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(54) Title: MICRO-PARTICULATE IDENTIFICATION AND CLASSIFICATION IN ULTRASOUND IMAGES

(57) Abstract: An ultrasonic diagnostic imaging system utilizes a two dimensional matrix array transducer to acquire image data of a volumetric region of a breast or testis. Two dimensional image planes are formed from the image data by multi-planar reformatting (MPR) in a plurality of different orientations and the 2D planes are examined to identify one or more images with a high number of micro-particulates. In a constructed embodiment this is done by forming histograms of bright specular reflectors in the images. Dim spots which may be caused by noise are eliminated, as are large spots from ligaments and connecting tissue in breast images. The image with the greatest number of identified micro-particulates and the number of micro-particulates are displayed to the user for diagnosis.

WO 2012/049586 A2

MICRO-PARTICULATE IDENTIFICATION AND CLASSIFICATION IN ULTRASOUND IMAGES

This invention relates to medical diagnostic ultrasound imaging and, in particular, to ultrasound imaging systems which can identify and classify micro-particulates in tissue in ultrasound images.

The presence of a large number of micro-particulates can be an indication of disease in several regions of the body. In the breast, micro-calcifications are specks of calcium that may be found in an area of rapidly dividing cells. The residue left by rapidly dividing cells can appear as micro-calcifications. When many are seen in a cluster, they may be an indication of a small cancer. About half of the breast cancers detected appear as these clusters.

Most breast calcifications are benign. The term micro-calcification is often used for calcifications found with malignancy, which are usually smaller, more numerous, clustered, and variously shaped (*e.g.*, rods, branches, teardrop or cup shapes). Calcifications associated with benign conditions are usually larger, fewer in number, widely dispersed, and round. When suspicious micro-calcifications appear on a mammogram, but no lump is felt, a needle localization biopsy is recommended, so that breast tissue can be removed and examined under a microscope by a pathologist.

Calcifications revealed on mammograms are thought to be associated with an increased risk of subsequent breast cancer. Women with calcifications in both breasts are at higher risk than women with calcifications in only one breast. Women with any calcifications are at higher risk than women with no

calcifications.

Ultrasound can play a role in detecting micro-calcifications. Ultrasound is able to visualize micro-calcifications, tiny calcium deposits that are often the first indication of breast cancer, and is also able to detect macro-calcifications, which are larger calcium deposits. However, breast ultrasound images are frequently characterized by numerous echogenic speckles, many of which are associated with ligaments and connecting tissue in the breast. When performing breast ultrasound imaging, clinicians do not always see the echogenic areas since breast images are very inhomogenous and contain numerous echogenic areas associated with ligaments and other parts of anatomy which are presented as bright echogenic lines. The detection of micro-calcifications by ultrasound can be more cumbersome because of the abundance of such echogenic structures in the field of view, making it difficult for the clinician to correctly interpret the image.

Some research has associated the finding of testicular microlithiasis with testicular cancer (Mayo Foundation for Medical Education and Research, (2009)). In ultrasound images, testicular microlithiasis is seen as small hyperechoic interfaces throughout the testis. Some researchers have defined microlithiasis as being characterized by multiple small non-shadowing echogenic foci of up to 3 mm in size, of which five or more are evident on a single planar image. See Backus et al, as cited in Cast et al, "Prevalence and tumor risk in a population referred for scrotal sonography," AJR, 175 at 1703-06 (2000). The current clinical practice is to evaluate the image plane of the testis which contains the greatest number of microlithiasis. The

clinician is required to manually angle the transducer into views of different planes to locate the view that has the greatest number of microlithiases. This introduces two problems. The first problem is that the clinician may spend a considerable amount of time examining the testis in numerous 2D (two dimensional) planes to locate the specific plane in which the clinician believe the most microlithiases of the required size are present, or at least 5 of such microlithiases are present. The second problem is that the clinician cannot be sure they have examined the testis in its entirety, which may exclude a plane that has 5 or more valid microlithiases. Moreover, if 3D (three dimensional) imaging is employed, today's mechanical 3D probe technology has resolution limitations, particularly in the "B" and "C" planes of the reconstructed display, that compromise image quality and may over-estimate the size of microlithiases due to resolution limitations, or underestimate the number of microlithiases as poor quality 3D image acquisition can lead to the omission of data in the reconstructed image planes.

Accordingly it is desirable to facilitate greater automation and classification of these micro-particulates in both the breast and the testes.

In accordance with the principles of the present invention, an ultrasonic diagnostic imaging system is described which utilizes a two dimensional matrix array transducer to acquire a three dimensional volume of image data of a volumetric region of a breast or testis. Two dimensional image planes are formed from the image data by multi-planar reformatting (MPR) in a plurality of different orientations and the 2D planes are examined to

identify one or more images with a high number of micro-particulates. In a constructed embodiment this is done by forming histograms of bright specular reflectors in the images. Dim spots which may be caused by noise are eliminated, as are large spots from ligaments and connecting tissue in the case of breast tissue. The image plane with the greatest number of identified micro-particulates is displayed, along with a calculation of the number of micro-particulates.

In the drawings:

FIGURE 1 illustrates in block diagram form an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention.

FIGURE 2 is a flowchart of a method for identifying and classifying micro-particulates in the breast or testes in accordance with the principles of the present invention.

FIGURES 3 and 4 are 2D MPR ultrasound images of testes containing microlithiases.

FIGURE 5 illustrates a histogram of the bright spots in a 2D ultrasound image.

FIGURE 6 illustrates the specular reflectors identified in a 2D ultrasound image.

FIGURE 7 illustrates the specular reflectors in the 2D ultrasound image of FIGURE 6 after elimination of noise effects and large spots.

Referring first to FIGURE 1, an ultrasound system constructed in accordance with the principles of the present invention is shown in block diagram form. An ultrasonic probe 12 includes a two dimensional array 14 of ultrasonic transducer elements that transmit ultrasonic pulses and receive echo signals over a three dimensional steering range.

A two dimensional matrix of transducer elements is capable of electronic beam steering in three dimensions. The array may less preferably be a one dimensional array that is mechanically swept back and forth by the probe to scan a three dimensional volume of the body. The ultrasonic transducer elements in the array 14 transmit ultrasonic energy and receive echoes returned in response to this transmission. A matrix array probe will typically have a microbeamformer located in the probe housing to partially beamform signals before final beam formation is done by the system beamformer 32. The partitioning of beam formation between a microbeamformer located in the probe and the main beamformer in the system mainframe is described in US Pat. 6,013,032 (Savord) and US Pat. 6,375,617 (Fraser). A transmit/receive ("T/R") switch 22 is coupled to probe 12 to selectively couple signals from the probe to A/D converters 30 during the receive phase of operation. The times at which the transducer array is activated to transmit signals may be synchronized to an internal system clock (not shown).

Echoes from the transmitted ultrasonic energy are received by the transducers of the array 14, which generate echo signals that are micro-beamformed in the probe and coupled through the T/R switch 22 and digitized by analog to digital ("A/D") converters 30 when the system uses a digital beamformer. Analog beamformers may alternatively be used. The A/D converters 30 sample the received echo signals at a sampling frequency controlled by a signal f_s generated by a central controller 28. The desired sampling rate dictated by sampling theory is at least twice the highest frequency of the received passband, and

might be on the order of 30-40 MHz. Sampling rates higher than the minimum requirement are also desirable. Control of the ultrasound system and of various control setting for imaging such as probe selection is effected by user manipulation of the controls of a control panel 20 which is coupled to and applies its control through the central controller 28.

The echo signal samples from the probe 12 are delayed and summed by a system beamformer 32 to form coherent echo signals. The coherent echo signals are then filtered by a digital filter 34. Typically the digital filter 34 bandpass filters the signals, and can also shift the frequency band to a lower or baseband frequency range. The digital filter could be a filter of the type disclosed in U.S. Patent No. 5,833,613 (Averkiou et al.), for example. Filtered echo signals from tissue are coupled from the digital filter 34 to a B mode processor 36 for B mode processing.

The output signals from the B mode processor may be scan converted and displayed as planar images, and are also coupled to a 3D image processor 42 for the rendering of three dimensional images, which are stored in a 3D image memory 44. Three dimensional rendering may be performed as described in U.S. patent 5,720,291 (Schwartz), and in U.S. patents 5,474,073 (Schwartz et al.) and 5,485,842 (Quistgaard), all of which are incorporated herein by reference.

The two dimensional image signals from the B mode processor 36 and the three dimensional image signals from the 3D image memory 44 are coupled to a Cineloop® memory 48, which stores image data for each of a large number of ultrasonic images. The image

data are preferably stored in the Cineloop memory 48 in sets, with each set of image data corresponding to an image obtained at a respective time. The groups of image data stored in the Cineloop memory 48 may also be stored in a permanent memory device such as a disk drive or digital video recorder for later analysis. In this embodiment 3D image datasets such as those rendered into 3D images by the 3D image processor 42 are coupled to a particulate processor 50, where the image data is analyzed and classified to identify 2D image planes exhibiting large numbers of micro-particulates (micro-calcifications and microlithiasis) in the breast and testes. The particulate processor can be used to analyze breast and testis image datasets as described more fully below. The particulate processor is controlled through user manipulation of controls such as buttons and a trackball of the control panel 20. The data and images produced by the particulate processor, as well as those produced otherwise by the ultrasound system 10, are displayed on a display 52 where the user may manipulate, annotate and make measurements of the displayed images through operation of the controls of the control panel 20 as described below.

The ultrasound system 10 with its particulate processor 50 can acquire and analyze breast and testes images for micro-particulates as illustrated by the flowchart of FIGURE 2. At 60 a matrix array probe 12 is used to scan an organ (*e.g.*, a breast or testis) and acquire a 3D dataset of a volumetric region of the organ. At 61 the picture elements (pixels, voxels) of the 3D dataset are used to form multiplanar reformatted (MPR) 2D image frames of multiple cut plane orientations. An MPR image is formed from a 3D dataset by incrementally addressing

two of the three data coordinates while holding the third coordinate constant. For example, assume that a 3D dataset has picture elements addressable in x,y, and z coordinates. An MPR image in x and y is formed by taking all x and y picture elements with the same z coordinate. By repeating the process for all x and y picture elements with the next z coordinate value, a second image in a plane parallel to the first can be formed. When the process is repeated for all z coordinate values, a stack of parallel x-y images (*e.g.*, "B" plane images) is produced over the full volume of the 3D dataset. Other image orientations can be produces as desired. For example, a y-z image plane is formed by taking all y and z picture elements with the same x coordinate in the 3D dataset (*e.g.*, a "C" plane image). The MPR images need not be parallel to the boundaries of the 3D dataset but can be formed by selectively incrementing all three coordinates to form a stack of parallel tilted images. A series of images can be formed which are all at different rotational angles about a common axis. In short, by selectively addressing picture elements in a 3D dataset, an image plane or series of image planes can be formed at any orientation through the volume of the 3D dataset. FIGURE 3 illustrates a 2D image plane of a testis with a number of microlithiases appearing as white spots in the tissue of the testis. FIGURE 4 illustrates another 2D image plane of a testis with microlithiases appearing as white spots, which is used in the image analysis described below. The micro-particulates in these images appear as white spots because the small particles are highly echogenic and act as bright specular reflectors of transmitted ultrasound.

The MPR images formed of multiple cut planes at

61 are analyzed at 62 to identify the image plane with the greatest number of microlithiases or micro-calcifications. A preferred way to do this is to classify the pixels of an image plane by brightness. An example of pixel classification is shown in the form of a histogram 70 as indicated at 63 and illustrated in FIGURE 5. For instance, a black pixel may have a value of zero and a maximal white pixel may have a value of 255. In the histogram 70 the pixels in an image are classified by brightness value (x-axis) and by the number of pixels at each brightness value (y-axis). The image data of the example of histogram 70 has a peak 72 at the average brightness value in the image of about 107. The smaller peak 76 at the black end of the brightness scale is from the black pixels at the lower left corner of the Fig. 4 image. The histogram 70 may be used to eliminate dim spots in the image as indicated at 64 in FIGURE 2. This may be done by assigning a threshold level 74 above which the brightest pixels are classified. In FIGURE 5, that part of the histogram 70 to the right of threshold level 74 are pixels of the brightest reflectors in the image. The remaining pixels below the threshold are rejected, thus forming a virtually binary, masked image as illustrated in FIGURE 6. (The images of FIGURES 6 and 7 are shown with black/white reversal for clarity of illustration.) The image of FIGURE 6 shows the specular reflectors of FIGURE 4 in which all but the brightest reflectors have been masked out, thus eliminating dim spots in the image.

The final processing step 65 in the method of FIGURE 2 is to eliminate large spots in the masked image of FIGURE 6. Ligaments and connecting tissue in the breast are generally larger than micro-

calcifications and manifest themselves as larger objects in the image. These may be identified in a breast image by looking for connected white pixels in the image which together are greater than a certain size. For example, a group of nine connected pixels may be set as a size that is too large to be a micro-calcification and is probably some other tissue structure that should be further masked out from the image. The elimination of these larger structures from the image results in an image of micro-calcification spots as illustrated by FIGURE 7. This image is displayed to the user, as well as the number of micro-particulates shown in the image plane. Another suitable display format is to shown the original anatomical image such as FIGURE 3 or FIGURE 4 with the bright spots identified as microlithiases or micro-calcifications enhanced in a distinguishing color. Several different display formats have been found suitable for presenting the results of the micro-particulate analysis to a user. One is a dual display of a 3D image rendering of the 3D volume dataset together with an image of the 2D image plane containing the highest number of identified micro-particulates and the number found. A second is a "4-up" display of the 3D rendering of the volume together with three planar images having the highest number of micro-particulates and the number of micro-particulates in each planar image.

The procedure of FIGURE 2 is repeated for each image in the set of MPR images formed during the procedure. Since the number of micro-particulates found is recorded for each image, the particulate processor is capable of automatically identifying and displaying the image plane with the highest number of micro-particulates. The number of micro-particulates

in every image plane of the volume can be summed to present to the user the number of microlithiasis or micro-calcifications in the full volume. The clinician is thus provided with a thorough analysis of the micro-particulate content of the organ being examined from which to make an informed diagnosis.

WHAT IS CLAIMED IS:

1. An ultrasonic diagnostic imaging system for the identification and classification of micro-particulates in an organ comprising:

a matrix array probe adapted to acquire a three dimensional (3D) image dataset of a volumetric region of the organ;

a multiplanar reformatter which is adapted to form a plurality of two dimensional (2D) images of different locations in the volumetric region from the 3D image dataset;

a processor responsive to the two dimensional images which is adapted to identify and quantify the number of small, bright specular reflectors in each of the 2D images; and

a display device, coupled to the processor, for displaying a two dimensional image with a large number of micro-particulates and the number of micro-particulates identified in the displayed image.

2. The ultrasonic diagnostic imaging system of Claim 1, wherein each two dimensional image is comprised of picture elements; and

wherein the processor is adapted to classify the picture elements of each image according to picture element brightness.

3. The ultrasonic diagnostic imaging system of Claim 2, wherein the picture elements are one of pixels or voxels.

4. The ultrasonic diagnostic imaging system of Claim 3, wherein the processor is further adapted to eliminate image data from ligaments and connecting

tissue.

5. The ultrasonic diagnostic imaging system of Claim 1, wherein the processor is adapted to produce a histogram of picture elements according to brightness and number of elements.

6. The ultrasonic diagnostic imaging system of Claim 1, wherein the processor is adapted to eliminate picture elements below a brightness threshold level.

7. The ultrasonic diagnostic imaging system of Claim 6, wherein the processor is further adapted to eliminate aggregates of picture elements which are above a given size.

8. The ultrasonic diagnostic imaging system of Claim 1, wherein the multiplanar reformatter is adapted to form a plurality of 2D images in parallel planes in a first orientation.

9. The ultrasonic diagnostic imaging system of Claim 8, wherein the multiplanar reformatter is further adapted to form a second plurality of 2D images in parallel planes in a second orientation.

10. The ultrasonic diagnostic imaging system of Claim 1, wherein the multiplanar reformatter is adapted to form a plurality of 2D images in planes which are tilted with respect to a boundary of the 3D dataset.

11. The ultrasonic diagnostic imaging system of Claim 1, wherein the multiplanar reformatter is adapted to form a plurality of 2D planes which are

differently angled with respect to an axis through the 3D image dataset.

12. The ultrasonic diagnostic imaging system of Claim 1, wherein the display device is further adapted to display a 3D rendered image of the 3D dataset, a 2D image, and the number of micro-particulates identified in the 2D image.

13. The ultrasonic diagnostic imaging system of Claim 12, wherein the display device is further adapted to display the number of micro-particulates identified in the 3 rendered image.

14. A method of identifying microlithiasis in a region of a testis or micro-calcifications in a region of a breast comprising:

acquiring a three dimensional (3D) image dataset of a volumetric region of a testis or breast;

forming a plurality of two dimensional (2D) planar images from the 3D image dataset;

identifying small, bright specular reflectors in each of the 2D images;

quantifying the number of micro-particulates in each of the 2D images; and

displaying a 2D image with a large number of micro-particulates and the quantified number.

15. The method of Claim 14, wherein identifying further comprises rejecting picture elements below a given brightness level.

16. The method of Claim 15, wherein identifying further comprises rejecting aggregates of picture elements above a given size.

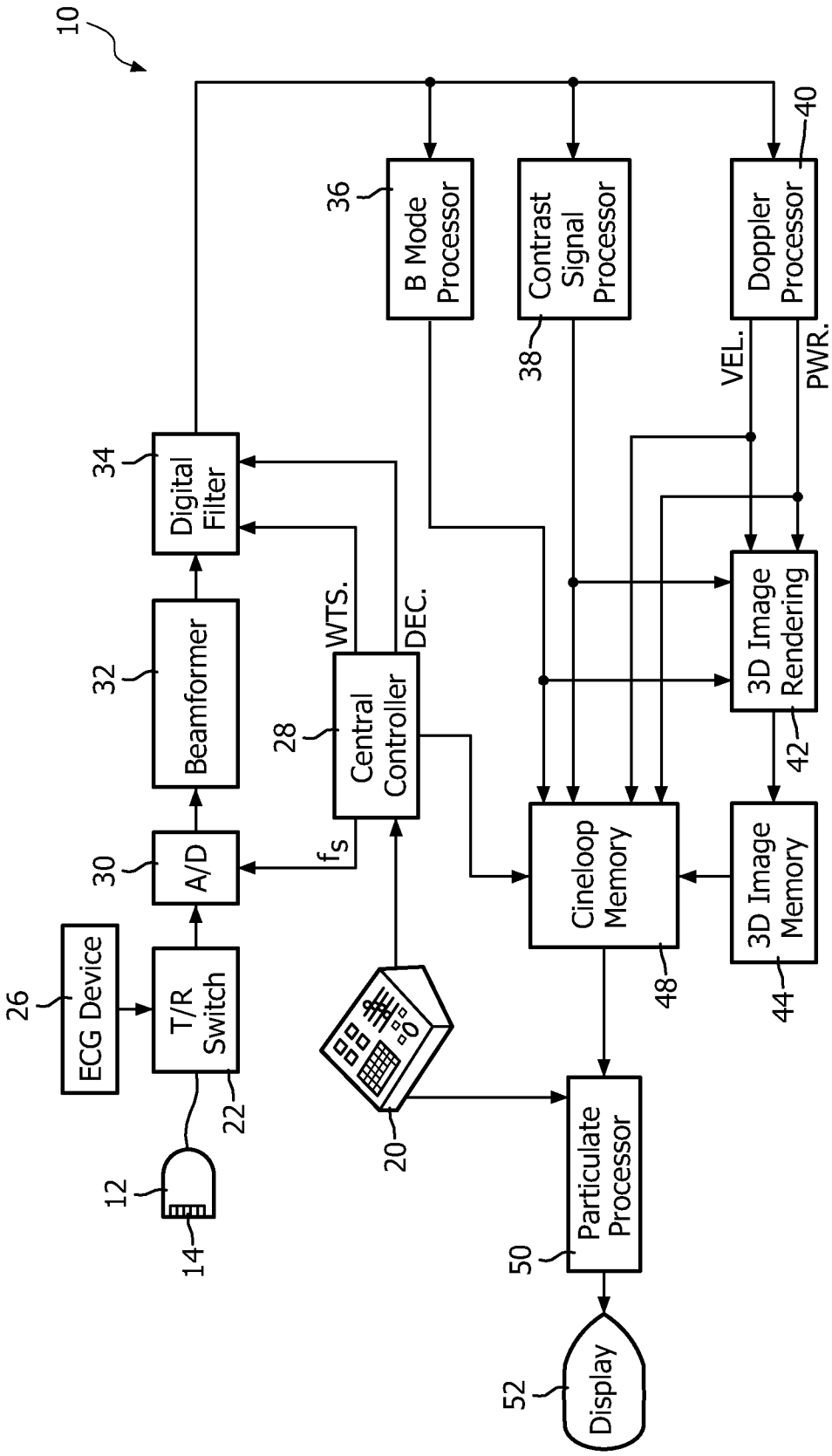
10
B Mode Processor
36
Contrast Signal Processor
38
Doppler Processor
40
VEL.
PWR.
Digital Filter
34
Beamformer
32
WTS.
DEC.
Central Controller
28
3D Image Rendering
42
A/D
30
f_s
Cineloop Memory
48
3D Image Memory
44
ECG Device
26
T/R Switch
22
12
14
20
Particulate Processor
50
Display
52

FIG. 1

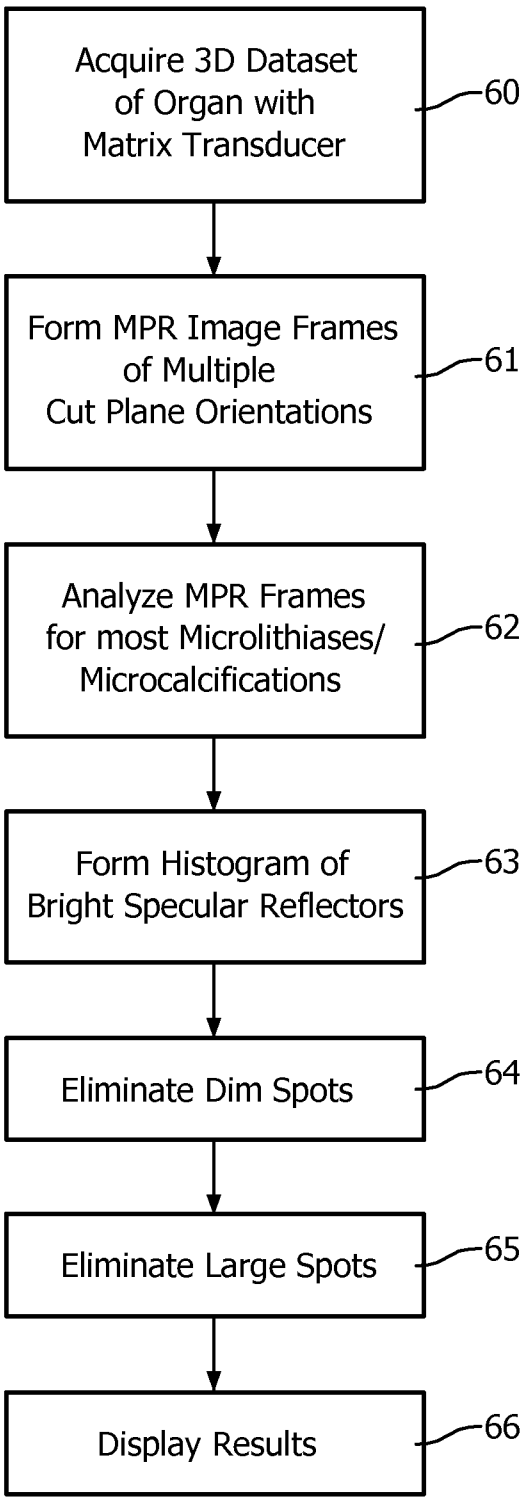
Acquire 3D Dataset of Organ with Matrix Transducer
60
Form MPR Image Frames of Multiple Cut Plane Orientations
61
Analyze MPR Frames for most Microlithiases/ Microcalcifications
62
Form Histogram of Bright Specular Reflectors
63
Eliminate Dim Spots
64
Eliminate Large Spots
65
Display Results
66

FIG. 2

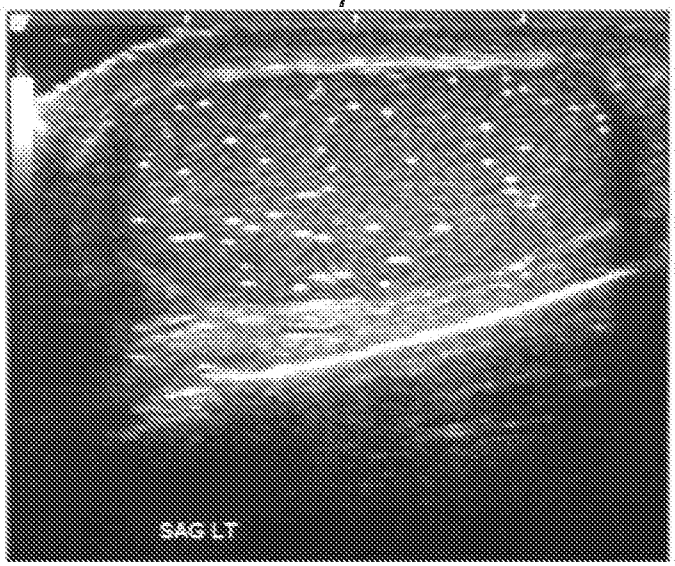

FIG. 3

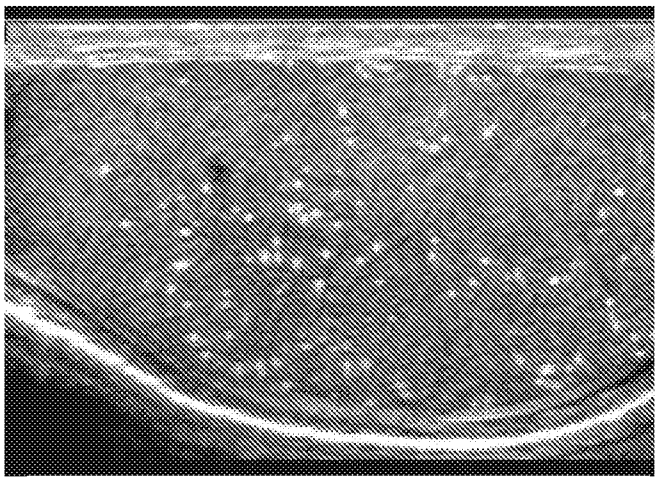

FIG. 4

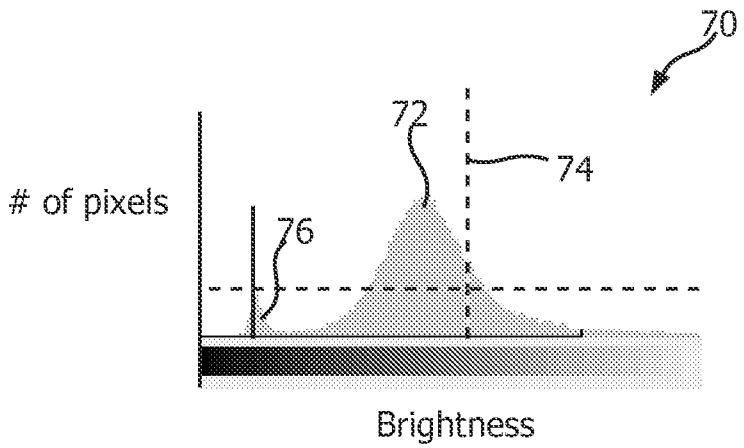

FIG. 5

FIG. 6

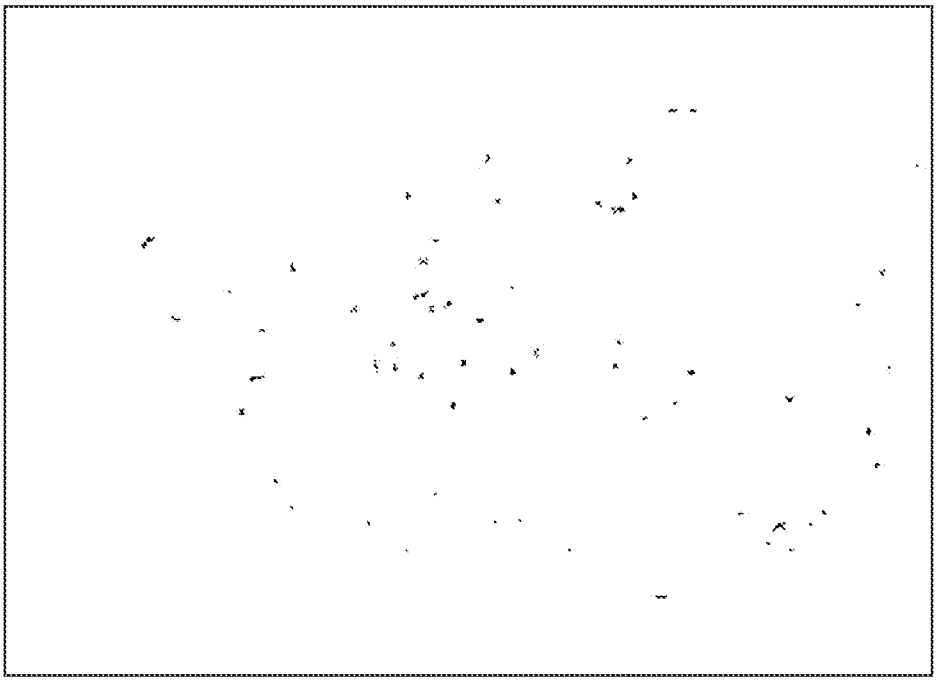

FIG. 7