding to subvolumes abutting the chest wall, which allows for detailed visual review of tissue structures near the chest wall. The three-dimensional data volume has been obtained while the breast was compressed in a chestward direction and scanned using a high frequency ultrasound probe, which allows for high resolution in the coronal thick-slice images.

[0013] In one preferred embodiment, all of the slab-like subvolumes corresponding to the coronal thick-slice images have the same thickness. In an alternative preferred embodiment, an average thickness of a first subset of the slab-like subvolumes located closer to the chest wall is less than an average thickness of a second subset of said slab-like subvolumes located farther from the chest wall, whereby detection of smaller structures nearer to the chest wall is facilitated while avoiding the presentation of "too much information" to the viewing clinician. Alternatively or in conjunction therewith, the three-dimensional data volume is processed according to at least one computer-aided detection (CAD) algorithm to detect anatomical abnormalities (*e.g.*, spiculated mass lesions, microcalcifications, etc.) in the breast, and the coronal thick-slice images are correspondingly annotated on the user display.

[0014] In another preferred embodiment, a method, apparatus, and related computer program products for displaying breast ultrasound information are provided including an interactive user interface that can be used in adjunctive ultrasound mammography environments and/or ultrasound-only mammography environments. According to a preferred embodiment, bilateral comparison is facilitated by displaying a first thick-slice image representing a sonographic property within a first slab-like subvolume of a first breast of a patient, and displaying a second thick-slice image adjacent to the first thick-slice image. The second thick-slice image represents the sonographic property within a second slab-like subvolume of a second breast opposite the first breast, the first and second slab-like subvolumes occupying generally similar positions within the first and second breasts, respectively.

[0015] According to another preferred embodiment, a thick-slice image representing a sonographic property of a breast within a slab-like subvolume thereof is displayed, wherein the slab-like subvolume has a thickness between 2 mm and 20 mm, and wherein the slab-like subvolume is substantially parallel to a coronal plane. The thick-slice image may be a member of a thick-slice image array corresponding to successive slab-like subvolumes within the breast substantially parallel to the coronal plane, a plurality of which can be simultaneously displayed for a quick overview of the internal breast tissue.

[0016] In another preferred embodiment, a single composite thick-slice image corresponding to the entire breast volume is displayed. Preferably, the composite thick-slice image is enhanced according at least one computer-aided detection (CAD) algorithm operating on the acquired three-dimensional breast volume.

[0017] In another preferred embodiment, a thick-slice image is displayed on a display monitor, the thick-slice image representing a sonographic property of a breast within a slab-like subvolume thereof, the slab-like subvolume being substantially parallel to a coronal plane. A nipple marker is displayed on the thick-slice image representing a projection of a nipple location onto that thick-slice image. A cursor is also displayed upon the thick-slice image according to a viewer manipulation of a pointing device associated with the display monitor. To facilitate easy and intuitive navigation and viewing, a breast icon is displayed near the thick-slice image, the breast icon including a cursor position indicator that is movably disposed thereon in a manner that reflects a relative current position between the cursor and the nipple marker on the thick-slice image. Preferably, the breast icon is configured to at least roughly resemble a clock face, and the center of that clock face represents the nipple marker position, *i.e.*, the cursor position indicator is placed relative to the center of the clock face in a manner that reflects the current position of the cursor on the thick-slice image relative to the nipple marker.

[0018] To further facilitate quick and intuitive viewing, a bookmarking capability is provided that allows the viewer to place bookmarks upon the thick-slice images as well as upon any planar ultrasound images being displayed. Advantageously, a bookmark-centric navigation capability is provided that allows the viewer to promptly proceed precisely to the next bookmark on the thick-slice image(s), as well as to cause the planar ultrasound image(s) to promptly correspond to that next bookmark location. Alternatively or in conjunction therewith, a computer-aided diagnosis (CAD)-centric navigation capability is provided that allows the viewer to proceed promptly along CAD detections, i.e., locations that may be suspicious as determined by a computer-aided diagnosis system, on both the thick-slice and planar ultrasound images.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 illustrates a conceptual diagram of a breast cancer screening and/or diagnosis system according to a preferred embodiment;

[0020] FIG. 2 illustrates a perspective view of a breast volume and slab-like subvolumes thereof substantially parallel to a coronal plane, and an array of two-dimensional coronal thick-slice images corresponding thereto;

[0021] FIG. 3 illustrates a method for processing and displaying breast ultrasound information according to a preferred embodiment;

[0022] FIG. 4 illustrates a front view of a breast, a front view of slab-like subvolumes thereof substantially parallel to standard x-ray mammogram planes, and arrays of standard-plane thick-slice images corresponding thereto for display in conjunction with the coronal thick-slice images of FIG. 2 according to a preferred embodiment;

[0023] FIG. 5 illustrates a user display according to a preferred embodiment;

[0024] FIGS. 6A and 6B illustrate a side view of a breast and an example of different slab-like coronal subvolume thickness schemes according to a preferred embodiment;

[0025] FIG. 7 illustrates a method for processing and displaying breast ultrasound information according to a preferred embodiment;

[0026] FIG. 8 illustrates a user display according to a preferred embodiment;

[0027] FIG. 9 illustrates a user display according to a preferred embodiment;

[0028] FIG. 10 illustrates a breast ultrasound display according to a preferred embodiment;

[0029] FIG. 11 illustrates a menu bar of a breast ultrasound display according to a preferred embodiment;

[0030] FIGS. 12 and 13 illustrate body marker icons according to a preferred embodiment;

[0031] FIG. 14 illustrates a thick-slice image and planar views according to a preferred embodiment;

[0032] FIG. 15 illustrates a bilateral comparison array of thick-slice images, corresponding body marker icons, and a display control button according to a preferred embodiment;

[0033] FIG. 16 illustrates a bilateral comparison view of thick-slice images and corresponding body marker icons according to a preferred embodiment;

[0034] FIG. 17 illustrates an array of thick-slice images with nipple markers, a body marker icon, and a frontal breast icon according to a preferred embodiment;

[0035] FIG. 18 illustrates a thick-slice image and planar images with displayed bookmarks, a body marker icon, a frontal breast icon, a marker display button, and marker navigation buttons according to a preferred embodiment;

[0036] FIG. 19 illustrates an array of thick-slice images with viewer-shifted nipple markers, a body marker icon, and a frontal breast icon according to a preferred embodiment;

[0037] FIG. 20 illustrates an array of thick-slice images with nipple markers and bookmarks, a marker display button, and marker navigation buttons according to a preferred embodiment;

[0038] FIGS. 21 and 22 illustrate breast ultrasound volume acquisition, processing, and display according to one or more preferred embodiments;

[0039] FIG. 23 illustrates a bilateral comparison array view of thick-slice images and corresponding body marker icons according to a preferred embodiment;

[0040] FIG. 24 illustrates examples of virtual probe reconstruction planes according to a preferred embodiment;

[0041] FIG. 25 illustrates a full-breast composite thick-slice image, a body marker icon, and a frontal breast icon according to a preferred embodiment; and

[0042] FIG. 26 illustrates a volume-rendered breast ultrasound volume with surface-rendered computer-assisted diagnosis (CAD) detections therein according to a preferred embodiment.

DETAILED DESCRIPTION

[0043] FIG. 1 illustrates a conceptual diagram of a breast cancer screening and/or diagnosis system according to a preferred embodiment. The breast of a patient 101 is ultrasonically scanned by an automated scanning apparatus while the patient is in a prone position (device 102), an upright position (device 102'), a supine position (device 102") or other position (not shown). By reducing the required ultr-asonic penetration depth to the chest wall, scanning of a chestwardly compressed breast can occur at higher frequencies, *e.g.*, 10-20 MHz, which can yield very high resolution images sufficient to facilitate detection of microcalcifications or other structures on the order of 1 mm near the chest wall.

[0044] Breast scans are obtained under the control of a scanning engine and workstation 104 including, for example, a monitor 106, keyboard 108, a mouse 110, and a scanning engine (not shown). During or after the scanning process, the ultrasound scan data is provided across a computer network 112 to an ultrasound server 114 that processes and generates display information according to the functionalities described herein. The ultrasound server 114 may perform other HIS/RIS (hospital information system/radiology information system) activities such as archiving, scheduling, etc. It is to be appreciated that the processing of the ultrasound scan data may be performed by any of a variety of different computing devices coupled to the computer network 112 in various combinations without departing from the scope of the preferred embodiments.

[0045] According to a preferred embodiment, a viewing workstation 122 is provided that displays an array 124 of coronal thick-slice images to a clinician 121, each coronal thick-slice image representing a sonographic property of the breast within a slab-like subvolume thereof substantially parallel to a coronal plane. As used herein, the term "clinician" generically refers to a medical professional, such as a radiologist, or other person that analyzes medical images and makes clinical determinations therefrom, it being understood that such person might be titled differently, or might have varying qualifications, depending on the country or locality of their particular medical environment. In another preferred embodiment, as shown in FIG. 1, one or more standard-plane thick slice image arrays are displayed to the clinician 121, such as a craniocaudal (CC) thick-slice image array 126 and a mediolateral oblique (MLO) thick-slice image array 128.

[0046] In another preferred embodiment (not shown), the clinician is also provided with the ability to view individual planar ultrasound slices (along sagittal, axial, coronal, or other cut-planes through the three-dimensional breast volume) as desired. An example of one desirable planar ultrasound display and navigation scheme is provided in the commonly assigned US2003/0212327A1, *supra,* and in other preferred embodiments described herein.

[0047] FIG. 2 illustrates a perspective view of a breast volume 201 and coronal slab-like subvolumes 204-210 thereof substantially parallel to a coronal plane, along with the array 124 oftwo-dimensional coronal thick-slice images generated therefrom according to a preferred embodiment. The coronal slab-like subvolumes 204-210, which are separated by planes 202, correspond to the coronal thick-slice images 212-218, respectively. Generally speaking, the coronal slab-like subvolumes nearer to the chest wall (*e.g.*, 204-206) have a larger cross-section in the coronal plane than the slab-like subvolumes nearer to the nipple 203 (*e.g.*, 208-210). As used herein, coronal slab-like subvolumes refer generally to slab-like subvolumes within the breast that are roughly parallel to the chest wall of the patient. The coronal slab-like subvolumes 204-210 typically have a thickness in the range of 2 - 20 mm. Optionally, the coronal slab-like subvolumes can be gently contoured to more closely follow the contours of the chest wall. In such cases, the coronal slab-like subvolumes would have surfaces roughly reminiscent of a section of a hyperboloid, or roughly reminiscent of a potato chip.

[0048] Generally speaking, a coronal thick-slice image comprises an integration of a plurality of individual ultrasound slices lying within a coronal slab-like subvolume. Thus, for example, where the coronal slab-like subvolume 204 is represented by a three-dimensional voxel array V(x,y,z) of scalar values, the corresponding coronal thick-slice image 212 would be a two-dimensional pixel array $P_{COR}(x,y)$ of scalar values. In one preferred embodiment, each pixel value $P_{COR}(x,y)$ is simply computed as an arithmetic average along the corresponding voxel column at (x,y) having the voxel values $V(x,y,z_0)$, $V(x,y,z_1)$, $V(x,y,z_2)$, ..., $V(x,y,z_N)$, where N is the number of individual ultrasound slices lying in the coronal slab-like subvolume. For clarity of description, the voxel column at (x,y) having the voxel values $V(x,y,z_0)$, $V(x,y,z_1)$, $V(x,y,z_2)$, ..., $V(x,y,z_N)$ is expressed herein as $V_{xy}(z)$.

[0049] Techniques for integrating the component ultrasound slices into the coronal thick-slice images $P_{COR}(x,y)$ according to the preferred embodiments include arithmetic averaging, geometric averaging, reciprocal averaging, exponential averaging, and other averaging methods, in each case including both weighted and unweighted averaging techniques. Other suitable integration methods may be based on statistical properties of the population of component ultrasound slices at common locations, such as maximum value, minimum value, mean, variance, or other statistical algorithms.

[0050] Preferably, the coronal slab-like subvolumes have a thickness related to the size of the lesions to be detected. At an upper end, a larger thickness of 20 mm, for example, may be used if it is desirable to overlook most of the breast details and direct the user's attention to larger features on the order 10 mm in size. At a lower end, a smaller thickness of 2 mm, for example, may he used if it is desirable to view small structures, such as microcalcifications, on the order of I mm in size. Thicknesses in the range of 4 mm - 10 mm are likely to be suitable for most breast cancer screening purposes.

[0051] In other preferred embodiments, the pixel value $P_{COR}(x,y)$ may be computed according to an algorithm that processes a neighborhood of voxel columns around the voxel column $V_{xy}(z)$, the algorithm being designed to result in coronal thick-slice images that emphasize lesions of a predetermined size range. In one such preferred embodiment, the integration method comprises weighting the voxels of the corresponding voxel column by a weighting vector and then summing the results, the weighting vector being computed according to neighborhood characteristics around that voxel column. This can be summarized by Eq. (1) below:

$$P_{COR}(x,y) = FUNC\{V_{xy}(z)\} = \sum_{n=1}^{N} W_{xy}(n) V_{xy}(z_n) \qquad \{1\}$$

[0052] Using known three-dimensional segmentation and computer-aided detection (CAD) techniques, the locations and sizes of lesions in the coronal thick-slice volume are identified, either directly or by way of mapping from the overall three-dimensional breast volume. Any of variety of known three-dimensional segmentation and/or CAD algorithms can be used such as those discussed in U.S. 6,317,6 7 to Gilhuijs, Giger, and Bick. In one preferred embodiment, for a given voxel column, the weighting vector $W_{xy}(n)$ comprises peaks at locations lying within the lesions and valleys elsewhere, thus causing the resulting coronal thick-slice image to emphasize mass lesions in the output. In another preferred embodiment, the weighting vector $W_{xy}(n)$ can be computed as described in the commonly assigned WO 02/101303A1. The CAD-detected abnormalities can include microcalcifications, suspicious masses, and/or other known breast abnormalities.

[0053] FIG. 3 illustrates a method fur processing and displaying breast ultrasound information according to a preferred embodiment. At step 302, volumetric ultrasound scans of the chestwardly-compressed breast are acquired, either in real-time as the breast is being scanned, or in an off-line manner as from a database or archive of previously-acquired images. At step, 304, coronal thick-slice images are computed corresponding to slab-like subvolumes of the chestwardly-compressed breast substantially parallel to coronal plane. At step 306, the array of coronal thick-slice images is displayed on a user display, preferably in a side-by-side manner. However, a variety of different spatial arrangements of the coronal thick-slice images are within the scope of the preferred embodiments. For example, the array may be presented in circular or matrix fashion. In one preferred embodiment, all of the coronal thick-slice images collectively corresponding to the entire breast volume are simultaneously displayed to the viewer, so that the whole breast is effectively shown at the same time, thereby facilitating clinical workflow efficiency. In another preferred embodiment, the coronal thick-slice images can be progressively displayed at successive time intervals, either automatically or responsive to user controls.

[0054] According to one preferred embodiment, at step 308 craniocaudal (CC) thick-slice images, which are one type of standard-plane thick-slice image, are computed corresponding to slab-like subvolumes of the chestwardly-compressed breast substantially parallel to an axial plane, which corresponds to the CC view. At step 310 mediolateral oblique (MLO) thick-slice images, which are another type of standard-plane thick-slice image, are computed corresponding to slab-like subvolumes of the chestwardly-compressed breast substantially parallel to an MLO plane. At step 312, the arrays of CC and MLO thick-slice images are presented on the user display.

[0055] FIG. 4 illustrates a conceptual front view of the breast 201 upon which are drawn (i) front-view outlines of slab-like subvolumes A-H corresponding to CC slab-like subvolumes, and (ii) front-view outlines of slab-like subvolumes I-VI corresponding to MLO slab-like subvolumes. Also shown in FIG. 4 is a portion of the viewing workstation 122 illustrating the CC thick-slice image array 126 and the MLO thick-slice image array 128 with indicators mapping them into the slab-like subvolumes A-H and I-VI, respectively. The CC and MLO thick-slice image arrays can be generated from the three-dimensional breast volume in a manner analogous to that described in WO 02/101303A1, *supra.* As known in the art, the MLO plane is usually about 55 degrees away from the CC plane. It is to be appreciated, however, that a variety of angles for the MLO plane can be used without departing from the scope of the preferred embodiments, including 90 degrees (in which case it corresponds to the mediolateral "ML" view) or greater.

[0056] Referring again to FIG. 3, according to one preferred embodiment, standard CC and MLO x-ray mammogram views of the breast are displayed at steps 314 and 316, respectively. FIG. 5 illustrates a viewing workstation 502 similar to the viewing workstation 122, *supra,* with the addition of CC and MLO x-ray mammogram images 504 and 506, respectively, which can further facilitate screening and diagnosis through back-and-forth viewing of interesting areas. The CC and MLO x-ray mammogram images 504 and 506 are preferably in digitized form for practical reasons, although it is within the scope of the preferred embodiments for these to be film-based x-ray mammograms on a light-box background.

[0057] FIGS. 6A and 6B illustrate side views of a breast 201 next to a chest wall 602 for the purpose of describing coronal slab-like subvolume thickness schemes according to the preferred embodiments. In the preferred embodiment of FIG. 6A, the thicknesses of coronal slab-like subvolumes 1-5 are substantially equal. However, in the preferred embodiment of FIG. 6B, there is a graded or phased approach to the thicknesses of coronal slab-like subvolumes 1-5. More particularly, the inner subvolumes 1-2 are thinner than the outer subvolumes 4-5. Thus, an average thickness of a first subset of said slab-like subvolumes located closer to the chest wall is less than an average thickness of a second subset of said slab-like subvolumes located farther from the chest wall.

[0058] The graded or phased approach of FIG. 6B has been found advantageous because a large percentage of breast lesions are nearby to the chest wall, and so a more precise viewing of these tissues (*i.e.*, approaching the precision of conventional thin-slice ultrasound images) is warranted. At the same time, however, it is still desirable to avoid "too much information" on the user display, and so thicker subvolumes for the regions farther away from the chest wall are used to keep the overall number of required images at manageable levels.

[0059] FIG. 7 illustrates a method for processing and displaying breast ultrasound information according to a preferred embodiment. At step 702, the three-dimensional data volume is processed according to at least one computer-aided detection (CAD) algorithm to detect anatomical abnormalities therein. These CAD algorithms can be the same as used *supra* for enhancing the visual appearance of lesions in the thick-slice images, or alternatively can be different and/or additional CAD algorithms. At step 704, the detected lesions in the three-dimensional data volume are mapped into their corresponding coronal thick-slice images. The detected lesions are also mapped into their corresponding CC and/or MLO thick-slice images if present. At step 706, annotations are superimposed on the corresponding coronal, CC, and/or MLO thick-slice images according to type and location of detected anatomical abnormality.

[0060] FIG. 8 illustrates a viewing workstation 802 according to a preferred embodiment, which is similar to the viewing workstation 122 but also includes CAD annotations on the coronal, CC, and MLO thick-slice images. The CAD annotations are placed according to type and location of detected anatomical abnormality. In the example of FIG. 8, a CAD-detected suspicious microcalcification cluster is denoted by triangles 804a, 804b, and 804c on the appropriate members of the coronal, CC, and MLO thick-slice image arrays, respectively. A CAD-detected suspicious mass is denoted by asterisk-shaped markers 806a, 806b, and 806c on the appropriate members of the coronal, CC, and MLO thick-slice image arrays, respectively.

[0061] FIG. 9 illustrates a portion 902 of a viewing workstation according to a preferred embodiment, including an array 904 of coronal thick-slice images. It has been found useful to identify the x-y location of the nipple relative to the coronal thick-slice images on the user display, as indicated by the nipple markers 906. For example, it will not always be the case that the nipple will be at the center of each coronal thick-slice image, for anatomical reasons as well as the fact that there may be variations in the angle of attack of the chestward compressive force on the breast. These variations in the angle of attack may be unintentional, as in the case of imperfect patient positioning, or may be intentional, as in the case where a particular area of the breast (*e.g.*, the upper inner quadrant) may be of concern in a follow-up scan. The position of the nipple can be determined using CAD algorithms on the three-dimensional data volume based on nipple shadow effects. Alternatively, the nipple position may be identified manually by the technician at the time of scanning, *e.g.*, by ensuring that the nipple falls on a predetermined point on the compression plate, or by interacting with the scanning system based on a quick exploratory sweep across the breast by the probe, or by manually positioning the probe at the nipple location and pressing a nipple identification button, or by any of a variety of other manual nipple identification schemes.

[0062] FIG. 10 illustrates a breast ultrasound display 1002 according to a preferred embodiment, generally comprising an image area 1004 and a menu bar 1006. In the particular display of FIG. 10, an array of six thick-slice images 1008a-1008e is displayed, as well as two planar ultrasound images 1010a-1010b. The display 1002 can. be used in the viewing workstation 122 of FIG. 1, *supra.* The display 1002 can be used as part of a multi-modality PACS workstation, as a stand-alone device, and/or in conjunction with an x-ray mammography softcopy or hardcopy (*i.e.*, lightbox) viewing station.

[0063] FIG. 11 illustrates a closer view of the menu bar 1006 comprising a variety of controls and information displays relating to the image area 1004. Menu bar 1006 comprises a body marker icon 1102, cine control (soft) buttons 1103, a marker display button 1104, marker navigation buttons 1106, a bilateral comparison control button 1108, a somogram button 1110, an invert button 1112, and a variety of file control buttons 1114. A designation of "/N" (N = 2, 3, ...) on a view-related one of the file control buttons 1114 indicates that N sets of data are available for display for that view, *e.g.*, N scans were taken corresponding to that view. The number preceding the "/N" denotes which of those sets is being displayed.

[0064] The cine control buttons 1103 allow the viewer to start a slice-by-slice ultrasound view cine loop sequence of the current breast view. It will start at the current cursor location, moving toward a first edge of the breast volume. It will delay there for a short period of time, then restart at the other edge of the breast volume. Pressing any button or moving the mouse while the cine is active will stop the cine loop, leaving the cursor at its most recent cine position. The invert button 1112 enables toggling of the thick-slice images between two different grayscale mapping modes, one for a generally white-on-black image mode, and another for a generally black-on-white image mode.

[0065] The bilateral comparison control button 1108 allows the viewer to dynamically toggle between displaying a bilateral comparison view format, as described further *infra* with respect to FIGS. 15-16 and FIGS. 19-20, or thick-slice views of a single breast. The somogram button 1110 allows the viewer to toggle between a first configuration in which only planar views are shown, a second configuration in which only thick-slice images are shown, and a third configuration in which combinations of thick-slice images and planar images are shown.

[0066] The marker display button 1104 allows the viewer to toggle between (i) non-annotated versions of the displayed images, and (ii) versions showing bookmarks as described further *infra.* The marker navigation buttons 1106 allow the viewer to perform bookmark-centric navigation wherein, upon selection, there is automatically displayed a corresponding one of the thick-slice images associated with a location of a next bookmark (forward) or prior bookmark (backward), as well as a one or more planar ultrasound images corresponding to that location. The bookmarks themselves may be entered by the viewer using a simple right-click and pull-down menu process, although the scope of the preferred embodiments is not so limited. By way of example, bookmarks may be provided by other users, automatically generated according to archived data, or by any of a variety of other processes.

[0067] Although not shown in FIG. 1, in another preferred embodiment there is provided a CAD display button and CAD navigation buttons providing similar navigational functionality as the marker display button 1104 and the marker navigation buttons 1106. In still another preferred embodiment, a nipple marker display button is provided for toggling between displaying nipple markers, described further *infra,* and not displaying nipple markers.

[0068] Body marker icon 1102 is automatically generated and provides fast communication of several different aspects of the images being displayed. A text section 1116 communicates a compression angle (for non-frontal, *i.e.*, non-coronal, compression planes such as CC, MLO, LAT, etc.), a separation distance between compression plates (again for non-frontal compression planes), and a compression force used during the scans. The body marker icon 1102 further displays a compression plane 1117 against which the breast was compressed, a thick-slice depth marker 1118 corresponding to the depth of the displayed thick-slice image (when one thick-slice image is displayed), and a plane marker 1.120 corresponding to a planar ultrasound image being displayed, if applicable.

[0069] FIG. 12 illustrates body marker icons for various non-frontal compression scenarios. The body marker icon 1202 corresponds to a LAT view of the right breast, the body marker icon 1204 corresponds to a CC view of the right breast, and the body marker icon 1206 corresponds to an MLO view of the left breast.

[0070] FIG. 13 illustrates body marker icons 1302, 1304, and 1306 for various frontal compression scenarios, each comprising a probe sweep indicator (*e.g.*, 1303) indicating a trajectory and orientation of the linear scanning probe that scanned the breast. The body marker icon 1302 corresponds to a frontal scan of a medial side of the left breast in the inferior-to-superior direction, the body marker icon 1306 corresponds to a frontal scan of a medial side of the right breast in a direction close to the inferior-to-superior direction, and the body marker icon 1304 corresponds to a frontal scan of the center area of the left breast in a direction close to a lateral-to-medial direction.

[0071] FIG. 14 illustrates a single thick-slice image 1401, which corresponds to the thick-slice image 1008f when the cursor is clicked at the location indicated in FIG. 10. It is to be appreciated that the menu bar 1006 is preferably displayed below all images but is omitted in this and subsequent figures for clarity. FIG. 14 further illustrates planar ultrasound images 1406 and 1408 corresponding respectively to the plane indicators 1402 and 1404, which intersect at the current cursor location.

[0072] FIG. 15 illustrates a bilateral comparison array 1502 of thick-slice images that is accessed by selection of the bilateral comparison control button 1108, comprising members of an LMLO thick-slice image array as positionally paired with corresponding members of an RMLO thick-slice image array, wherein the slab-like subvolumes of the left breast corresponding to the LMLO thick-slice image array have an at least general positionwise association with the slab-like subvolumes of the right breast corresponding to the RMLO thick-slice image array. A body marker icon 1504 illustrates the scanning orientations and other scanning parameters associated with each of the volumetric scans.

[0073] FIG. 16 illustrates an expanded bilateral comparison view 1602 of the fourth thick=slice image pair of the bilateral comparison array 1502, which is displayed to when either of those fourth thick-slice images is clicked by the viewer on the display of FIG. 15. A body marker icon 1604 includes thick-slice depth markers 1606 showing the location of the fourth thick-slice subvolume within each of the left and right breasts. Nipple locations are also indicated on the body marker icon 1602.

[0074] Notably, it is not required that the associations between slab-like subvolumes of the left and right breasts be precise for the preferred embodiments of FIGS. 15-16. The opposing breasts can be of different sizes and there can be many incidental variations between the ways they were scanned. Nevertheless, it has been found highly useful to present thick-slice image data in bilateral comparison formats such as those of FIGS. 15-16. For example, breast symmetry is readily analyzed.

[0075] FIG. 17 illustrates an array of thick-slice images 1702, two planar images 1704a-b corresponding to a current cursor position 1708 on a selected thick-slice image, a body marker icon 1710, nipple markers 1706, and a frontal breast icon 1712 according to a preferred embodiment. The nipple markers 1706 can be placed on the thick-slice images according to any of (i) a manually-entered nipple position provided with the associated volumetric ultrasound scan, (ii) a computer-derived nipple position automatically generated from the associated volumetric ultrasound scan, (iii) a computer-derived nipple position automatically generated based on manual placement of a physical nipple token for the associated volumetric ultrasound scan, and (iv) a viewer-determined position for the nipple marker. Physical nipple token can refer to a marker placed on the skin of the breast at the nipple location that is at least partially transparent to ultrasound but that also provides a degree of obscuration sufficient for automatic identification of its presence. Examples can include small silicone toroids, optionally with specks of metal therein, or any of a variety of other objects that can have similar effects. Physical nipple token can alternatively refer to a such a marker placed on the ultrasound scanning device itself, *e.g.*, on one of the compression plates, at the nipple location.

[0076] Frontal breast icon 1712 comprises a cursor position indicator 1716 variably disposed thereon in a manner that reflects a relative position between the cursor 1708 and the nipple marker 1706 on the selected thick-slice image. Preferably, the frontal breast icon 1712 has a layout at least roughly resembling a clock face, and the cursor position indicator 1716 is positioned relative to the center of that clock face to reflect both (i) the distance "D" between the cursor 1708 and the nipple marker 1706, and (ii) the direction of the cursor 1708 from the nipple marker 1706 on the display (*e.g.*, about 1:00 in the example of FIG. 17). The location of the cursor position indicator 1716 dynamically moves on the clock face as the cursor 1708 is moved around the thick-slice image. The combined display of the frontal breast icon 1712 and the body marker icon 1710 facilitates quick, intuitive comprehension of the physical and positional relevance of the images being displayed. Frontal breast icon 1712 further comprises a text portion 1714 numerically indicating (i) the distance "D," and (ii) the depth of the currently selected thick-slice image from the compressed surface across which the ultrasound probe was swept..

[0077] FIG. 18 illustrates a thick-slice image 1802, two planar images 1804a-b corresponding to a current cursor position on the thick-slice image, a body marker icon 1810, nipple markers 1806, a plurality of bookmarks 1822, 1824, and 1826, and a frontal breast icon 1812. According to a preferred embodiment, the bookmarks are projected onto corresponding locations of the currently displayed planar images 1804a-b, if applicable, under an assumption that the bookmark spot is volumetrically in the middle plane of the slab-like subvolume corresponding to the thick-slice image. Accordingly, FIG. 18 illustrates corresponding bookmarks 1822' and 1824' on the superior-inferior planar image 1804b, because the bookmarks 1822 and 1824 lie along the vertical plane indicator 1825 passing through the current cursor location. The medial-lateral planar image 1804a only shows a corresponding bookmark 1822" because only the bookmark 1822 lies along the horizontal plane indicator 1827. Since neither plane indicator 1825 or 1827 intersects the bookmark

1826, there is no corresponding bookmark on the planar images 1804a-b for that bookmark.

[0078] The presence of all of the bookmarks can be toggled on and off by pressing the marker display button 1104. The marker navigation buttons 1106 allow the viewer to perform bookmark-centric navigation wherein, upon selection, the cursor is moved to a next bookmark (forward) or prior bookmark (backward), and the corresponding planar images are instantly displayed. As a default setting, navigation among the bookmarks is ordered in the same order as the bookmarks were entered by the viewer, although the scope of the preferred embodiments is not so limited. In the example of FIG. 18, the viewer has just pressed the one of the marker navigation buttons and has landed at the bookmark 1822. Notably, as indicated by the cursor position indicator 1816, the frontal breast icon 1812 keeps up automatically with the current cursor position, which in FIG. 18 is about 3 cm from the nipple marker location at a clock angle of roughly 4:00. The nipple markers and bookmarks can have any of a variety of shapes, sizes, colors, etc. without departing from the scope of the preferred embodiments.

[0079] FIG. 19 illustrates an array of thick-slice images 1902 with nipple markers 1906 that have been shifted by the viewer (using a click-and-drag method, for example). Although not necessarily warranted in this example (because the original position appears accurate based on nipple shadow positions), it may be desirable for the viewer to move the nipple marker location based on their observations, or on other extrinsic information. The position of the cursor 1908 relative to the nipple marker 1906 having shifted, the position of the cursor position indicator 1916 automatically shifts on the clock face of the frontal breast icon from 1916-old to 1916-new (*e.g.*, from about 0.5 cm at 12:00 to about 3 cm at 4:00).

[0080] FIG. 20 illustrates an array of thick-slice images 2002 with bookmarks 2010, 2011, 2012, and 2013 placed thereon, for illustrating a multi-slice bookmark-centric navigation process according to a preferred embodiment. By the viewer clicking on the forward marker navigation button 1106, the cursor is instantly taken to the next bookmark, and corresponding planar images (not shown) are displayed.

[0081] Generally speaking, as in the example of FIG. 20, there will often be bookmarks on several of the thick-slice images. Convenient navigation analogous to that shown in FIG. 20 is provided when only one of the thick-slice images is displayed at a time (see, *e.g.,* FIG. 14, *supra*). In particular, when only a single thick-slice image is being shown and one of the marker navigation buttons 1106 is pressed, the current thick-slice image is replaced (if applicable) with a next thick-slice image corresponding to a next bookmark, and the cursor is placed at the next bookmark in that thick-slice image with corresponding planar views being displayed. Rapid navigation among bookmarks is thereby achieved.

[0082] In another preferred embodiment, similar navigation capabilities are provided among CAD detections, *i.e.*, by the viewer clicking on a CAD navigation button, the cursor is instantly taken to the next CAD marker location, and corresponding planar images are displayed. Among other advantages, bookmark-centric and/or CAD-centric navigation according to the preferred embodiments can substantially reduce the time needed to examine a case and increase radiologist productivity.

[0083] FIG. 21 illustrates breast ultrasound volume processing and display according a preferred embodiment. At step 2102, nipple position is obtained either manually or in an automated manner relative to an acquired breast volume that is preferably chestwardly-compressed for head-on scanning. At step 2104, one or more thick-slice ultrasound images is displayed. At step 2106, nipple markers are shown on the thick-slice image(s), the nipple marker positions representing a projection of the nipple location thereupon. At step 2108, the current cursor position relative to the displayed nipple marker position is communicated on a clock face style icon. At step 2110, the viewer is allowed to change the nipple marker position relative to the breast volume through direct interaction on thick-slice image(s).

[0084] FIG. 22 illustrates breast ultrasound volume processing and display according a preferred embodiment. At step 2202, bookmarks are added via bookmarking commands, *e.g.*, through a right-click and drop-down menu style command upon a thick-slice image or a planar image. At step 2204, that bookmark location is associated with its corresponding location within the 3D breast volume. At step 2206, that bookmark is projected onto all relevant displayed thick-slice and planar ultrasound images as required to preoperly reflect its position in the 3D breast volume. If a marker navigation command is received at step 2208, then the display automatically navigates to a next bookmark location and shows the appropriate thick-slice image and corresponding planar images at step 2210.

[0085] FIG. 23 illustrates a bilateral comparison array 2302 of thick-slice images that is easily navigated to by selection of the bilateral comparison control button 1108, *supra,* comprising members of an LAP (left anterior-posterior) thick-slice image array as positionally paired with corresponding members of an RAP (right anterior-posterior) thick-slice image array, wherein the slab-like subvolumes of the left breast corresponding to the LAP thick-slice image array have an at least general positionwise association with the slab-like subvolumes of the right breast corresponding to the RAP thick-slice image array. A body marker icon 2304 illustrates the scanning orientations for each breast volume.

[0086] FIG. 24 illustrates examples of a virtual probe reconstruction (VPR) plane "S" around a point "P" within a breast volume 2402 according to a preferred embodiment. The viewer is provided with a pointing device, which can be the regular mouse in a particular mode, or which can be a separate joystick or similar control. With at least one thick-slice image and at least one planar image being displayed, the viewer can invoke a VPR command for the present cursor position. This causes the cursor to freeze at the present location "P" within the breast volume, wherein the viewer can then change the orientation of the plane "S" corresponding to the displayed planar image from a normal "vertical" position within the breast volume, see FIG. 24 at (i), to any of a variety of different orientations under control of the pointing device. For example, as indicated in FIG. 24, there is provided a roll capability, see FIG. 24 at (ii), a yaw capability, see FIG. 24 at (iii), and combinations of roll and yaw, see FIG. 24 at (iv).

[0087] FIG. 25 illustrates a full-breast composite thick-slice image 2502, corresponding planar images 2504a-b, a body marker icon 2510, and a frontal breast icon 2512 according to a preferred embodiment. Composite thick-slice image 2502 is preferably a CAD-enhanced expression of the sonographic properties of substantially the entire breast volume, *i.e.*, all of the tissue imaged by the volumetric ultrasound scans. Any of a variety of CAD algorithms can be used such as those discussed U.S. 6,317,617, *supra,* and those described in the commonly assigned WO 03/101303 A1, *supra.* The lesions can then be enhanced according to their likelihood of malignancy (or other metric of interest) on the composite thick-slice image 2502. The composite thick-slice image 2502 can serve as a useful "guide" or "road map" for viewing the planar ultrasound images and the other thick-slice images, and can optionally be provided with explicit CAD markings near the enhanced lesion locations.

[0088] FIG. 26 illustrates a display 2602 comprising a volume-rendered breast ultrasound volume 2604 with surface-rendered computer-assisted diagnosis (CAD) detections 2606 therein according to a preferred embodiment. A three-dimensional nipple marker 2608 is provided to properly orient the viewer in visualizing the breast volume. In one preferred embodiment, the volume-rendered breast ultrasound volume 2604 is rotated in a cine-like fashion, as indicated by the sequence A-D in FIG. 26.

[0089] Whereas many alterations and modifications of the present invention will no doubt become apparent to a person of ordinary skill in the art after having read the foregoing description, it is to be understood that the particular embodiments shown and described by way of illustration are in no way intended to be considered limiting. By way of example, although primarily described *supra* in the context of ultrasound imaging, it is to be appreciated that data from other full-field breast imaging modalities (*e.g.*, MRI, CT, PET) can be advantageously processed and displayed according to one or more of the described preferred embodiments. One or more of the displays described herein is similar to SOMOGRAM™ displays provided by U-Systems, Inc. of San Jose, California. By way of further example, although described *supra* as being volumetrically segregated, the coronal slab-like subvolumes from which the coronal thick-slice images are computed can be partially overlapping, which can be useful in dealing with lesions that would otherwise straddle the borders of the subvolumes. By way of even further example, although most nipple markers are described in the preferred embodiments *supra* in the context of coronal thick-slice images, in other preferred embodiments the nipple markers are shown on the MLO, CC, and other thick-slice image views.

[0090] By way of further example, it is to be appreciated that substantially parallel to a coronal plane is used herein to generally reflect the practical realities of situations such as head-on scanning of the breast, and that there may be some deviation from the plane of the chest wall. For example, for a particular patient having highly pendulous breasts it might be found most optimal to compress the breast at some small angle, such as 15 degrees, away from the plane of the chest wall. In this case, slab-like subvolumes that are taken parallel to the plane of compression would still be considered substantially parallel to the coronal plane.

[0091] By way of still further example, in alternative preferred embodiments the coronal slab-like subvolumes described *supra* can be replaced by thin-slice coronal images, *i.e.* thin-slice planar ultrasound images along planes substantially parallel to a coronal plane. This can be particularly useful in a follow-up diagnosis setting in which fine details are desired for viewing. By way of still further example, in another alternative preferred embodiment, the clinician is given the ability to interchangeably switch among, or pick-and-choose between, displaying the coronal slab-like subvolumes and the thin-slice coronal images.

Claims

1. A method for processing a three-dimensional data volume of a sonographic property of a breast, said three-dimensional data volume having been acquired from ultrasonic scans of the breast while the breast was compressed in a chestward direction, the method comprising:

   generating a plurality of two-dimensional coronal thick-slice images (212, 214) from the three-dimensional data volume, each coronal thick-slice image representing said sonographic property of the breast within a coronal slab-like subvolume (204, 206) thereof substantially parallel to a coronal plane, said coronal slab-like subvolume having a thickness between about 2 mm and 20 mm, wherein said generating comprises integrating the sonographic properties of at least two individual ultrasound slices lying within the coronal siab-like subvolume; and displaying said plurality of coronal thick-slice images on a user display (122).

2. The method of claim 1, said coronal slab-like subvolume (204) encompassing N individual ultrasound slices V_{xy}

$(z_1),\ldots V_{xy}(z_N)$, $N \geq 2$, wherein said two-dimensional coronal thick-slice image (212) $P_{COR}(x,y)$ is computed from said N individual ultrasound slices $V_{xy}(z_1),\ldots V_{xy}(z_N)$ according to a weighted summation algorithm designed such that lesions of a predetermined size range are emphasized.

3. The method of claim 1, further comprising:

generating a plurality of two-dimensional standard-plane thick-slice images (126, 128) from the three-dimensional data volume, said standard-plane thick-slice images representing said sonographic property of the breast within slab-like subvolumes thereof substantially parallel to a standard x-ray mammogram view plane; and
concurrently displaying said standard-plane thick-slice images (126, 128) and said coronal thick-slice images (124) on the user display (502).

4. The method of claim 3, wherein said standard x-ray mammogram view plane is the craniocaudal (CC) or the mediolateral oblique (MLO) view plane.

5. The method of claim 4, further comprising:

receiving an x-ray mammogram image (504, 506) of the breast corresponding to said standard x-ray mammogram view plane; and
concurrently displaying said x-ray mammogram image (504, 506) on said user display (502) with said concurrent display of said standard-plane thick-slice images (126, 128) and said coronal thick-slice images (124).

6. The method of claim 5, each coronal slab-like subvolumes being defined between first and second planes substantially parallel to said coronal plane; each slab-like subvolume having a said thickness of between about 2 mm and 20 mm as measured between said first and second planes.

7. The method of claim 6, said thickness being between about 4 mm and 10 mm.

8. The method of claim 7, wherein all of said coronal slab-like subvolumes have the same thickness.

9. The method of claim 8, wherein an average thickness of a first subset of said coronal slab-like subvolumes located closer to a chest wall is less than an average thickness of a second subset of said coronal slab-like subvolumes located farther from the chest wall, whereby detection of smaller structures nearer to the chest wall is facilitated.

10. The method of claim. 1, further comprising:

processing said three-dimensional data volume according to at least one computer-aided detection (CAD) algorithm to detect anatomical abnormalities in the breast;
associating said detected abnormalities with corresponding coronal thick-slice images based upon their relative position within the three-dimensional data volume; and
displaying annotations on said corresponding coronal thick-slice images according to type and location of detected anatomical abnormality.

Patentansprüche

1. Verfahren zur Verarbeitung eines dreidimensionalen Datenvolumens einer sonografischen Eigenschaft einer Brust, wobei das dreidimensionale Datenvolumen aus Ultraschallscans der Brust erfasst worden ist, während die Brust in einer Richtung zur Brust hin zusammengedrückt wurde, wobei das Verfahren umfasst:

Erzeugen mehrerer zweidimensionaler koronaler Thick-Slice-Bilder (212, 214) aus dem dreidimensionalen Datenvolumen, wobei jedes koronale Thick-Slice-Bild die sonografische Eigenschaft der Brust innerhalb eines plattenförmigen Teilvolumens (204, 206) derselben repräsentiert, das im Wesentlichen parallel zu einer koronalen Ebene ist, wobei das koronale plattenförmige Teilvolumen eine Dicke zwischen ungefähr 2 mm und 20 mm aufweist, wobei das Erzeugen das Integrieren der sonografischen Eigenschaften von mindestens zwei einzelnen Ultraschall-Schnittbildern umfasst, die innerhalb des koronalen plattenförmigen Teilvolumens liegen; und
Anzeigen der mehreren koronalen Thick-Slice-Bilder auf einem Benutzerdisplay (122).

2. Verfahren nach Anspruch 1, wobei das koronale plattenförmige Teilvolumen (204) N einzelne Ultraschall-Schnittbilder $V_{xy}(z_1)$, ..., $V_{xy}(z_N)$, $N \geq 2$, umfasst, wobei das zweidimensionale koronale Thick-Slice-Bild (212) $P_{COR}(x,y)$ aus den N einzelnen Ultraschall-Schnittbildern $v_{xy}(z_1)$, ..., $v_{xy}(z_N)$ gemäß einem Algorithmus der gewichteten Addition berechnet wird, der so gestaltet ist, dass Läsionen eines vorgegebenen Größenbereichen hervorgehoben werden.

3. Verfahren nach Anspruch 1, ferner umfassend:

Erzeugen mehrerer zweidimensionaler Standardebenen-Thick-Slice-Bilder (126, 128) aus dem dreidimensionalen Datenvolumen, wobei die Standa'rdebenen-Thick-Slice-Bilder die sonografische Eigenschaft der Brust innerhalb von plattenförmigen Teilvolumina derselben repräsentieren, die im Wesentlichen parallel zu einer standardmäßigen Röntgenmammogramm-Sichtebene sind; und
gleichzeitiges Anzeigen der Standardebenen-Thick-Slice-Bilder (126, 128) und der koronalen Thick-Slice-Bilder (124) auf dem Benutzerdisplay (502).

4. Verfahren nach Anspruch 3, wobei die standardmäßige Röntgenmammogramm-Sichtebene die Ebene der craniocaudalen Sicht (CC) oder der mediolateralen Schrägsicht (MLO) ist.

5. Verfahren nach Anspruch 4, ferner umfassend:

Empfangen eines Rontgenmammogramm-Bildes (504, 506) der Brust, welches der standardmäßigen Röntgenmammogramm-Sichtebene entspricht; und
gleichzeitiges Anzeigen des Röntgenmammogramm-Bildes (504, 506) auf dem Benutzerdisplay (502) mit der gleichzeitigen Anzeige der Standardebenen-Thick-Slice-Bilder (126, 128) und der koronalen Thick-Slice-Bilder (124).

6. Verfahren nach Anspruch 5, wobei jedes koronale plattenförmige Teilvolumen zwischen einer ersten und einer zweiten Ebene definiert ist, die im Wesentlichen parallel zu der koronalen Ebene sind, wobei jedes plattenförmige Teilvolumen die Dicke zwischen ungefähr 2 mm und 20 mm aufweist, gemessen zwischen der ersten und der zweiten Ebene.

7. Verfahren nach Anspruch 6, wobei die Dicke zwischen ungefähr 4 mm und 10 mm liegt.

8. Verfahren nach Anspruch 7, wobei die koronalen plattenförmigen Teilvolumina alle dieselbe Dicke aufweisen.

9. Verfahren nach Anspruch 8, wobei eine durchschnittliche Dicke einer ersten Teilmenge der koronalen plattenförmigen Teilvolumina, die sich näher an einer Brustwand befindet, kleiner ist als eine durchschnittliche Dicke einer zweiten Teilmenge der koronalen plattenförmigen Teilvolumina, die sich weiter entfernt von der Brustwand befindet, wodurch die Detektion kleinerer Strukturen, die sich näher an der Brustwand befinden, erleichtert wird.

10. Verfahren nach Anspruch 1, ferner umfassend:

Verarbeiten des dreidimensionalen Datenvolumens gemäß mindestens einem Algorithmus der computergestützten Detektion (Computer-aided detection, CAD), um anatomische Anomalien in der Brust zu detektieren;
Verknüpfen der detektierten Anomalien mit entsprechenden koronaren Thick-Slice-Bildern auf der Basis ihrer relativen Position innerhalb des dreidimensionalen Datenvolumens; und
Anzeigen von Beschriftungen auf den entsprechenden koronalen Thick-Slice-Bildern entsprechend Typ und Ort der detektierten anatomischen Anomalie.

Revendications

1. Procédé permettant de traiter un volume de données tridimensionnelles d'une caractéristique sonographique d'un sein, ledit volume de données tridimensionnelles ayant été acquis à partir d'analyses par ultrasons du sein alors que le sein était comprimé suivant une direction orientée vers le thorax, le procédé consistant à :

former une pluralité d'images coronales de tranches épaisses bidimensionnelles (212, 214) à partir du volume de données tridimensionnelles, chaque image coronale de tranche épaisse représentant ladite caractéristique sonographique du sein à l'intérieur d'un sous-volume coronal de type couche (204, 206) de celui-ci essentiellement parallèle à un plan coronal, ledit sous-volume coronal de type couche présentant une épaisseur comprise entre 2 mm et 20 mm environ, dans lequel ladite formation d'images comporte le fait d'intégrer les caractéristiques sonographiques d'au moins deux tranches individuelles d'ultrasons reposant à l'intérieur du sous-volume coronal de type couche ; et

afficher ladite pluralité d'images coronales des tranches épaisses sur un écran d'utilisateur (122).

2. Procédé selon la revendication 1, ledit sous-volume coronal de type couche (204) englobant N tranches individuelles d'ultrasons $V_{xy}(Z_1)$, ... $V_{xy}(Z_N)$, $N \geq 2$, dans lequel ladite image coronale bidimensionnelle de tranche épaisse (212) P_{COR} (x,y) est calculée à partir desdites N tranches individuelles d'ultrasons $V_{xy}(Z_1)$, ... $V_{xy}(Z_N)$ selon un algorithme de sommation pondérée conçu de telle sorte que des lésions d'une plage de dimensions prédéterminées se trouvent amplifiées.

3. Procédé selon la revendication 1, comprenant de plus :

la formation d'une pluralité d'images bidimensionnelles de tranches épaisses en plan standard (126, 128) à partir du volume de données tridimensionnelles, lesdites images de tranches épaisses en plan standard représentant ladite caractéristique sonographique du sein à l'intérieur de ses sous-volumes de type couche essentiellement parallèles à un plan d'examen standard d'une mammographie par rayons X ; et

l'affichage simultanément desdites images de tranches épaisses en plan standard (126, 128) et desdites images de tranches épaisses coronales (124) sur l'écran de l'utilisateur (502).

4. Procédé selon la revendication 3, dans lequel ledit plan d'examen d'une mammographie par rayons X standard est le plan d'examen craniocaudal (CC) ou médiolatéral oblique (MLO).

5. Procédé selon la revendication 4, comprenant, de plus:

la réception d'une image de mammographie par rayons X (504, 506) du sein correspondant au dit plan d'examen de mammographie par rayons X standard ; et

l'affichage simultanément de ladite image de la mammographie par rayons X (504, 506) sur ledit écran d'utilisateur (502) avec ledit affichage simultané desdites images de tranches épaisses en plan standard (126, 128) et lesdites images coronales de tranches épaisses (124).

6. Procédé selon la revendication 5, chaque sous-volume coronal de type couche étant défini entre des premier et second plans essentiellement parallèles au dit plan coronal, chaque sous-volume de type couche présentant une dite épaisseur comprise entre 2 mm et 20 mm environ telle que mesurée entre lesdits premier et second plans.

7. Procédé selon la revendication 6, ladite épaisseur se situant entre 4 mm et 10 mm environ.

8. Procédé selon la revendication 7, dans lequel l'ensemble desdits sous-volumes coronaux de type couche présente la même épaisseur.

9. Procédé selon la revendication 8, dans lequel une épaisseur moyenne d'un premier sous-ensemble desdits sous-volumes coronaux de type couche se trouvant plus près d'une paroi de thorax est inférieure à une épaisseur moyenne d'un second sous-ensemble desdits sous-volumes coronaux de type couche se trouvant plus éloignés de la paroi de thorax, de sorte que la détection de structures plus petites plus proches de la paroi du thorax est facilitée.

10. Procédé selon la revendication 1, comprenant, de plus:

le traitement dudit volume de données tridimensionnelles selon au moins un algorithme de détection assistée par ordinateur (CAD) en vue de détecter des anomalies anatomiques dans le sein ;

l'association desdites anomalies détectées à des images coronales correspondantes de tranches épaisses sur la base de leur situation relative à l'intérieur du volume de données tridimensionnelles ; et

l'affichage des annotations sur lesdites images coronales correspondantes de tranche épaisse selon le type et la situation de l'anomalie anatomique détectée.

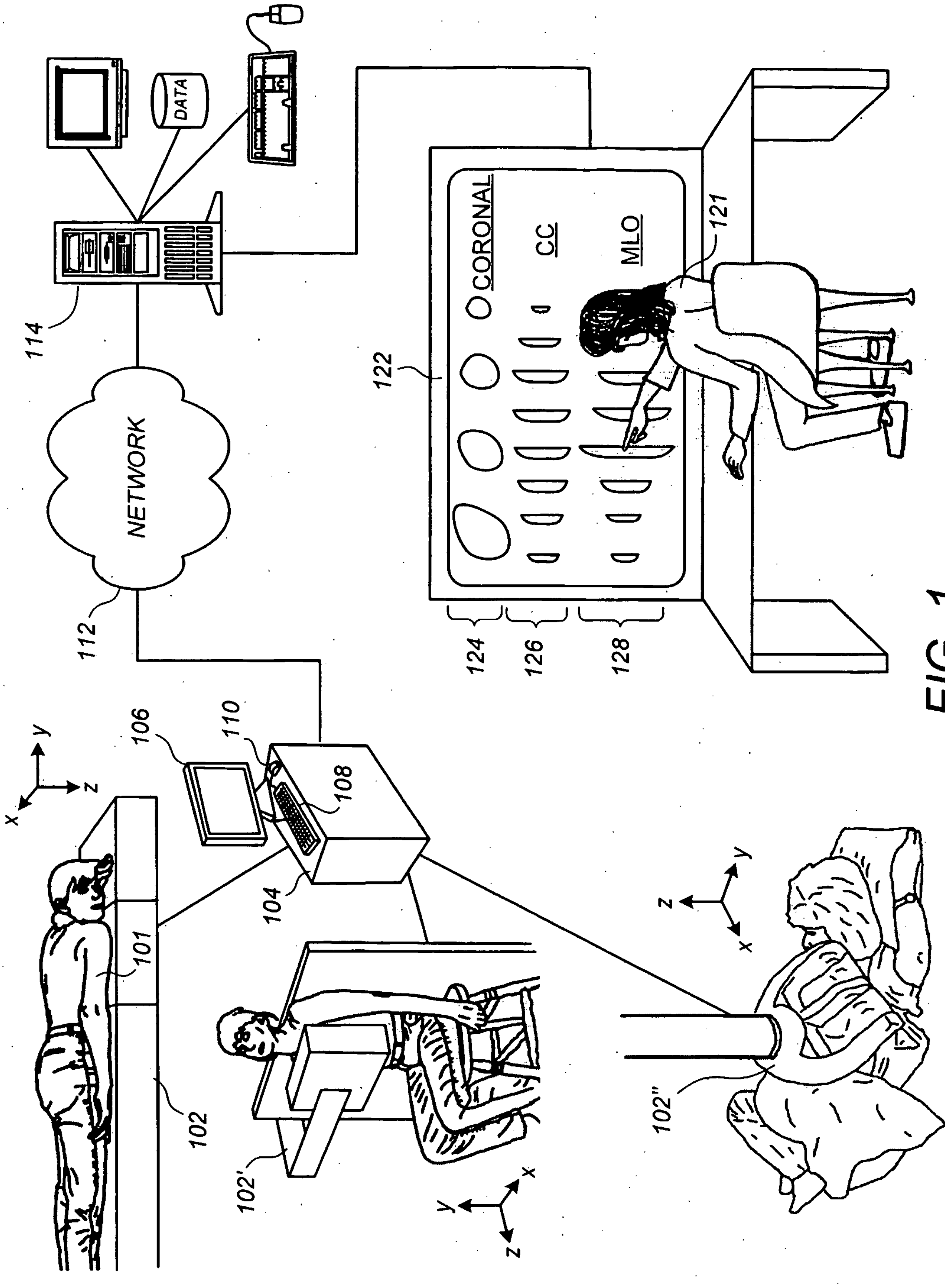

114
DATA
NETWORK
112
122
CORONAL
CC
MLO
121
124
126
128
106
110
108
104
101
102
102'
102''
x
y
z

FIG. 1

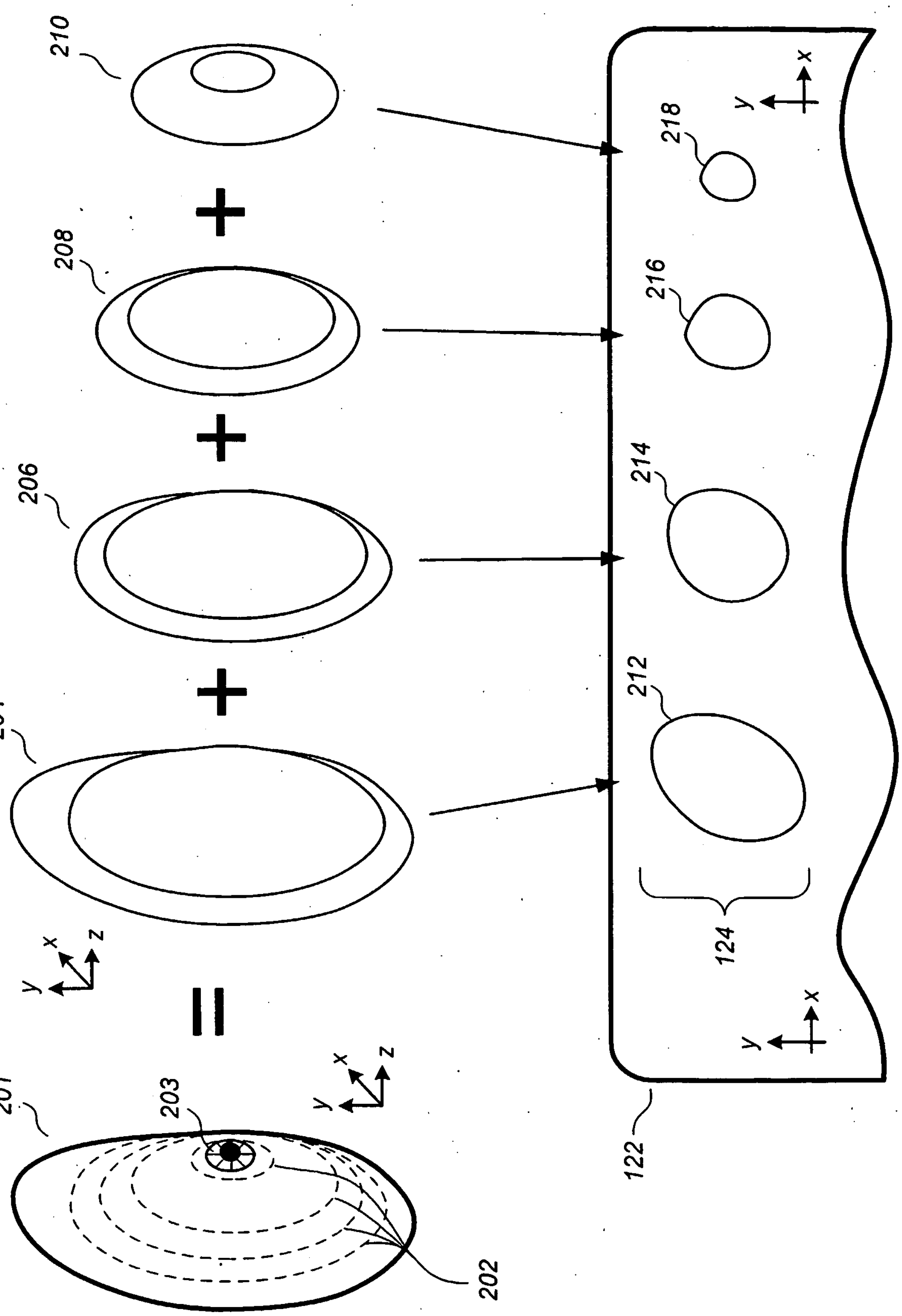


FIG. 2

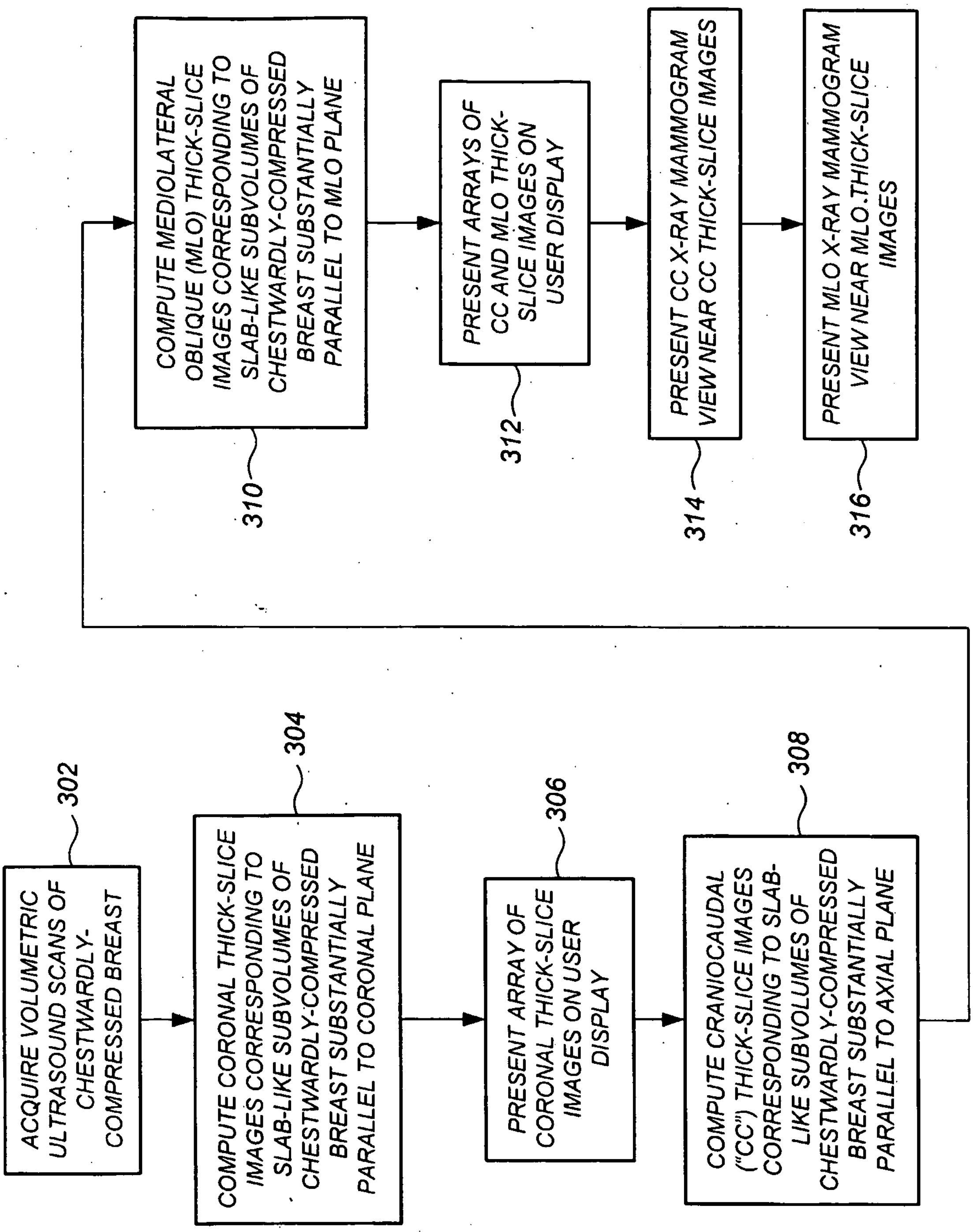

ACQUIRE VOLUMETRIC ULTRASOUND SCANS OF CHESTWARDLY-COMPRESSED BREAST
302
COMPUTE CORONAL THICK-SLICE IMAGES CORRESPONDING TO SLAB-LIKE SUBVOLUMES OF CHESTWARDLY-COMPRESSED BREAST SUBSTANTIALLY PARALLEL TO CORONAL PLANE
304
PRESENT ARRAY OF CORONAL THICK-SLICE IMAGES ON USER DISPLAY
306
COMPUTE CRANIOCAUDAL ("CC") THICK-SLICE IMAGES CORRESPONDING TO SLAB-LIKE SUBVOLUMES OF CHESTWARDLY-COMPRESSED BREAST SUBSTANTIALLY PARALLEL TO AXIAL PLANE
308
COMPUTE MEDIOLATERAL OBLIQUE (MLO) THICK-SLICE IMAGES CORRESPONDING TO SLAB-LIKE SUBVOLUMES OF CHESTWARDLY-COMPRESSED BREAST SUBSTANTIALLY PARALLEL TO MLO PLANE
310
PRESENT ARRAYS OF CC AND MLO THICK-SLICE IMAGES ON USER DISPLAY
312
PRESENT CC X-RAY MAMMOGRAM VIEW NEAR CC THICK-SLICE IMAGES
314
PRESENT MLO X-RAY MAMMOGRAM VIEW NEAR MLO.THICK-SLICE IMAGES
316

FIG. 3

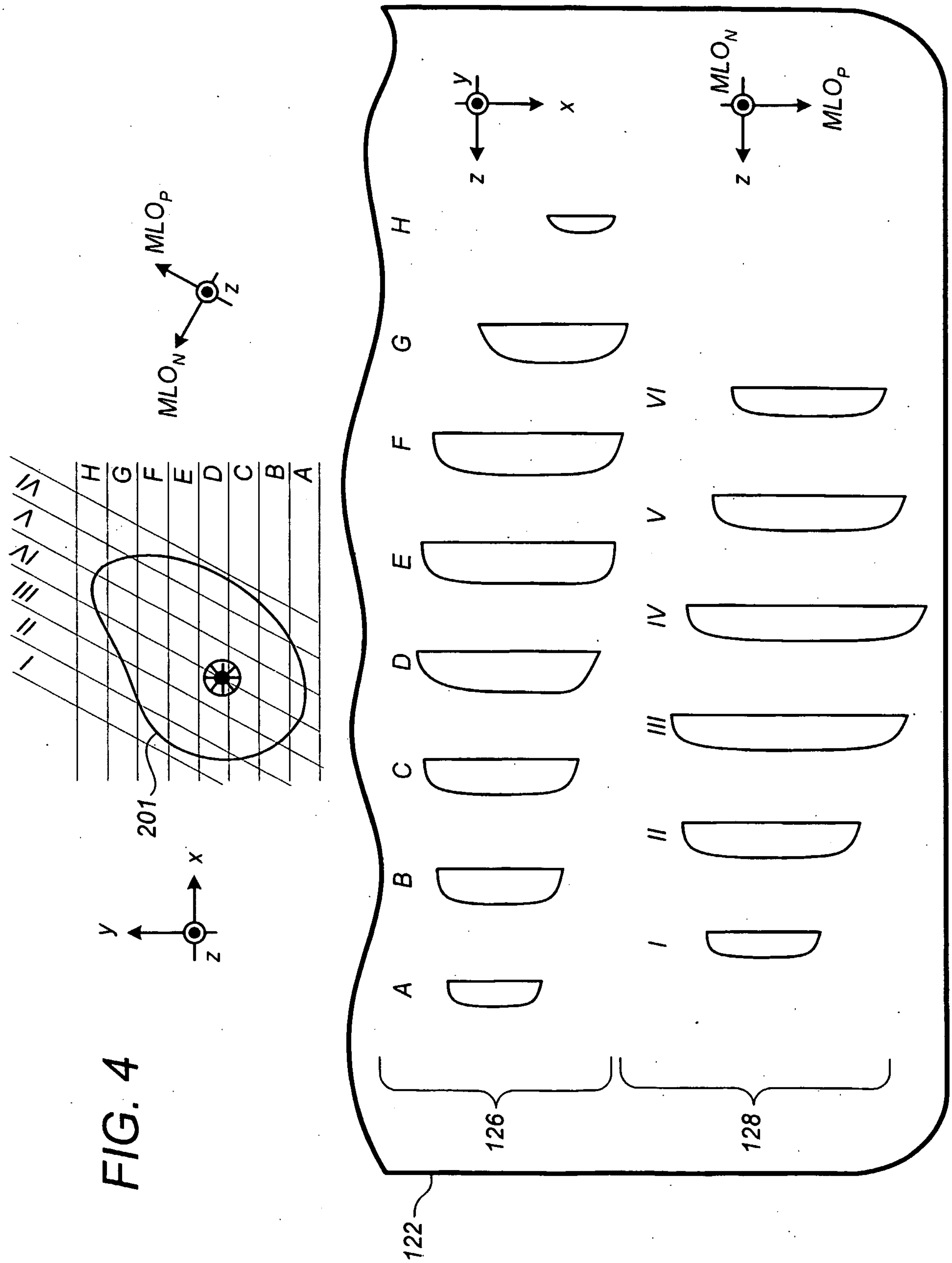


FIG. 4

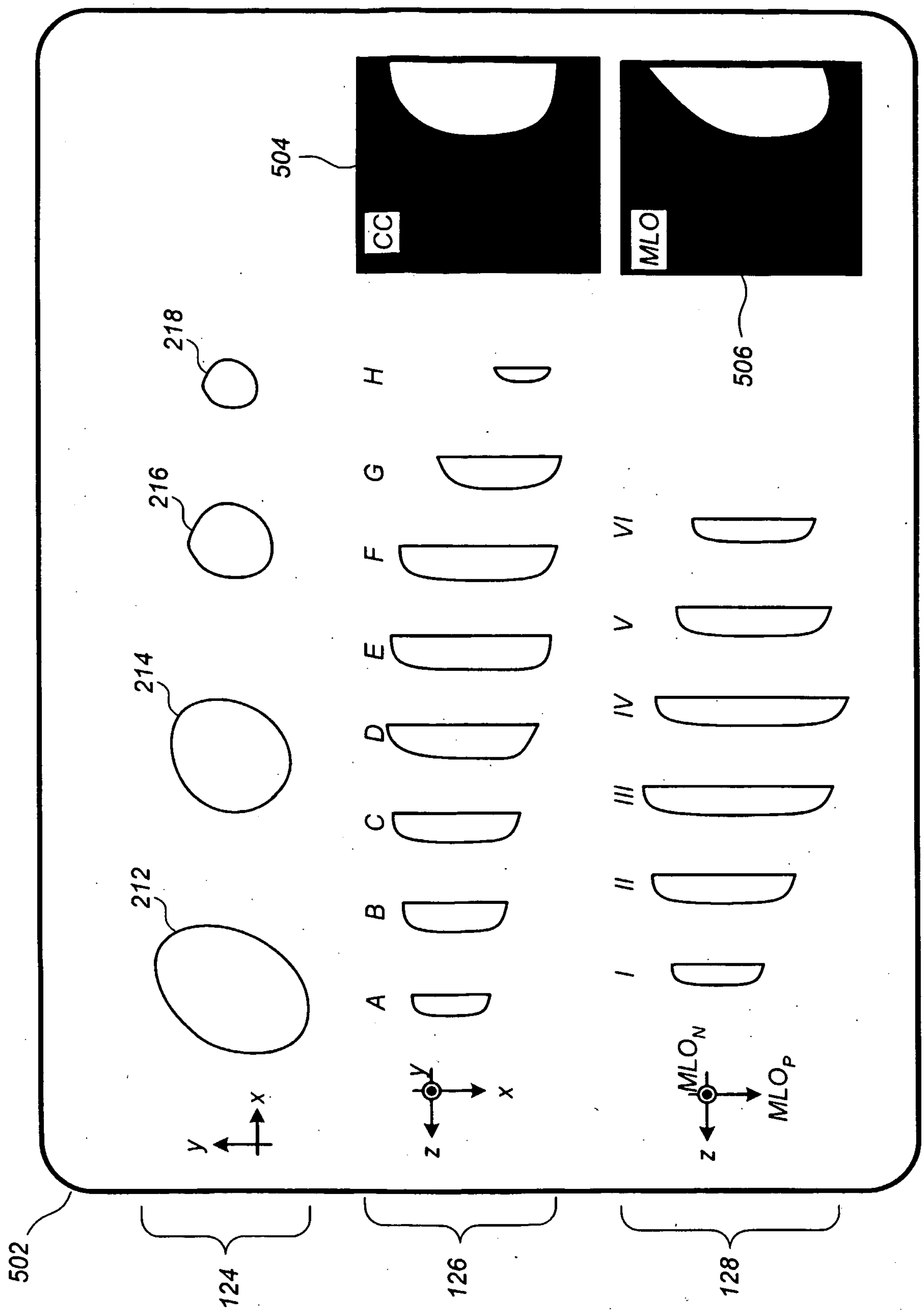

502
124
126
128
212
214
216
218
504
506
A
B
C
D
E
F
G
H
I
II
III
IV
V
VI
CC
MLO
x
y
z
MLON
MLOP

FIG. 5

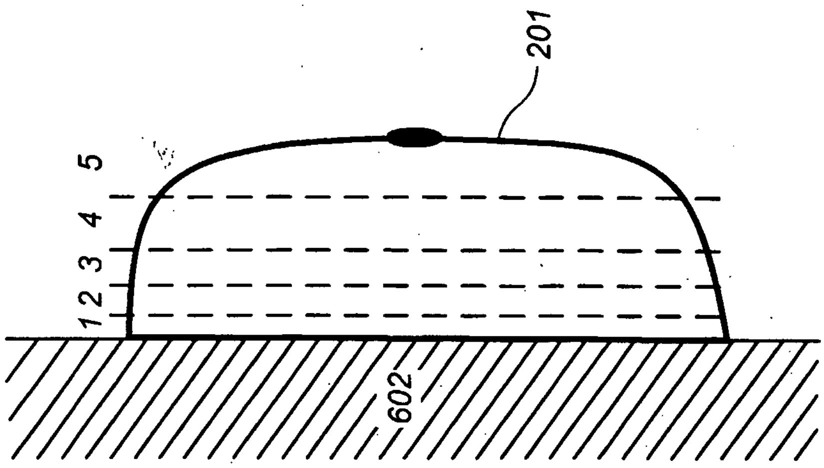


FIG. 6B

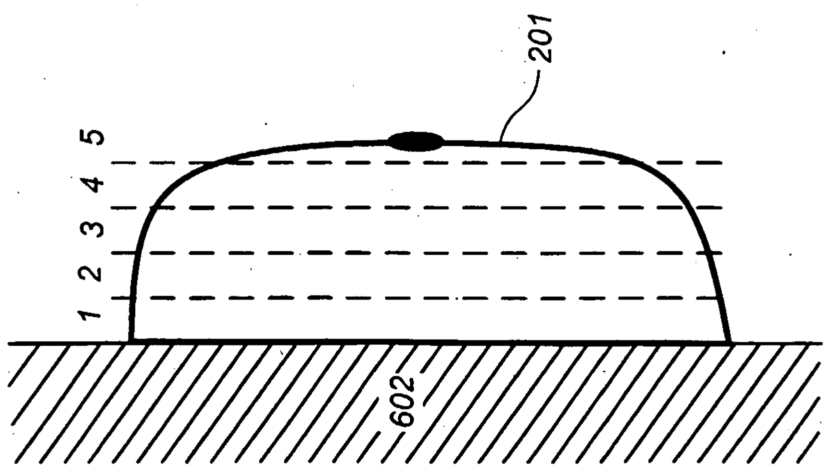


FIG. 6A

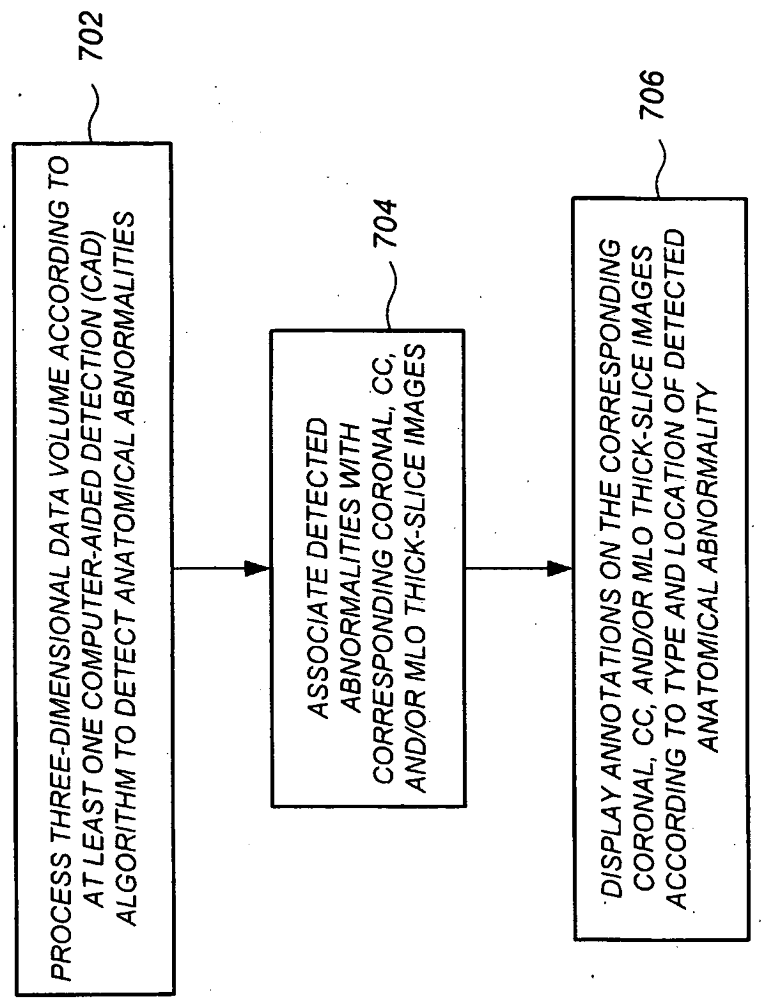

702
PROCESS THREE-DIMENSIONAL DATA VOLUME ACCORDING TO AT LEAST ONE COMPUTER-AIDED DETECTION (CAD) ALGORITHM TO DETECT ANATOMICAL ABNORMALITIES
704
ASSOCIATE DETECTED ABNORMALITIES WITH CORRESPONDING CORONAL, CC, AND/OR MLO THICK-SLICE IMAGES
706
DISPLAY ANNOTATIONS ON THE CORRESPONDING CORONAL, CC, AND/OR MLO THICK-SLICE IMAGES ACCORDING TO TYPE AND LOCATION OF DETECTED ANATOMICAL ABNORMALITY

FIG. 7

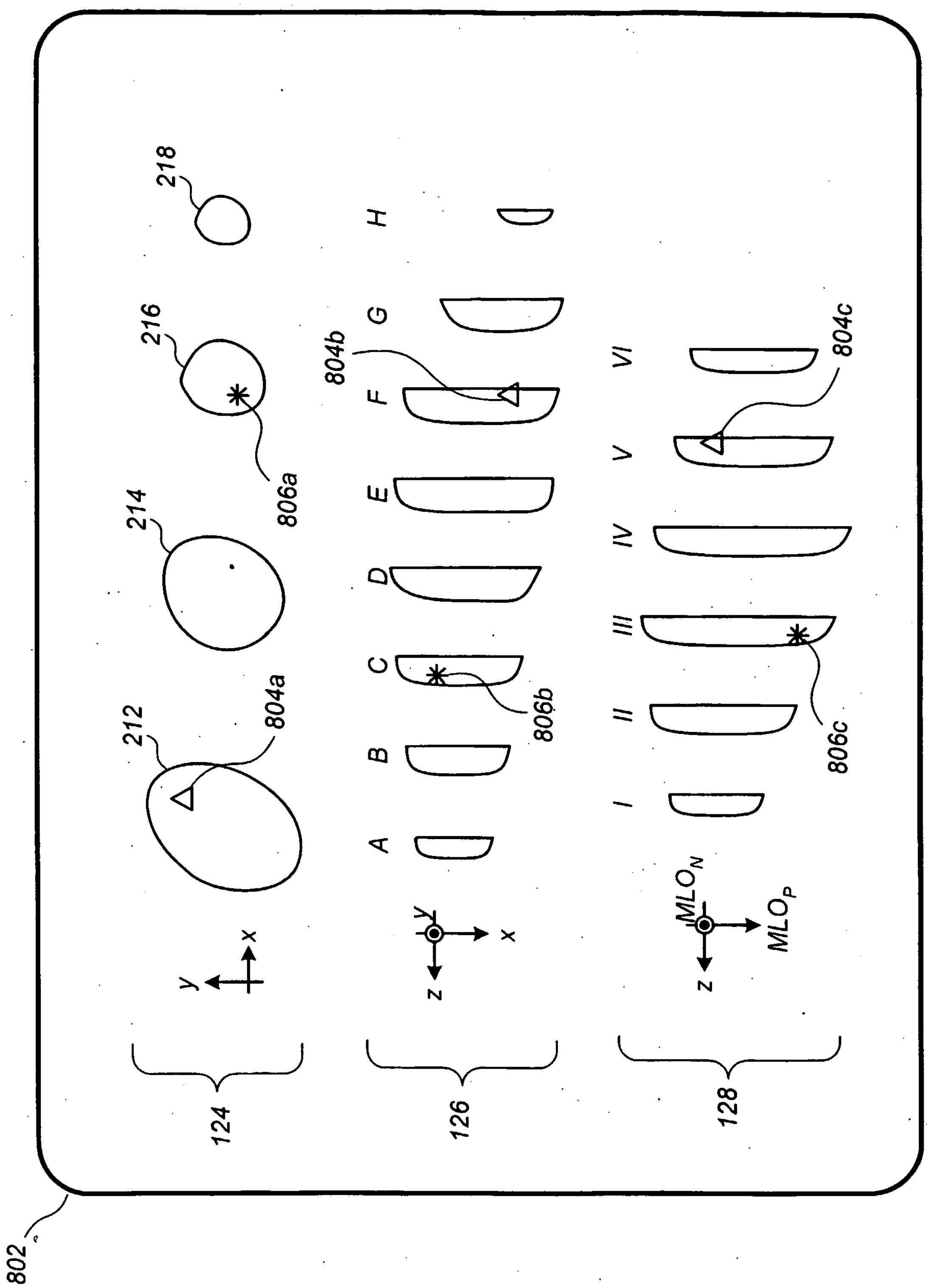

802
124
126
128
212
214
216
218
804a
806a
804b
806b
804c
806c
A
B
C
D
E
F
G
H
I
II
III
IV
V
VI
x
y
z
MLO_N
MLO_P

FIG. 8

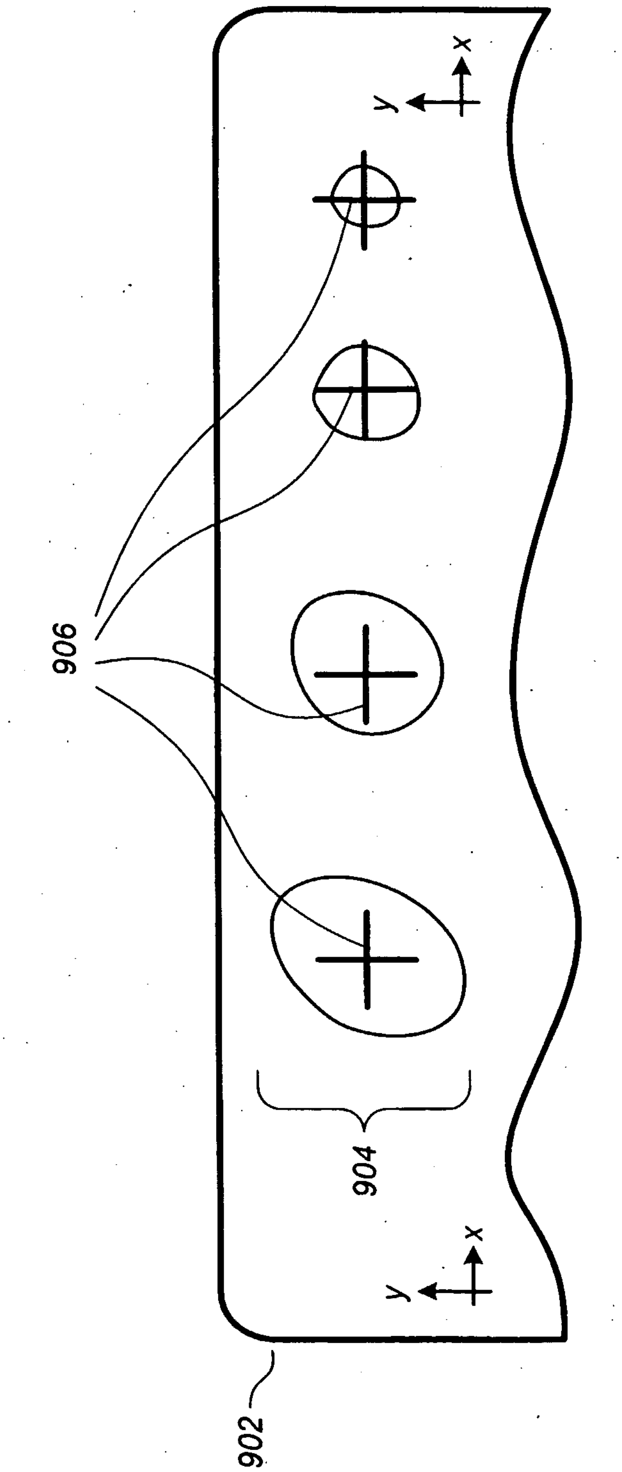


FIG. 9

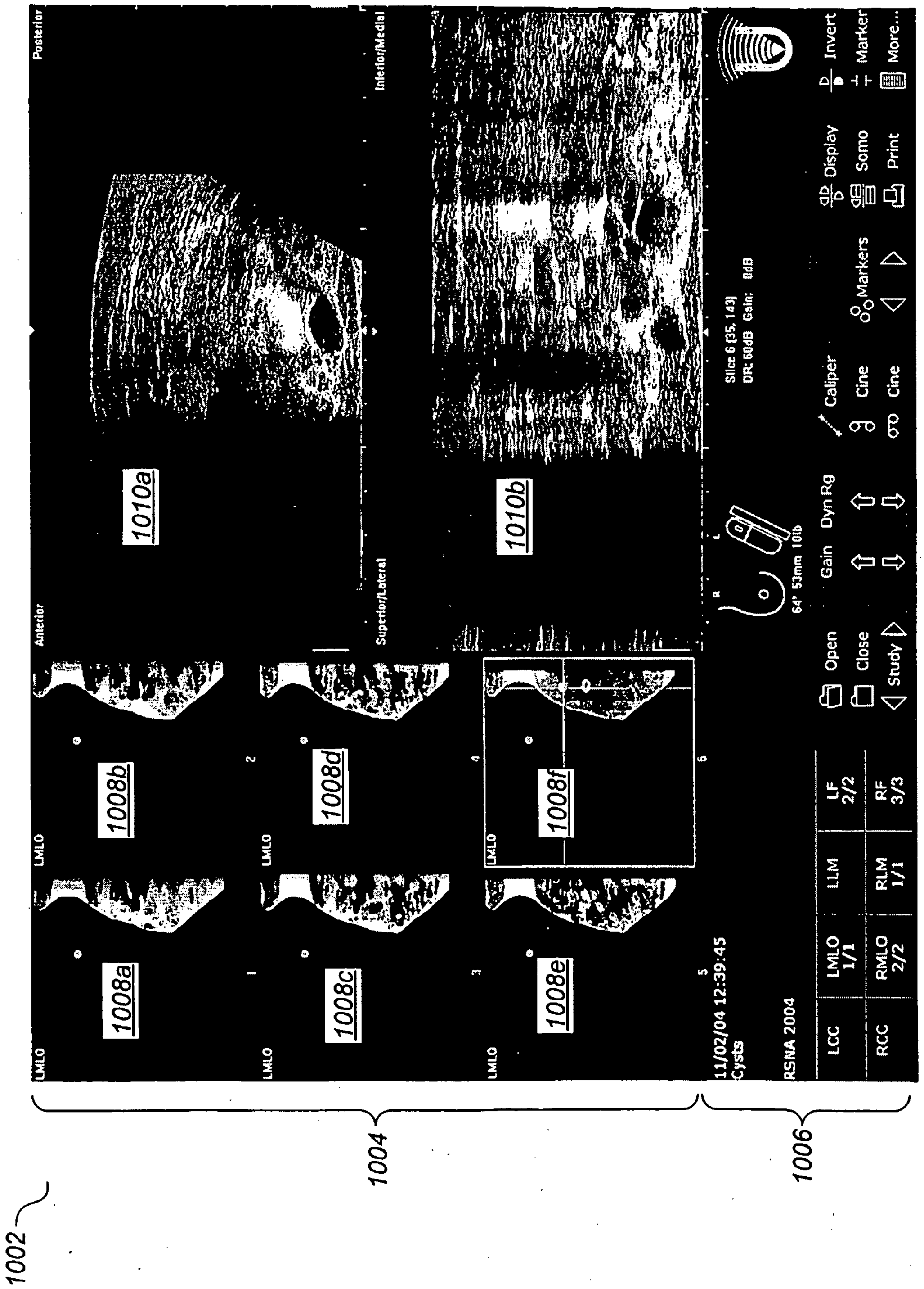

1002
1004
1006
1008a
1008b
1008c
1008d
1008e
1008f
1010a
1010b
LMLO
Anterior
Posterior
Superior/Lateral
Inferior/Medial
11/02/04 12:39:45
Cysts
RSNA 2004
LCC
LMLO 1/1
LLM
LF 2/2
RCC
RMLO 2/2
RLM 1/1
RF 3/3
Open
Close
Study
Gain
Dyn Rg
Caliper
Cine
Markers
Display
Somo
Print
Invert
Marker
More...

FIG. 10

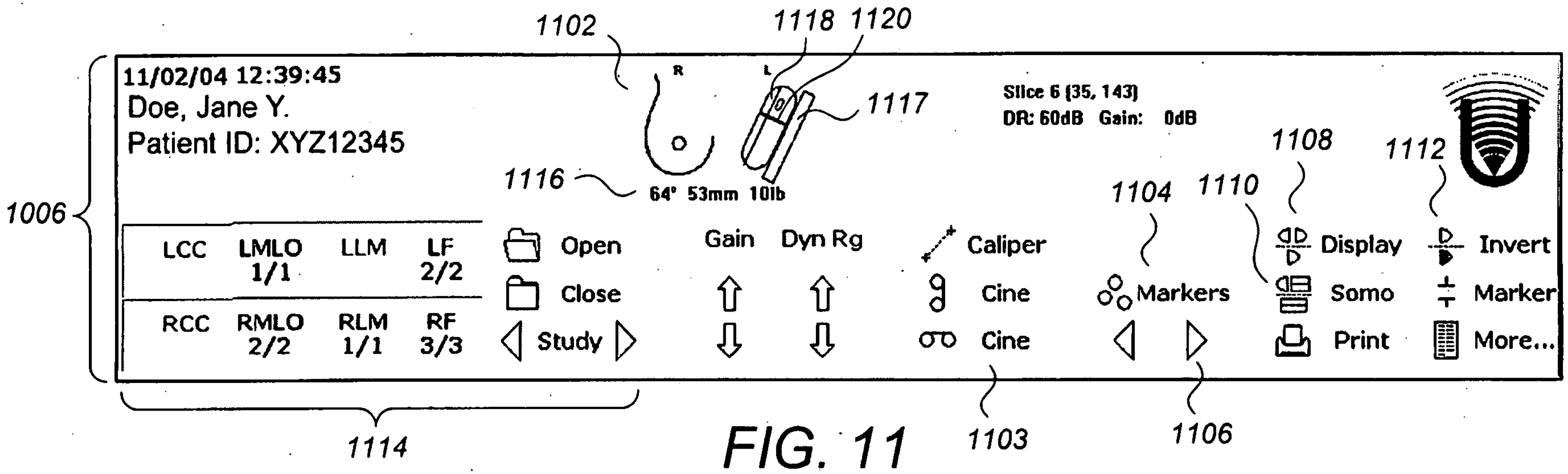


FIG. 11

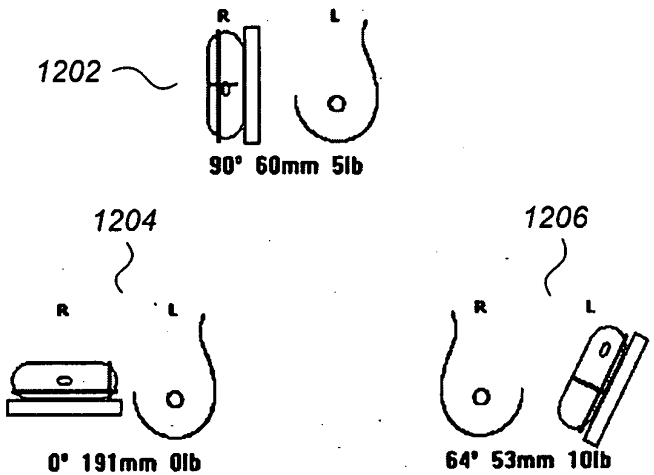


FIG. 12

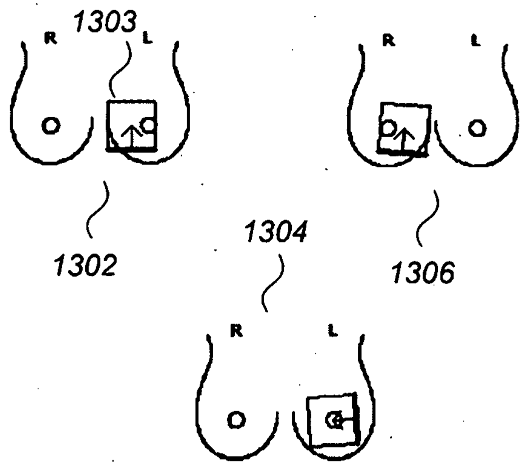


FIG. 13

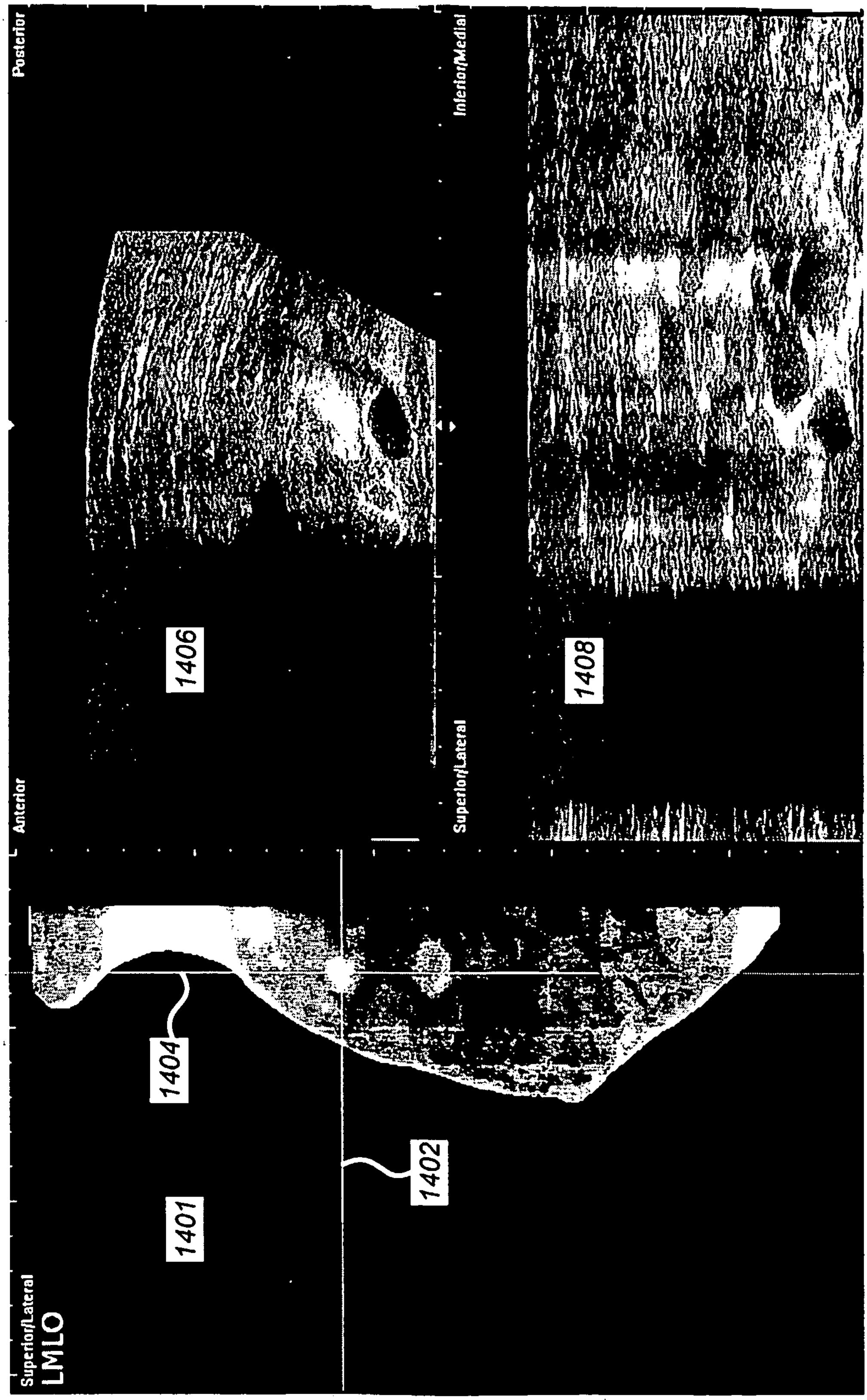

LMLO
Superior/Lateral
Anterior
Posterior
Superior/Lateral
Inferior/Medial
1401
1402
1404
1406
1408

FIG. 14

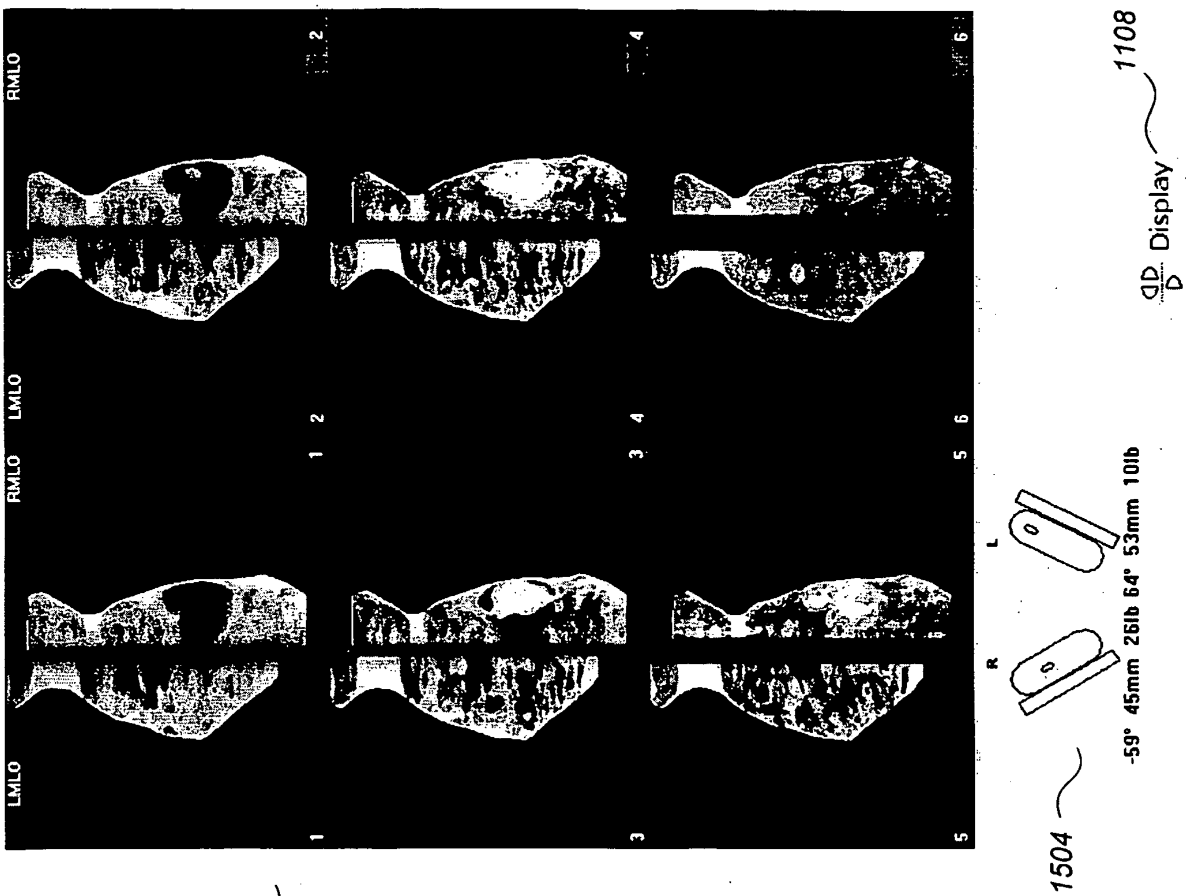
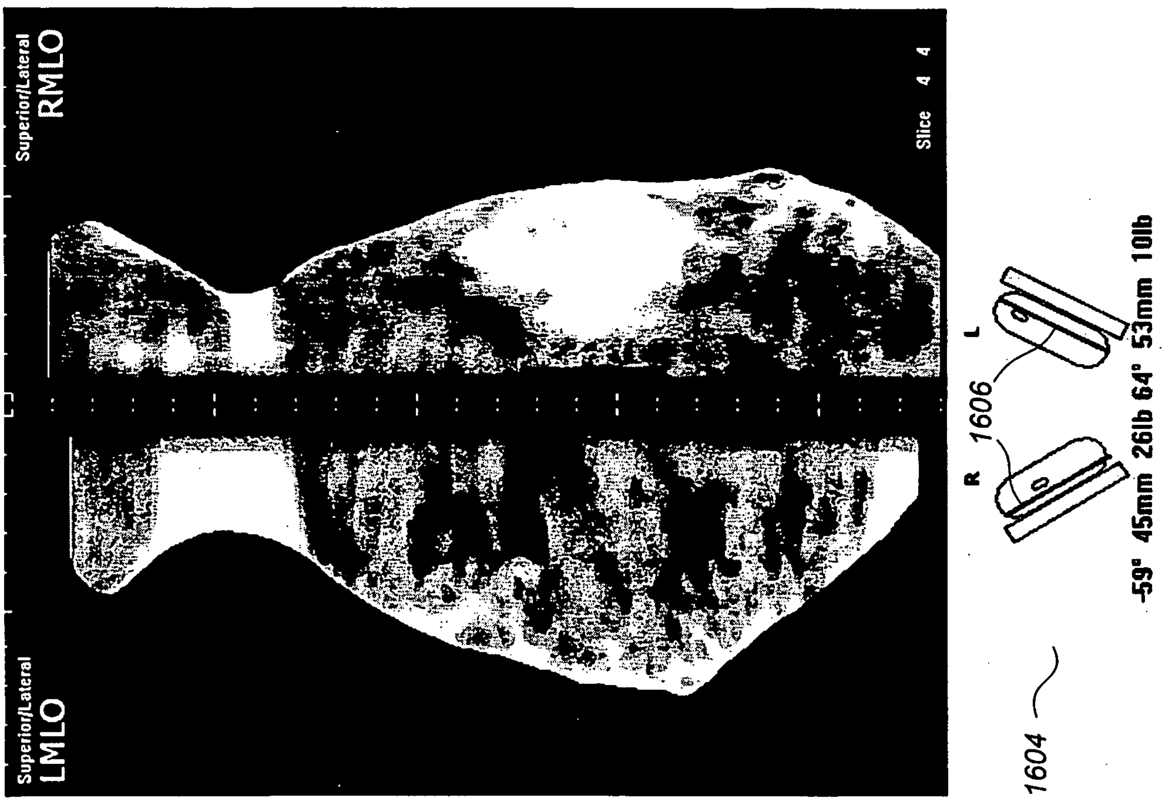

LMLO
RMLO
1
2
3
4
5
6
R
L
-59° 45mm 26lb 64° 53mm 10lb
dD/D Display
1108
1502
1504

FIG. 15



1602

1604

FIG. 16

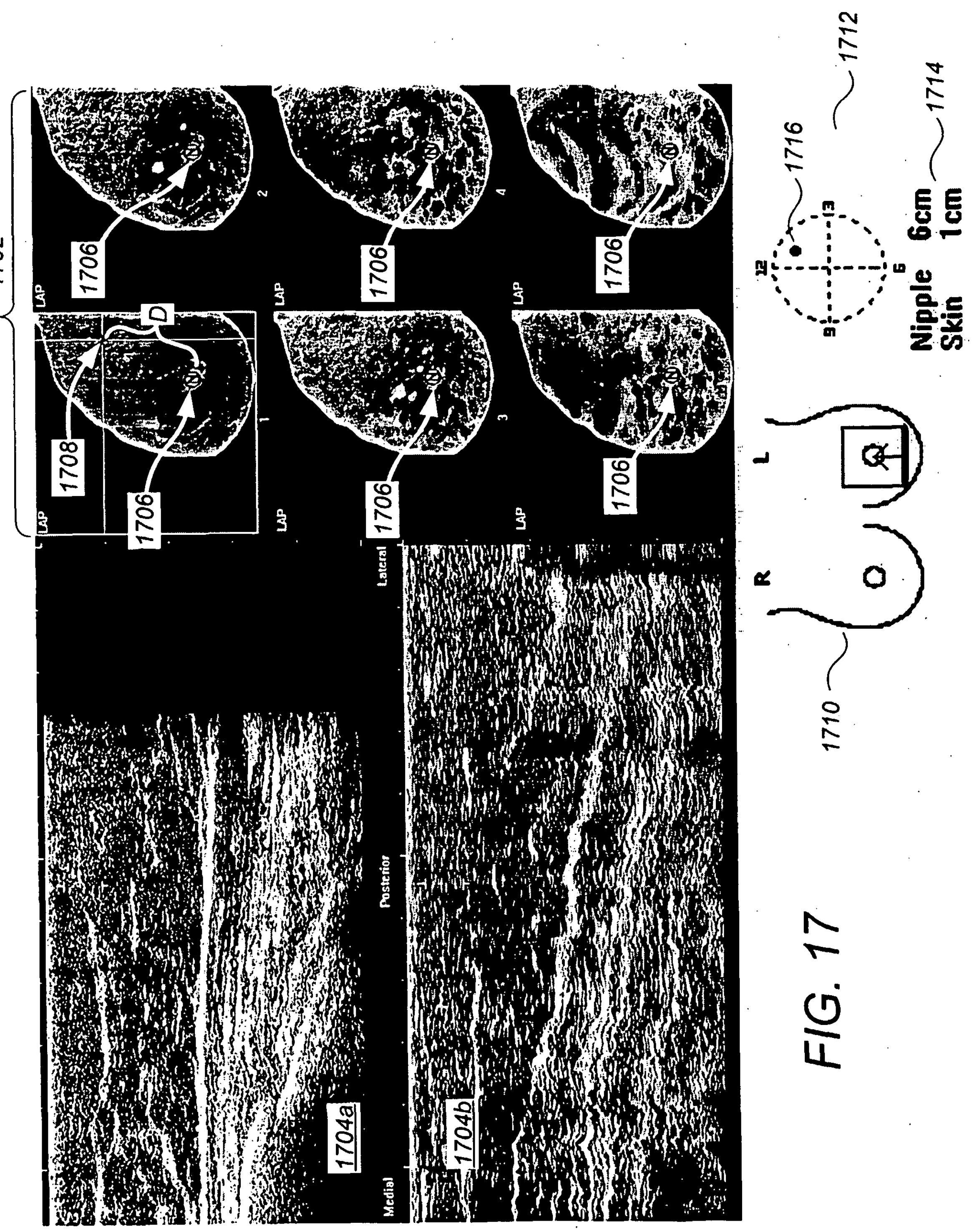

1702
1706
1708
D
LAP
1
2
3
4
1704a
1704b
Medial
Posterior
Lateral
R
L
1710
1712
1714
1716
12
3
6
9
Nipple 6cm
Skin 1cm

FIG. 17

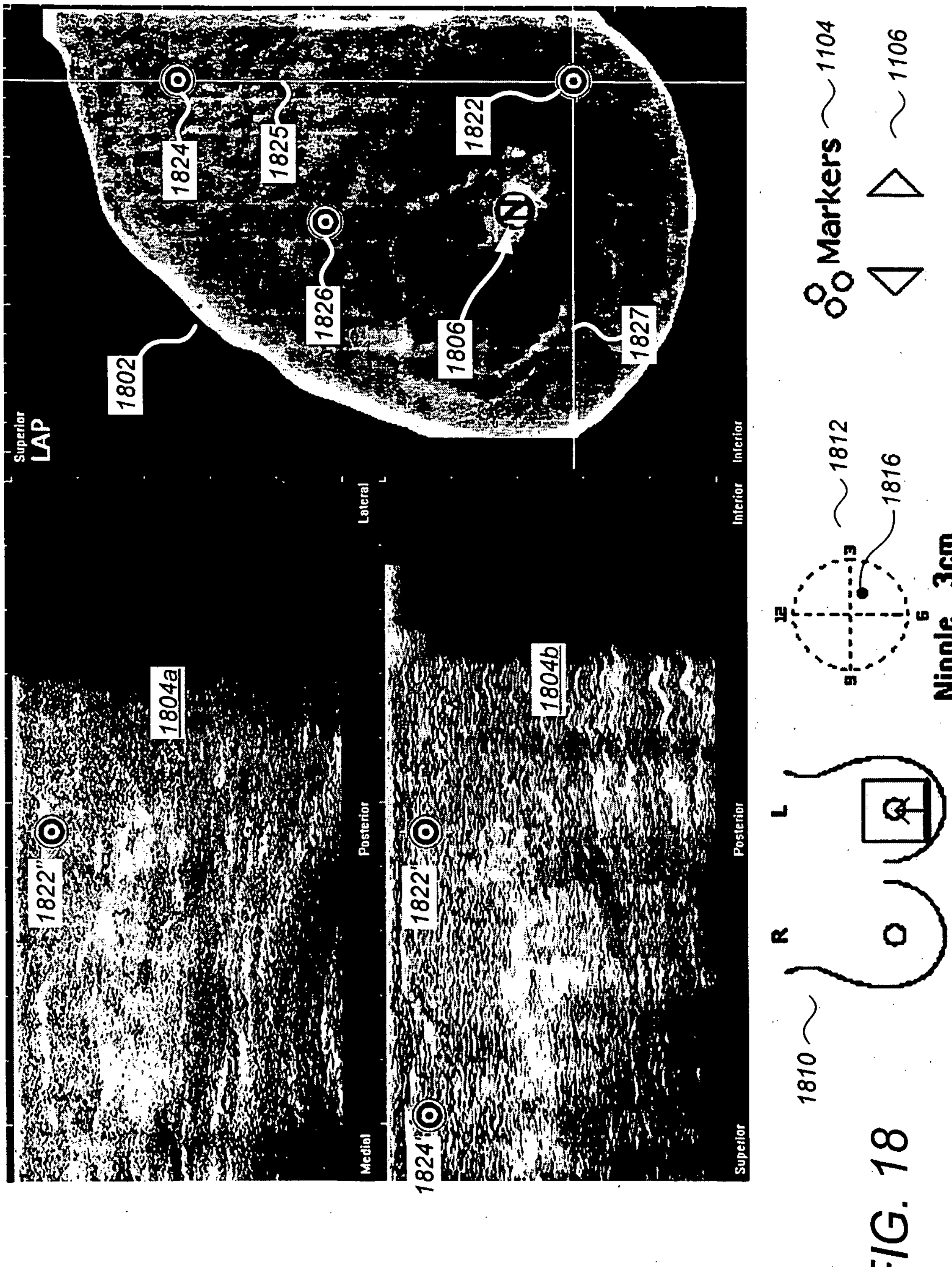

Superior
LAP
1802
1824
1825
1826
1822
1806
1827
Lateral
Inferior
Medial
Posterior
Superior
1804a
1804b
1822''
1822'
1824'
Markers
1104
1106
1812
1816
12
9
6
13
Nipple 3cm
Skin 1cm
R
L
1810

FIG. 18

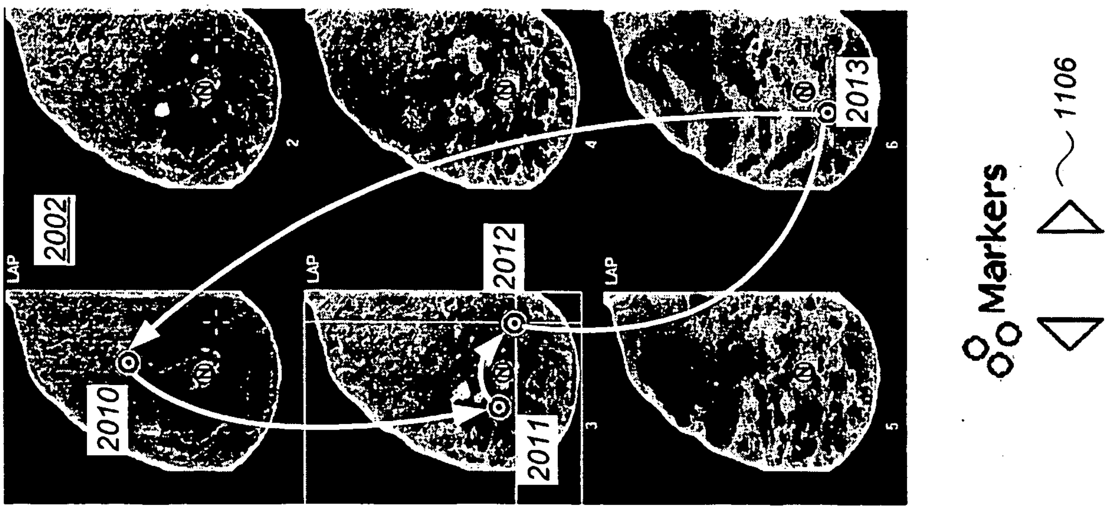

LAP
2002
2010
2011
2012
2013
Markers
1106

FIG. 20

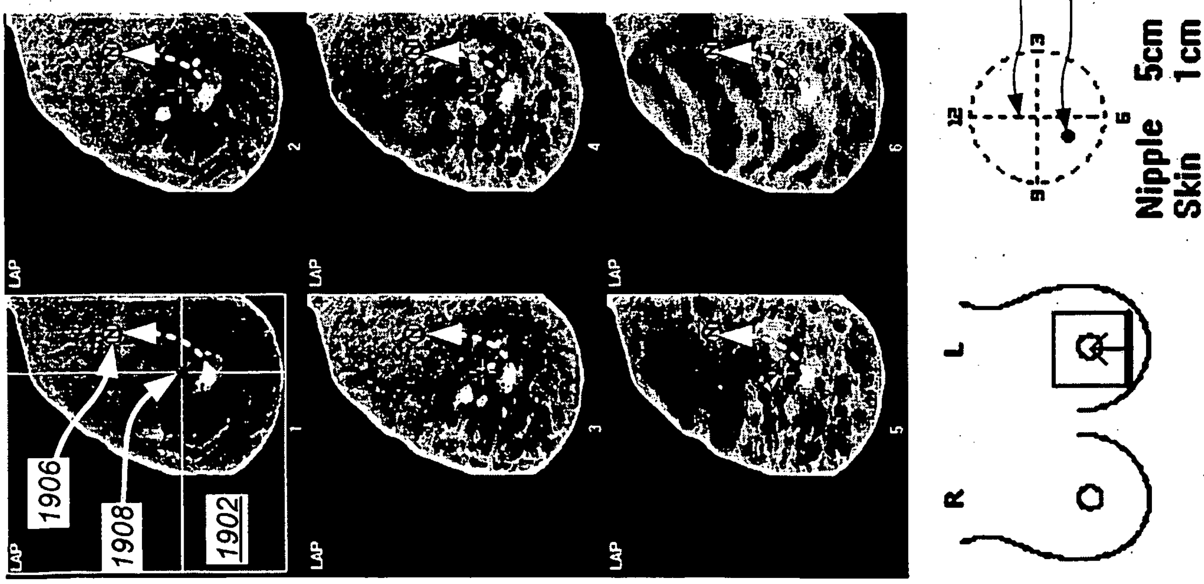

LAP
1906
1908
1902
R
L
1916-old
1916-new
Nipple 5cm
Skin 1cm

FIG. 19

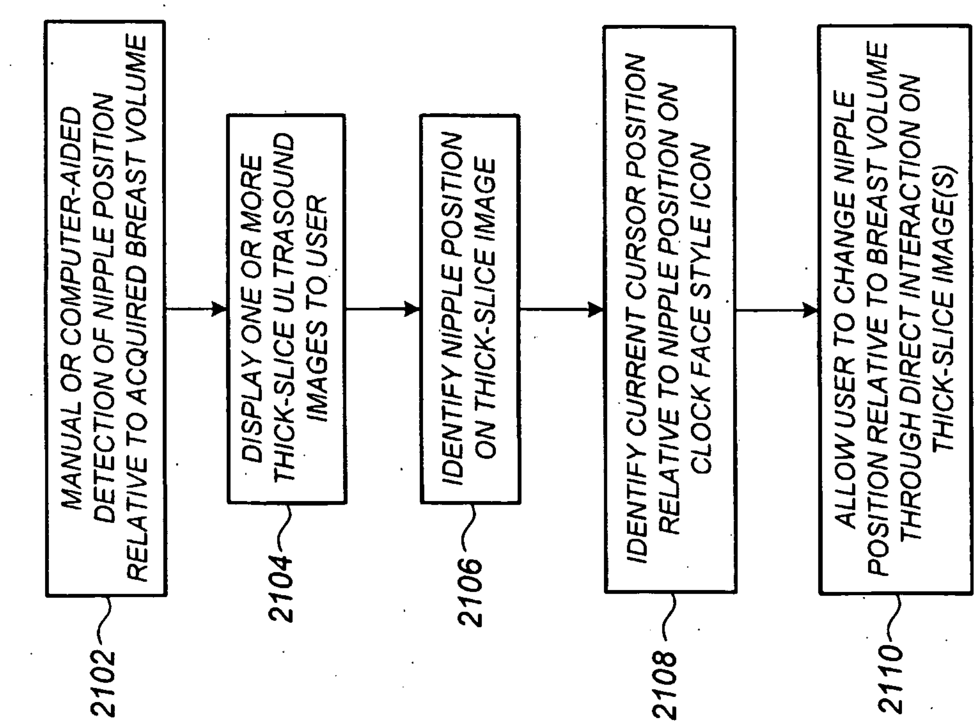

2102
MANUAL OR COMPUTER-AIDED DETECTION OF NIPPLE POSITION RELATIVE TO ACQUIRED BREAST VOLUME
2104
DISPLAY ONE OR MORE THICK-SLICE ULTRASOUND IMAGES TO USER
2106
IDENTIFY NIPPLE POSITION ON THICK-SLICE IMAGE
2108
IDENTIFY CURRENT CURSOR POSITION RELATIVE TO NIPPLE POSITION ON CLOCK FACE STYLE ICON
2110
ALLOW USER TO CHANGE NIPPLE POSITION RELATIVE TO BREAST VOLUME THROUGH DIRECT INTERACTION ON THICK-SLICE IMAGE(S)

FIG. 21

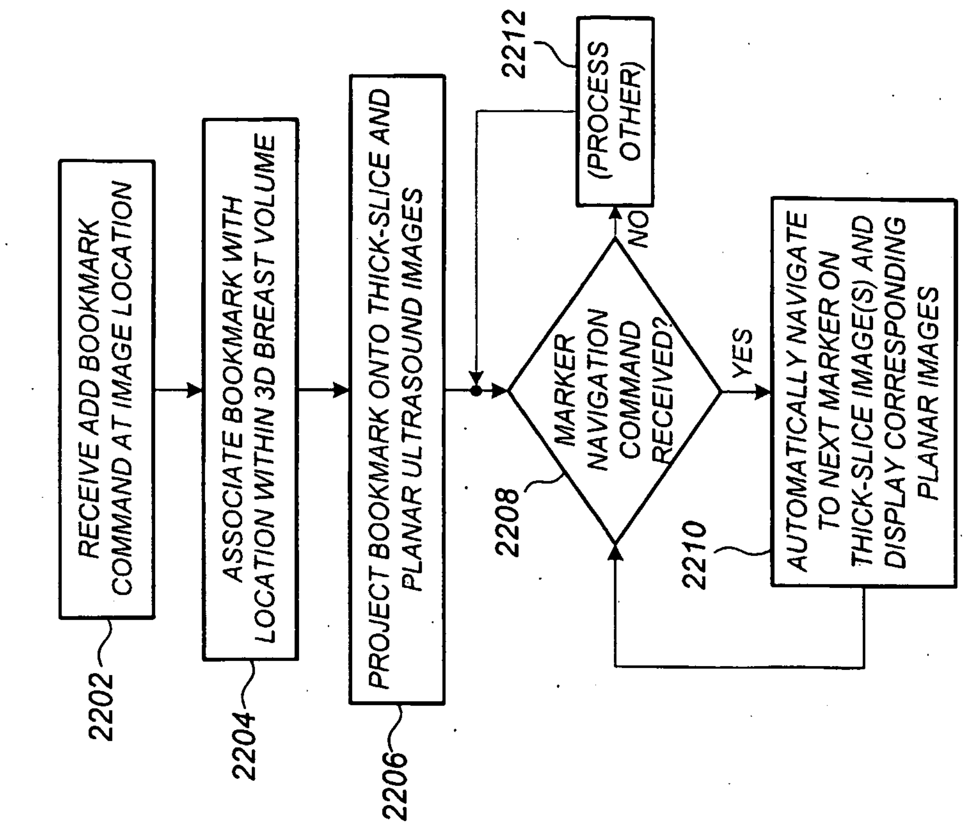

2202
RECEIVE ADD BOOKMARK COMMAND AT IMAGE LOCATION
2204
ASSOCIATE BOOKMARK WITH LOCATION WITHIN 3D BREAST VOLUME
2206
PROJECT BOOKMARK ONTO THICK-SLICE AND PLANAR ULTRASOUND IMAGES
2208
MARKER NAVIGATION COMMAND RECEIVED?
NO
YES
2212
(PROCESS OTHER)
2210
AUTOMATICALLY NAVIGATE TO NEXT MARKER ON THICK-SLICE IMAGE(S) AND DISPLAY CORRESPONDING PLANAR IMAGES

FIG. 22

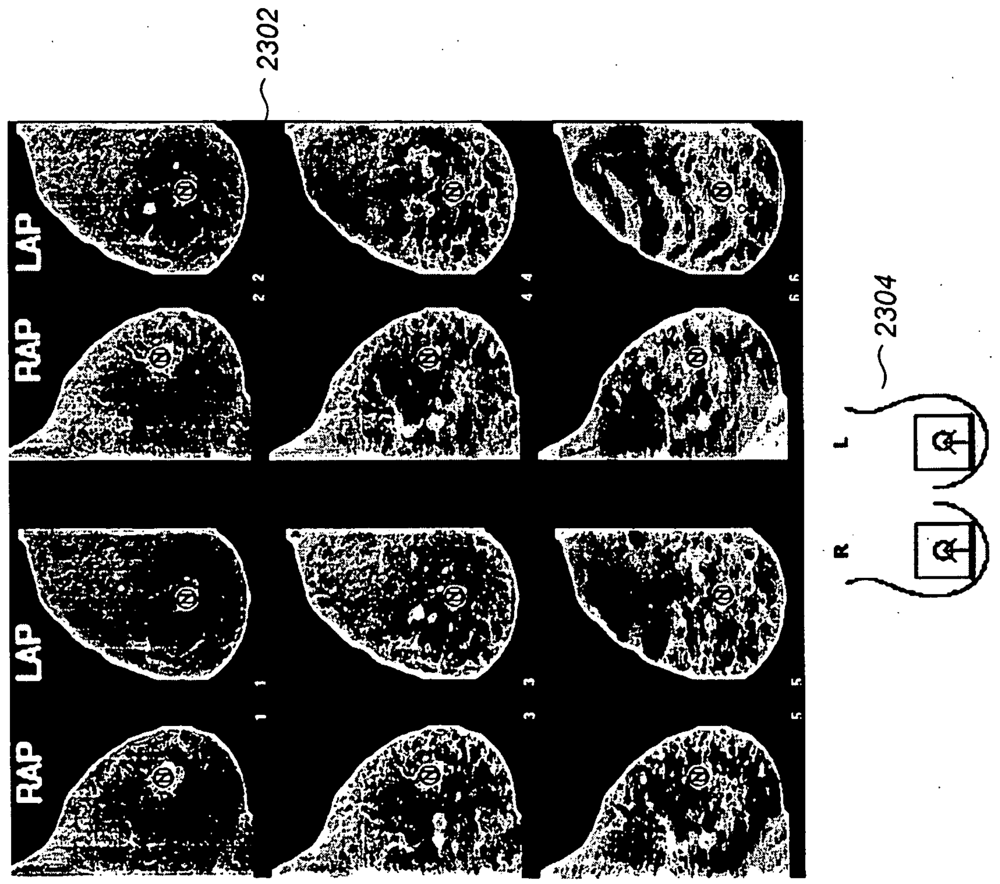


FIG 23

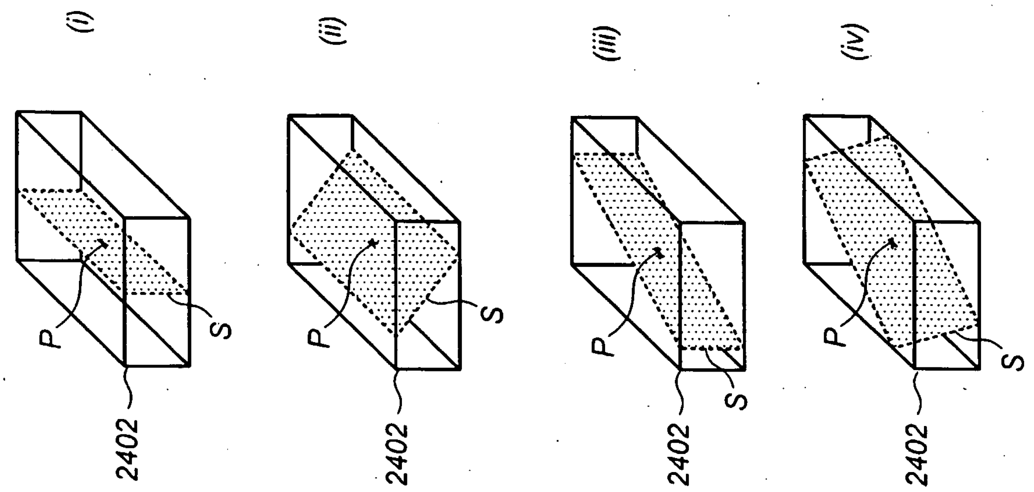


FIG 24

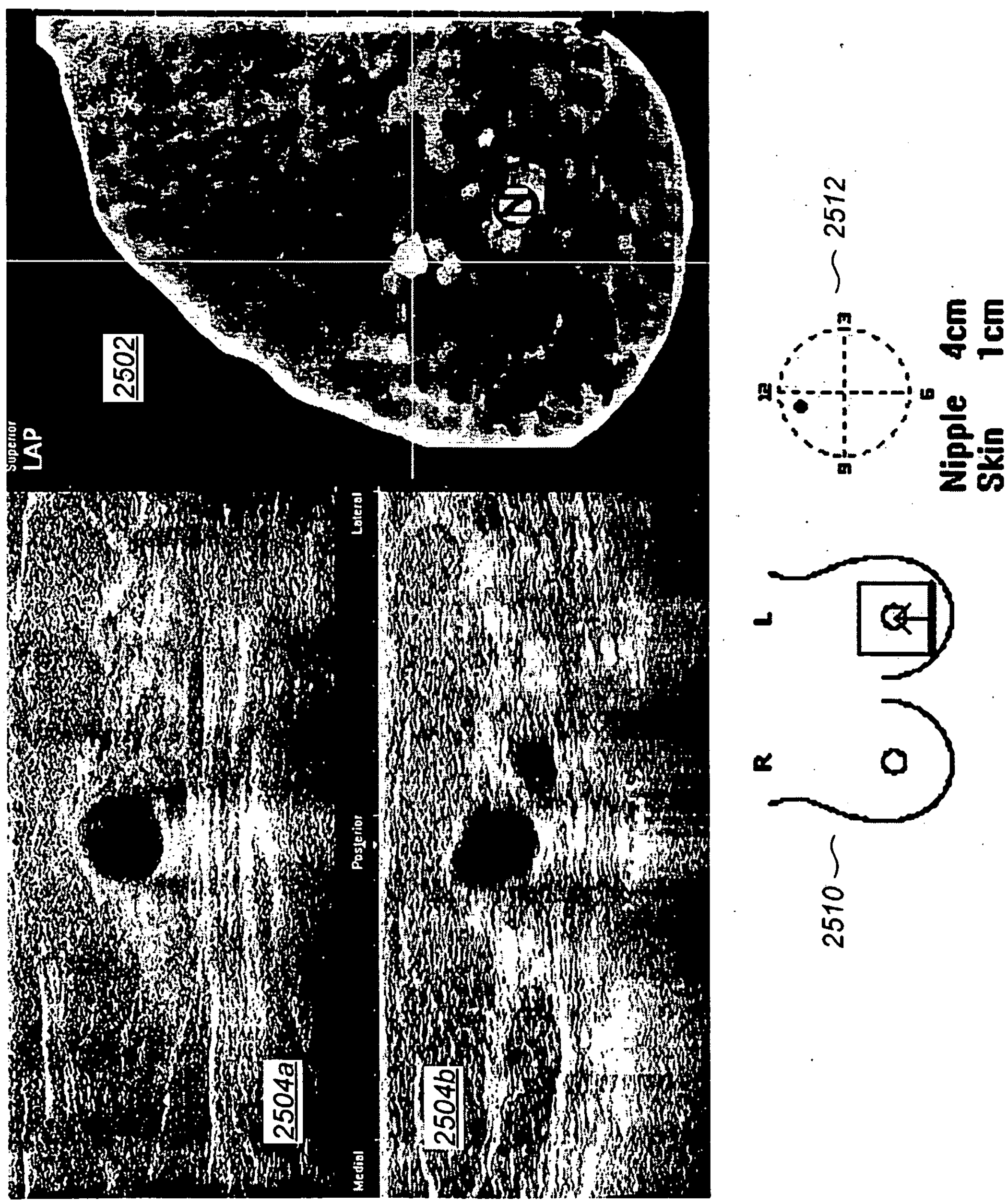
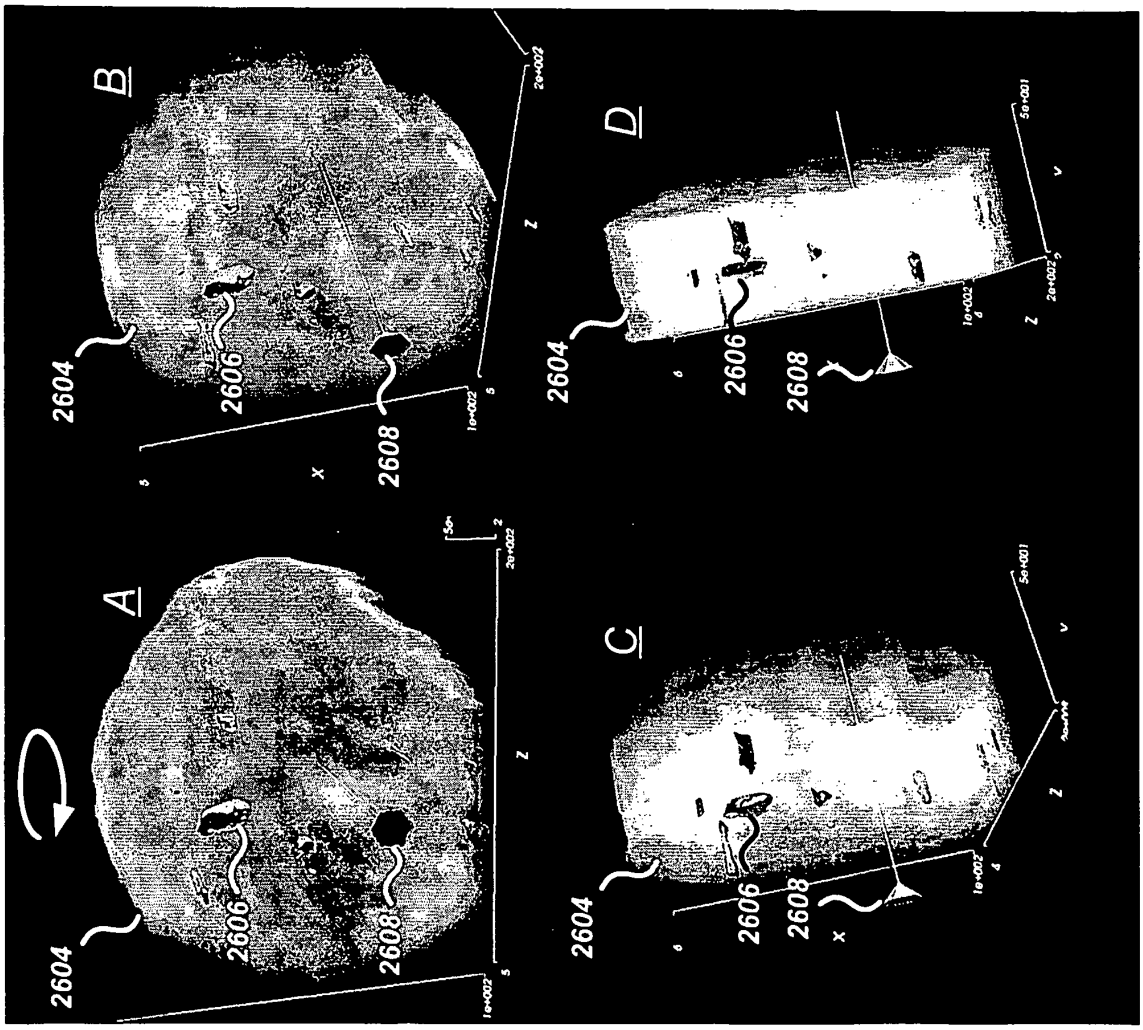

Superior
LAP
2502
N
2504a
2504b
Medial
Posterior
Lateral
R
L
2510
2512
12
3
6
9
Nipple 4cm
Skin 1cm

FIG. 25



2602

FIG. 26

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- US 20030212327 A1 **[0002] [0046]**
- US 631767 A, Gilhuijs, Giger, and Bick **[0052]**
- WO 02101303 A1 **[0052] [0055]**
- US 6317617 B **[0087]**
- WO 03101303 A1 **[0087]**

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公开(公告)号	[EP1793740A4](EP1793740A4)	公开(公告)日	2007-10-24
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[标]申请(专利权)人(译)	U系统公司		
申请(专利权)人(译)	U-SYSTEMS INC.		
当前申请(专利权)人(译)	U-SYSTEMS INC.		
[标]发明人	ZHANG WEI WANG SHIH PING CHEN JIAYU YU ZENGPIN CUPPLES TOMMY EARL REED MICHAEL E		
发明人	ZHANG, WEI WANG, SHIH-PING CHEN, JIAYU YU, ZENGPIN CUPPLES, TOMMY, EARL REED, MICHAEL, E.		
IPC分类号	A61B8/00 A61B6/00 A61B8/08 A61B8/12 A61B8/13 A61B8/14		
CPC分类号	A61B8/5238 A61B6/463 A61B6/502 A61B6/5247 A61B6/563 A61B8/0825 A61B8/13 A61B8/406 A61B8/4281 A61B8/4405 A61B8/462 A61B8/463 A61B8/465 A61B8/466 A61B8/467 A61B8/565		
优先权	60/577388 2004-06-04 US 60/577326 2004-06-04 US 10/997293 2004-11-23 US		
其他公开文献	EP1793740A2 EP1793740B1		
外部链接	Espacenet		

摘要(译)

描述了在交互式用户界面上显示乳房超声信息，该用户界面在辅助超声乳腺摄影环境和/或仅超声乳腺摄影环境中有用。 通过成对显示对应于左右乳房中类似板状子体积的厚切片图像，可以促进双边比较。 描述了冠状厚切片成像以及在冠状厚切片图像上和之间的便捷导航。 在一优选实施例中，乳头标记被显示代表乳头位置在其上的投影的冠状厚切片图像。 还显示了方便的乳房图标，其包括光标位置指示器，该光标位置指示器以反映光标和乳头标记之间的相对位置的方式可变地布置在其上。 优选地，乳房图标被配置为至少大致类似于钟面，钟面的中心代表乳头标记位置。 还描述了厚切片图像内部和之间的以书签为中心的导航和以CAD标记为中心的导航。

$$P_{cor}(x,y) = FUNC\{V_{xy}(z)\} = \sum_{n=1}^{N} W_{xy}(n) V_{xy}(z_n)$$