



(19) **United States**

(12) **Patent Application Publication**
Rafter et al.

(10) **Pub. No.: US 2010/0056921 A1**
(43) **Pub. Date: Mar. 4, 2010**

(54) **QUANTIFIED PERFUSION STUDIES WITH
ULTRASONIC THICK SLICE IMAGING**

Related U.S. Application Data

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(60) Provisional application No. 60/911,598, filed on Apr.
13, 2007.

Publication Classification

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**PHILIPS INTELLECTUAL PROPERTY &
STANDARDS
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BRIARCLIFF MANOR, NY 10510 (US)**

(51) **Int. Cl.**
A61B 8/14 (2006.01)
(52) **U.S. Cl.** **600/447; 600/459**
(57) **ABSTRACT**

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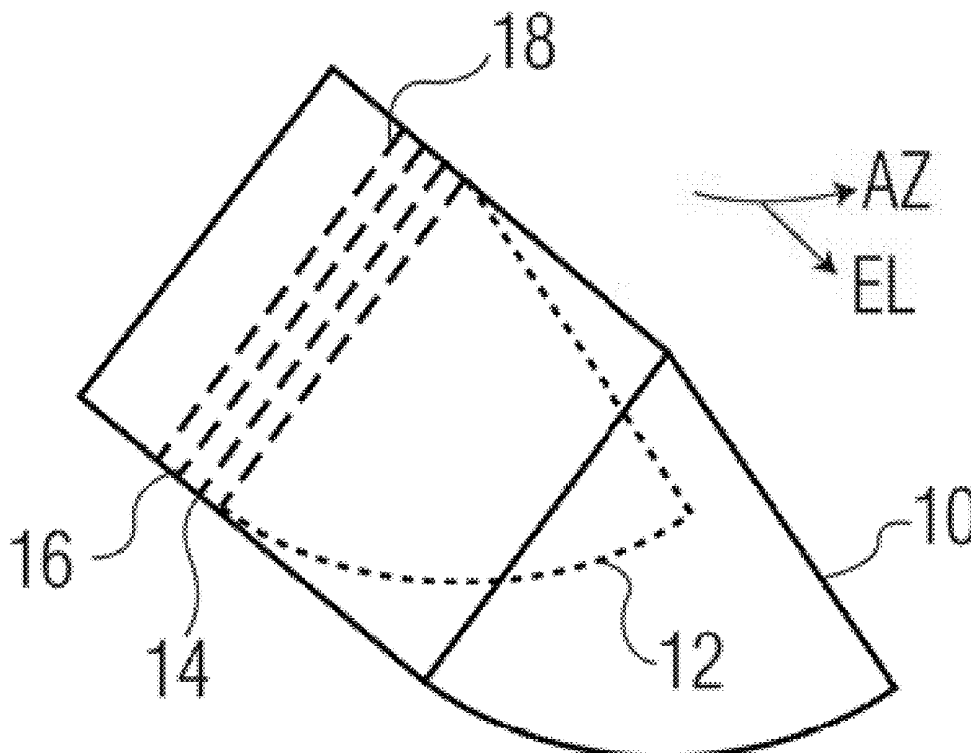
An ultrasonic diagnostic imaging system scans a plurality of planar slices in a volumetric region containing tissue which has been perfused by a contrast agent. The plurality of slices scanned are parallel to each other. Following detection of the image data of the slices the slice data is combined by projecting the data in the elevation dimension to produce an elevationally combined slice image. Combining may be by means of an averaging or maximum intensity detection or weighting process or by raycasting in the elevation dimension in a volumetric rendering process. The elevationally combined slice image is processed to produce a qualitative or quantitative measure of perfusion, such as an image with degrees of perfusion indicated by a range of brightness levels, an image of color perfusion parameters, or a perfusion curve or curve parameter indicating rate of perfusion.

(21) Appl. No.: **12/594,906**

(22) PCT Filed: **Apr. 9, 2008**

(86) PCT No.: **PCT/US08/59705**

§ 371 (c)(1),
(2), (4) Date: **Oct. 6, 2009**



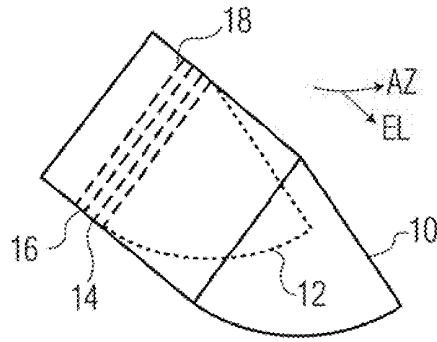


FIG. 1

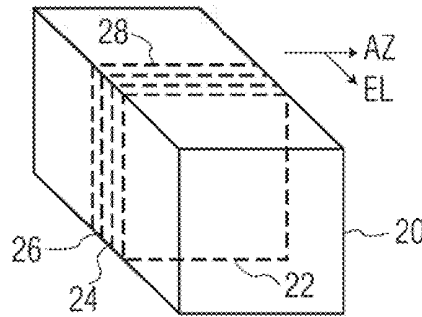


FIG. 2

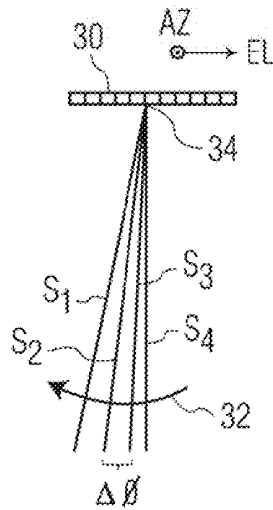


FIG. 3

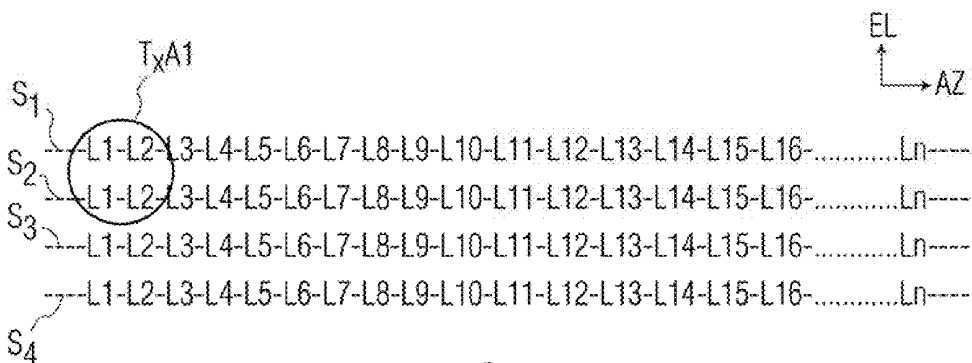


FIG. 4a

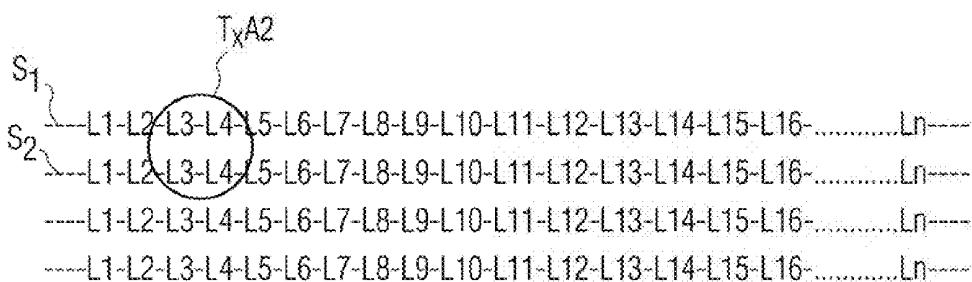


FIG. 4b

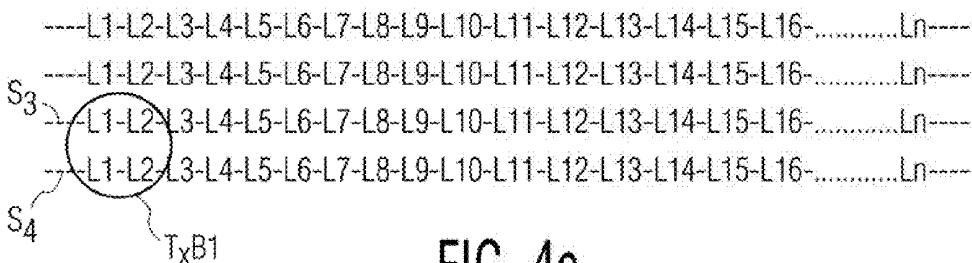


FIG. 4c

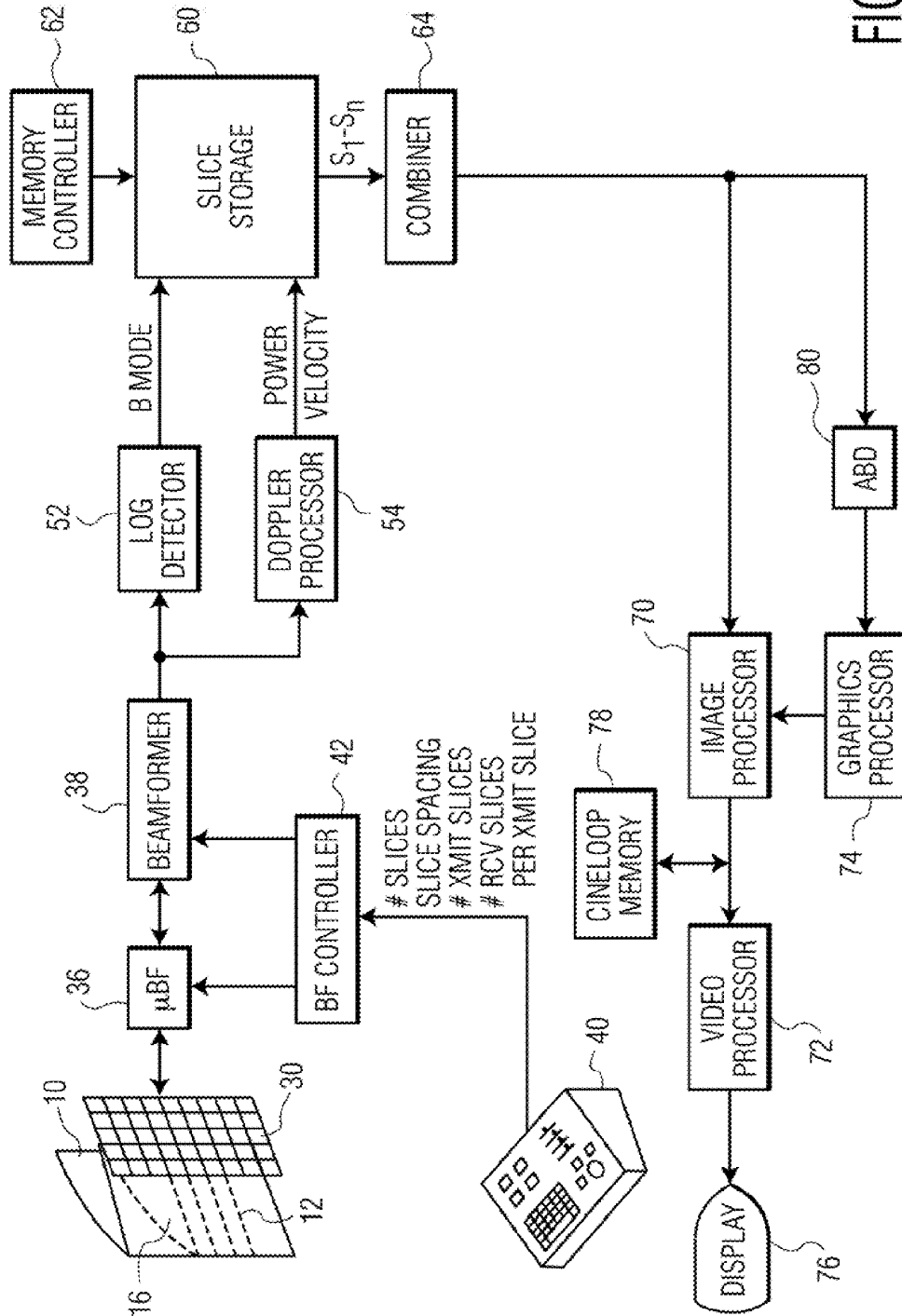


FIG. 5

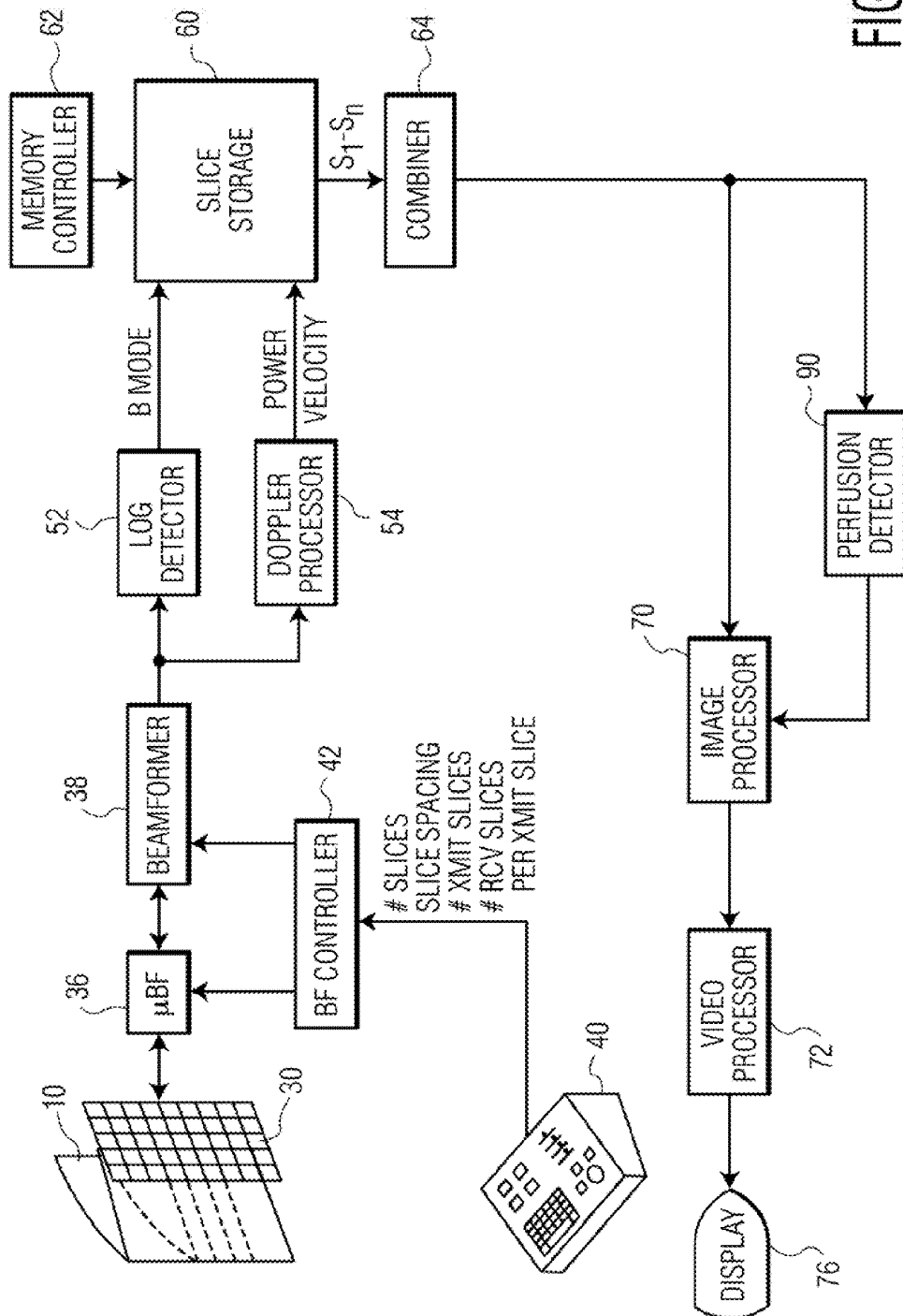


FIG. 6

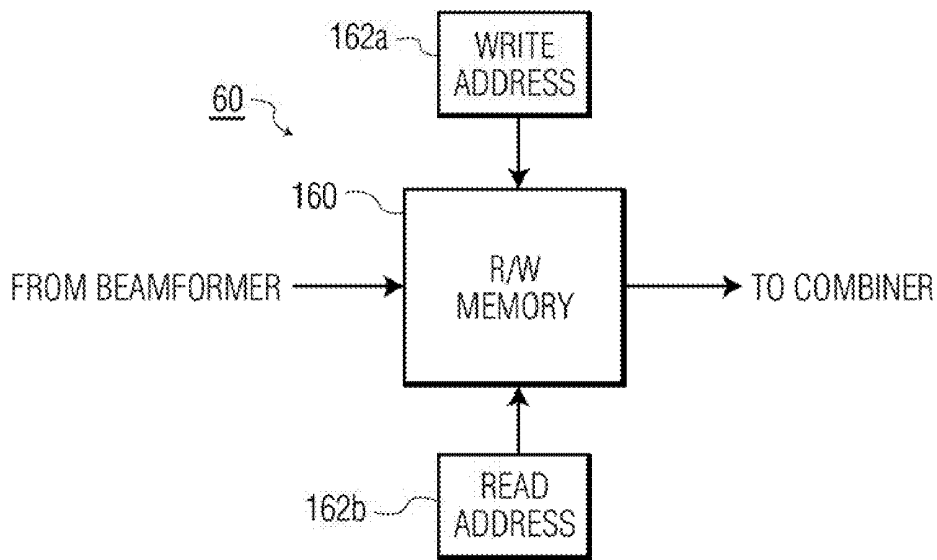


FIG. 7a

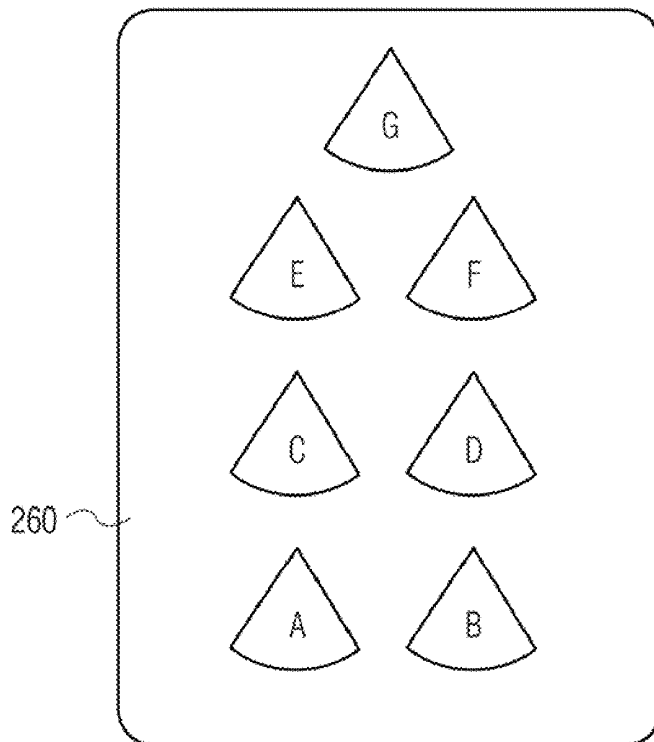


FIG. 7b

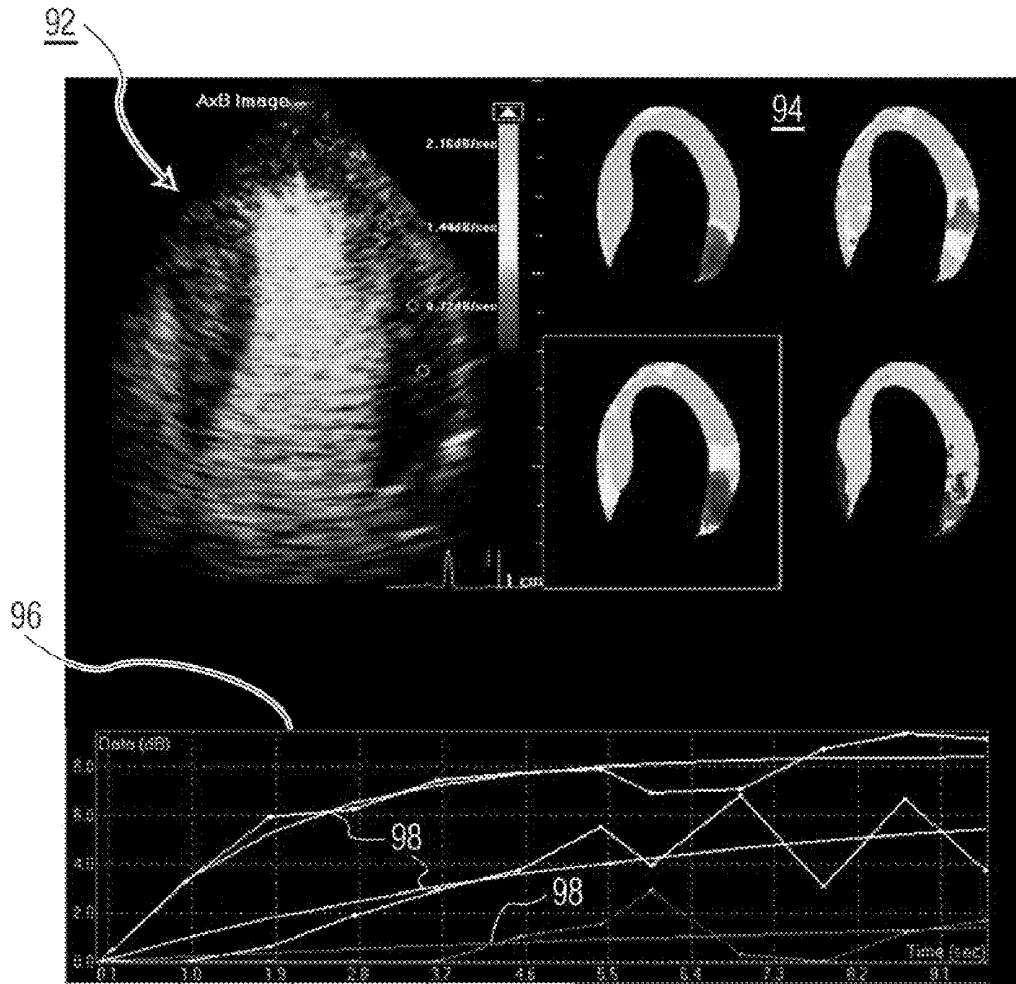


FIG. 8

QUANTIFIED PERFUSION STUDIES WITH ULTRASONIC THICK SLICE IMAGING

[0001] This invention relates to medical diagnostic ultrasound systems and, in particular, to ultrasound systems which enable the performance of perfusion display and quantification with ultrasonic thick slice images.

[0002] It has long been the desire of echo-cardiographers to be able to use ultrasound for the quantification of myocardial perfusion. Infarcted myocardial tissue which is completely lacking in blood flow is sometimes easy to diagnose by reason of both its blood flow and motional characteristics. However, it is much more difficult to detect and diagnose partially infarcted or ischemic regions of the myocardium which may be suffering perfusion deficit. This task has been aided considerably in recent years by the advent of ultrasonic microbubble contrast agents. Not only does the contrast agent better highlight the perfusion of the myocardium, but it also enables "flash-replenishment," by which the microbubbles are disrupted by high ultrasonic energy, then the replenishment of microbubbles by the blood flow is observed and measured. A quantified measure of this replenishment is the time-intensity curve of replenishment which measures the rate of blood flow in localized regions of interest. By this technique the perfusion of the myocardium can be displayed qualitatively with color depicting the flow characteristic, and quantified parameters derived which measure the rate of reperfusion of a region of the heart.

[0003] One of the difficulties that has always been present in ultrasound is the mottling of images by the speckle artifact. Ultrasonic imaging is an imaging modality which forms images of coherent signal information. The nature of the coherent ultrasonic signals used, like the monochromatic lightwaves used for holographic imaging, results in constructive and destructive interference of the waves in the medium being imaged. As a result, the image contains noise in the form of a random mottling of the image known as "speckle." When a region of interest is monitored for the replenishment of blood as indicated by the replenishment of the contrast agent carried by the blood flow, relatively low transmit power is used so that the microbubbles of the agent can be observed without disruption. As a result, contrast images exhibit lower signal-to-noise ratios than do standard images. In addition the contrast images will exhibit a lower display dynamic range than standard images, causing them to have reduced contrast resolution. These factors combine to make the speckle artifact more pronounced and more severe for contrast images.

[0004] Since the speckle pattern of an image is constant and does not vary with time, the common approach to reducing the effect is to combine uncorrelated image data and reduce the speckle by an averaging effect proportional to the square root of two. The types of uncorrelated data used are typically data that are of different frequencies or acquired from different look directions, commonly known as frequency compounding (see, e.g., U.S. Pat. No. 4,350,917 to Lizzi et al.) and spatial compounding (see, e.g., U.S. Pat. No. 4,649,927 to Fehr et al.) Frequency compounding, however, leads to a reduction in contrast-to-tissue ratio and signal-to-noise. This is because the different frequency bands that are compounded will have different signal-to-noise and different contrast-to-tissue ratios, which are generally equalized by adjusting the gain in one or more of the bands. The increase in gain will also

increase the noise in the affected band, thereby decreasing the signal-to-noise ratio of the frequency compounded image.

[0005] U.S. Pat. No. 6,464,638 to Adams et al. describes a new approach to spatial compounding which makes good utilization of probes designed for three dimensional imaging. In the Adams et al. technique a 3D imaging probe acquires images of planes which are substantially parallel to each other in the elevational dimension, the dimension normal to the image plane. In a typical implementation, Adams et al. use a probe with electronic beam steering and focusing in both azimuth and elevation to acquire not only an image of the slice plane of interest but also image planes offset from that slice plane. The slices are then combined elevationally and the at least minimally uncorrelated data in the elevational dimension effects speckle reduction by spatial compounding in the elevational dimension. It would be desirable to apply this approach to reduce the speckle of an ultrasound contrast image while having a minimal effect on spatial resolution and signal-to-noise, thereby enabling more robust quantification and parametric imaging with ultrasound contrast agents.

[0006] In accordance with the principles of the present invention, a diagnostic ultrasound system and method are described in which a plurality of slices of tissue which may have perfusion defects are scanned with a 3D imaging probe. The acquired image slices are substantially parallel in the elevational dimension. Following the acquisition of multiple slices, the image data of the slices is projected and combined in the elevation dimension to form a "thick slice" image. The thick slice image is then subjected to perfusion detection to highlight areas of perfused and unperfused tissue in the image in accordance with their concentrations of microbubbles, or to quantify the rate of perfusion as by the measurement of wash in, wash out curves and curve parameters at localized regions of the tissue.

[0007] In the drawings:

[0008] FIG. 1 illustrates a plurality of sector slices acquired in the elevational direction.

[0009] FIG. 2 illustrates a plurality of rectilinear slices acquired in the elevational direction.

[0010] FIG. 3 illustrates a plurality of slices which are at different angular increments in the elevational direction.

[0011] FIGS. 4a-4c illustrate the acquisition of multiple slices simultaneously by multiline acquisition in accordance with the principles of the present invention.

[0012] FIG. 5 illustrates in block diagram form an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention.

[0013] FIG. 6 illustrates in block diagram form a second implementation of an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention.

[0014] FIG. 7a illustrates a dual ported memory used for slice storage in an implementation of the present invention.

[0015] FIG. 7b illustrates partitioning of memory areas in an implementation of the present invention.

[0016] FIG. 8 illustrates an ultrasound system display screen showing qualitative and quantitative indications blood flow perfusion of the myocardium.

[0017] Referring first to FIG. 1, a volumetric region 10 is shown in perspective. In this example the volumetric region 10 is sector-shaped and contains a plurality of planar sector-shaped areas which are referred to herein as "slices." Four slices 12-18 are illustrated in this example. The slices are oriented parallel to each other in the elevation direction with

their azimuth and elevation dimensions indicated to the right of the drawing. Each slice may be scanned by an array transducer located above the volumetric region by transmitting successive scanlines across a slice **12-18** in the azimuth direction and progressing from slice to slice in the elevation direction.

[0018] FIG. 2 illustrates a rectilinear volumetric region **20** which also includes a plurality of slices oriented in parallel in the elevation direction. Four such slices **22-28** are shown in the drawing. These slices may be scanned in the same manner as the slices of FIG. 1 by a transducer array located above the volumetric region **20**. In this example the slices are scanned by parallel scanlines in the azimuth direction rather than by angularly incremented scanlines from a common origin as is the case in the example of FIG. 1.

[0019] FIG. 3 provides another example of slices of a volumetric region. These slices are of a pyramidal volumetric region with an apex **34** at the top of the volume. In this example four sector-shaped slices S_1 - S_4 are shown in an "edge-on" view. That is, the elevation direction of the slices is indicated by the arrow **32**, and the azimuth direction is into the plane of the drawing. The azimuth and elevation directions with respect to the array transducer **30** are shown above the transducer array. In this example neighboring elevation slices are substantially parallel and are separated from each other by an angular increment $\Delta\phi$.

[0020] In each of these examples a single slice of a volume may be scanned and displayed. But in accordance with the principles of the present invention, a plurality of slices which are elevationally aligned are scanned and their data combined to form an image for display. Since each of the elevationally distinct slices is scanned by scanlines having different transmit-receive signal paths, each of the slices will exhibit its own unique speckle pattern. By combining the image data of a plurality of slices which define a thickness in the elevation dimension, the speckle artifact of the combined image will be reduced.

[0021] In accordance with a further aspect of the present invention, the slices may be scanned at a high speed by multiline acquisition. In multiline acquisition, one transmit beam insonifies multiple receive line locations and multiple receive lines are acquired in response to the single transmit event. FIGS. 4a-4c provide an example of multiline acquisition of four slices S_1 - S_4 which are arranged in parallel in the elevational dimension. Each slice is made up of receive lines arrayed in the azimuth direction and identified in the drawing as $L1, L2, \dots, Ln$, where "n" may be **128**, for instance. In the view of FIG. 4, each receive line is being viewed axially as it would from the perspective of the transducer array. Rather than transmit a single transmit beam down each line and receive echoes from only that receive line, four receive lines are insonified by a single transmit beam. In the example of FIG. 4a a transmit beam $TxA1$, outlined radially, insonifies receive lines $L1$ and $L2$ of slice S_1 and receive lines $L1$ and $L2$ of slice S_2 . Thus, two receive lines in azimuth and two receive lines in elevation, a total of four receive lines, are acquired simultaneously and processed. See, e.g., U.S. Pat. No. 5,318,033 (Savord) for an explanation of the processing of simultaneously received multilines. FIG. 4b illustrates the next transmit event, in which a transmit beam $TxA2$ insonifies another four receive lines, $L3$ and $L4$ of slice S_1 and receive lines $L3$ and $L4$ of slice S_2 . Scanning proceeds in this manner until all of the lines of slices S_1 and S_2 have been acquired. Thus in the interval during which the full azimuth of a slice

has been scanned, from line $L1$ through line Ln , echo data from two slices, S_1 and S_2 , has been acquired. The process then continues with a second azimuth scanning interval as shown in FIG. 4c with the scanning of receive lines $L1$ and $L2$ of slice S_3 together with receive lines $L1$ and $L2$ of slice S_4 by transmit beam $TxB1$. Slices S_3 and S_4 are scanned during this second azimuth scanning interval in the same manner as slices S_1 and S_2 were acquired during the first. In these two scanning intervals all four slices S_1 - S_4 are scanned in the time required to scan a single slice in the conventional line-by-line approach. The speed of acquisition and hence the frame rate of display have been increased by a factor of four by the use of this 4x multiline acquisition.

[0022] An ultrasound system constructed in accordance with the principles of the present invention is shown in block diagram form in FIG. 5. A two dimensional array transducer **30** is provided which electronically steers and focuses beams over a volumetric region **10** under control of a microbeamformer **36**, main beamformer **38**, and beamformer controller **42**. Alternatively, a one dimensional array transducer can be mechanically oscillated to scan the volumetric region. In this case the microbeamformer **36** located in the probe case with the 2D transducer array **30** controls the scanning of groups of elements called subarrays or patches in scanning a volumetric region **10**. Partially beamformed signals from the microbeamformer **36** are formed into fully beamformed signals by the main beamformer **38**. A beamformer controller **42** provides control signals for the beamformer and microbeamformer. Further details on microbeamformer-controlled scanning of volumetric regions may be found in U.S. Pat. No. 6,623,432 (Powers et al.), and U.S. Pat. No. 6,709,394 (Frisa et al.), PCT publication WO 2005/099579 (Rafter) and U.S. patent application 60/777,831 (Savord), filed Mar. 1, 2006. In this example a user control panel **40** is coupled to the beamformer controller **42** and is operated to control a number of parameters of the scanning of slices **12-16** of the volumetric region **10**, including the number of slices to be scanned, the spacing between slices, the number of transmit slices, and the number of receive slices per transmit slice. Referring back to FIGS. 4a-4c, in that example the number of slices to be scanned was four, the spacing between slices was a specified angular or linear parameter, the number of transmit slices was two, and the number of receive slices per transmit slice was two.

[0023] The beamformed echo signals received from the scanned slices are detected by a log detector **52** for B mode imaging. Alternatively or in addition, the received echo signals may be Doppler processed by a Doppler processor **54** for the display of flow or motion in the image field. The B mode image data and the Doppler image data (e.g., Doppler power and/or velocity) of each slice are stored in slice storage buffer **60**. Addressing of the buffer **60** to write data into the buffer or read data out of the buffer is controlled by memory controller **62**. In an implementation of the present invention a plurality of elevationally different slices are read out of the slice storage buffer **60** and combined by a combiner **64**.

[0024] The combiner **64** may combine the image data of multiple elevationally different slices in various ways. Combining is preferably performed on image data from different slices which have the same azimuth and depth coordinates in each slice. Alternatively, raylines can be mathematically projected through the multiple slices in the manner of raycasting for volume rendering. Preferably the raylines are projected normal to the planes of the slices. The image data intersected

by each rayline is the data which is combined. In the combining process the image data can be averaged or can be summed and normalized. A mean or median value of the data values can be computed, or a peak value of the data being combined can be used. The data from the central slice can be weighted more greatly than the data of neighboring slices, with slice data being weighted in relation to its distance from the central slice. Slice data can be weighted in relation to its proximity to the viewer with slice data in the front of the volume being weighted more greatly than slice data in the back. The combined data thus forms a "thick slice" which can be displayed as a planar display of a slice with characteristics of multiple elevationally offset individual slices. The thick slice data is coupled to an image processor **70** for further processing such as scan conversion into the desired display format (e.g., sector or linear) and is processed into video signals by a video processor **72** for display on a display **76**. The image data can also be saved or stored in a Cinelooop® memory **78**, harddrive or other image storage device. The thick slice display will exhibit reduced speckle artifacts as compared to an individual one of the acquired slices.

[0025] Another example of the present invention is to scan a volume in a coordinate system appropriate for the transducer or for the clinical application. A group of substantially parallel MPR (multi-planar-reformatted) planes are then derived from the acquired volumes, which may be but are not typically aligned with the acquisition slices contained within the volume. These parallel MPR planes are then combined in the aforementioned techniques to produce an MPR thick slice, which is then used to facilitate the visualization of perfusion defects. Such an implementation increases the diagnostic likelihood of detecting infarcted and ischemic regions of the myocardium.

[0026] In accordance with a further aspect of the present invention a high frame rate of display for thick slice images may be obtained by means of the apparatus and techniques depicted in FIGS. *7a* and *7b*. FIG. *7a* illustrates the slice storage buffer **60** implemented as a dual port memory **160** which can be written to and read from simultaneously. The use of such a R/W memory **160** enables the new data of a slice being scanned by the transducer array and beamformer to be written into one area of the R/W memory while the data of other slices previously stored in the memory is read out and combined to form a thick slice image. The writing of new slice image data into the memory **160** is controlled by a write address controller **162a** while the reading of slice image data from other locations in the memory is under the control of a read address controller **162b**. In this technique a new thick slice image can be combined for display while the image data from a new slice is being acquired. One example of the allocation of memory for a combined four-slice thick slice image is illustrated by FIG. *7b*. The storage area **260** of the memory is shown to contain seven image storage areas labeled A through G.

[0027] An example employing the 4× multiline scanning technique of FIGS. *4a-4c* for four component slices S_1 - S_4 is as follows. Using the user interface **40**, the ultrasound system is set to scan four slices with a given slice spacing, using two transmit slices and two receive slices per transmit slice. Scanning of the first two slices proceeds during a first scanning interval as shown in FIGS. *4a* and *4b* and the data of the two acquired slices S_1 and S_2 is written into memory areas A and B. Slices S_3 and S_4 are then scanned during a second interval and the data of these two slices is written into memory areas

C and D. The transducer array and beamformer then begin to scan slices S_1 and S_2 again and write the data from the rescanning of slices S_1 and S_2 into memory areas E and F. While these slices are rescanned, the image data of memory areas A,B,C, and D is read out of the memory and coupled to the combiner **64** where the individual slice data is combined into a thick slice image. The resultant thick slice image is written into memory area G, from which it is read out and coupled to the image processor (and other components as described below) as needed for processing and display. In a typical implementation the time required to composite the thick slice image and process the image for display will take less time than the time required to rescan slices S_1 and S_2 . After the rescanning of slices S_1 and S_2 is complete, the image data of slices S_1 , S_2 , S_3 , and S_4 which is stored in memory areas C,D,E, and F is read out for combining into a new thick slice image for display, and the new thick slice image is written into memory area G to update the real time thick slice image. Simultaneously, slices S_3 and S_4 are rescanned and their slice data is written into memory areas A and B. In the next scanning interval iteration slices S_1 and S_2 are scanned again and their data written into memory areas C and D while the slice data of memory areas E,F,A, and B is combined to form another thick slice image to update the image in memory area G. This use of 4× multiline for slice acquisition and the combination of new slice data with the most recent data of the other slices of the thick slice image is seen to enable a frame rate of display of the thick slice image which is equal to that of a single slice scanned and displayed by conventional single line scanning. Thus, there would be no degradation of frame rate when changing from conventional single slice imaging to thick slice imaging of four component slices by this technique.

[0028] An implementation of the present invention has been found to be especially useful in colorflow imaging, particular for the detection of small, localized and intermittent flow conditions such as a heart valve jet. Colorflow has long been used in the detection of flow jets from valve leakage, a clinical application for which sensitivity far outweighs precise image resolution. Normally this procedure takes a long time as the clinician slowly moves the image plane around the heart valve, looking for a short burst of color characteristic of a jet. However, with the system of FIG. *5*, this procedure is considerably enhanced. Since the combiner combines a number of elevationally distinct planes spread over a small volumetric region in elevation, the jet need not occur in the center plane in order to be detected. The occurrence of a jet in the plane of an adjacent slice which is collapsed into the thick slice will enable the jet to be detected even when it is not present in the central slice plane of the thick slice. Furthermore, the jet is more easily detected by the reduction of speckle artifact and color dropout in the thick slice image. While the processing of one of the component slices by the Doppler processor **54** may result in black holes in the colorflow image where destructive interference from the speckle pattern has manifested itself, the differing speckle pattern of the neighboring slice may not exhibit this problem at the same point in the image. Thus, when the colorflow slices are combined in the elevation dimension into the thick slice image, the black hole of one slice may be filled in by valid colorflow of a neighboring slice. The colorflow field will appear smoother and more sensitive to out-of-central plane jets with less far field degradation. Sensitivity of the procedure to jet detection is accordingly enhanced. There are sev-

eral clinically accepted techniques for using jet area as a means of classifying the severity of pathologic regurgitant flow. The combined color flow thick slice will improve both the qualitative and quantitative outline of the jet, further facilitating the use of techniques for automatically calculating jet area.

[0029] These techniques may be extended to other cardiac applications such as the detection and visualization of coronary arteries. A thick slice image will better display the curved and tortuous paths of coronary arteries around the myocardium than a conventional single slice image. This is the case for contrast images as well as color flow images.

[0030] For the production of a Doppler thick slice image, ensembles of echo signals are received from locations where flow or motion is present and are processed by the Doppler processor **54** to produce a Doppler estimate at those locations. The Doppler estimate may be one of Doppler power at the location, or velocity or variance. Corresponding B mode images may also be acquired if desired so that the Doppler information may be overlaid on structural detail framing the motion. The Doppler slice images are stored in slice storage **60**, then combined by combiner **64** using a selected combining technique. Defects in the flow or motion display due to speckle or dropout are thereby reduced, and flow or motion defects in adjacent slice planes are more easily identified by the projection of multiple Doppler slices in the elevation dimension. Furthermore, since the acquisition of multiple temporally different samples from each flow or motion location will decrease the frame rate of acquisition in the Doppler mode, at least some of this frame rate degradation may be overcome by use of the high speed thick slice display technique discussed in conjunction with FIGS. *7a* and *7b* above.

[0031] In accordance with a further aspect of the present invention, the thick slice images are also coupled to an automated or semi-automated border detector (ABD) **80**. As is well known, border detectors are used to identify tissue borders in ultrasound images. The border detectors can operate with initial user involvement to identify points on one border in one image, then use that input to automatically identify the full border and the border in other images of a real time image sequence. Other border detectors operate automatically by identifying tissue landmarks in an image then drawing borders using those landmarks. See, for example, U.S. Pat. No. 6,491,636 (Chenal et al.) and U.S. Pat. No. 6,447,453 (Rounthill et al.) and US patent publication 2005/0075567 (Skyba et al.) The border detector **80** identifies a tissue border in a thick slice image with or without user assistance (semi-automated or automated) and couples data identifying the location of the border in one or more thick slice images to a graphics processor **74**. The graphics processor **74** creates a graphic outline of the border to the image processor **70** which overlays the identified border over the corresponding thick slice image. It has been found that automated or semi-automated border detection performs better on thick slice images than on comparable single slice images. This is because a tissue border defined by thin tissue which is not a strong reflector of ultrasonic echoes such as the endocardial border of the myocardium can produce a poorly defined tissue border in a single slice image. Image dropout at the border region can produce an ill-defined image border which is difficult to trace reliably by an automated or semi-automated process. In addition, the poorly-defined border can be further disrupted by the image speckle pattern. The combining of elevationally distinct images into a thick slice image can reduce the speckle artifact

and make the border more distinct in the image. In addition, missing border segments in one slice can be augmented by identifiable border segments in adjoining slices, causing the consolidated tissue border of the thick slice image to be more clearly defined and hence more reliably processed and identified by the border detector **80**.

[0032] In accordance with a further aspect of the present invention, thick slice imaging can be used with ultrasound contrast agents. Ultrasound contrast agents have been approved in the United States for delineation of endocardial borders in difficult-to-image patients. These agents have also proven to be extremely valuable in quantification of volumes and ejection fraction. In several studies, quantification without contrast agents has been shown to underestimate volumes compared to other techniques like MRI. On the other hand, contrast-enhanced images have demonstrated values closer to these techniques. However, previous attempts for automated detection techniques with contrast agents have had limited success. Typically contrast images are acquired with lower power levels to minimize microbubble destruction—often 10-15 dB lower than standard imaging. Consequently the resultant images can have a display dynamic range which is 10 dB or more lower than conventional images without contrast, causing speckle artifact to have a more pronounced adverse impact on the ability to automatically detect endocardial borders.

[0033] In accordance with a further aspect of the present invention, thick slice imaging is used in the diagnosis and quantification of perfusion defects with the aid of ultrasonic contrast agents. When a contrast agent is present in a blood pool such as a blood vessel or chamber of the heart, the contrast agent will generally be present in considerable volume and density in the blood pool. The relatively high concentration of the microbubbles of the contrast agent enable quick and reliable detection of its presence in an ultrasound image. However in perfusion studies such as those conducted with contrast agents to detect poorly perfused tissue such as myocardial tissue which has been infarcted, the contrast agent is only present in small amounts in the tiny capillaries which perfuse the tissue. This low concentration of the microbubbles often makes their detection and quantification difficult or unreliable. This is at a time when high resolution is required since perfusion defects often show up as thin subendocardial regions of slower filling as well as potentially lower blood volume. In addition, perfusion studies are generally conducted at low transmit power levels to avoid breaking or disrupting the microbubbles in the capillary bed and causing them to disappear. Consequently the signal-to-noise ratio of the perfusion images is relatively low, frequently by as much as 20 dB lower than standard imaging techniques, causing further degradation in resolution. The resultant images can have a display dynamic range which is 20 dB or more lower than conventional images without contrast, causing the speckle artifact to have a more pronounced adverse impact on image resolution and the detection of subendocardial regions of poor perfusion.

[0034] Accordingly, contrast images for perfusion diagnosis and/or quantification are improved in accordance with the present invention by scanning multiple planes in the elevation dimension and projecting these multiple elevation slices in the elevation dimension. By performing such operations it is possible to reduce speckle without sacrificing resolution and signal to noise. The methods for compositing or combining slices which have been described above may be employed,

including simple averaging and maximum intensity projection, or using compositing techniques from volume rendering (e.g., raycasting). By performing these techniques, the contrast agent speckle will be greatly reduced, subendocardial defects will be more evident, and quantification techniques such as parametric imaging will yield better results. Furthermore, since "destruction-replenishment" techniques require exactly the same elevation slice to be maintained for 10 seconds or more, thick-slice imaging will be more robust in the presence of small movements of the probe, since a plurality of adjacent slices are used to form the thick slice image plane. Thus, slight movement of the probe to different slice locations will have only minimal effect on the results obtained.

[0035] An ultrasound system constructed in accordance with the principles of the present invention for perfusion studies is shown in block diagram form in FIG. 6, in which elements previously described in conjunction with FIG. 5 are identified by the same reference numerals. In this system thick slice images of microbubble-perfused tissue which are produced by the combiner 64 may be processed as B mode images by the image processor 70, the video processor 72, and the display 76 for the display of real time grayscale images of perfusion which exhibit better resolution of tissue perfusion by virtue of reduced speckle caused by the elevational slice combining process. In this example the thick slice contrast images are also coupled to a perfusion detector 90. The perfusion detector 90 may be constructed in the same manner as the contrast signal detector described in PCT publications WO 2005/044108 (Rafter) and WO 2005/099579 (Rafter) to detect and enhance the display of contrast agent perfusion in the images. Alternatively or in addition the perfusion detector may be configured as the contrast signal detector described in U.S. Pat. No. 6,692,438 (Skyba et al.) to produce a color overlay of the B mode image which depicts perfused tissue in a qualitative color display, or a quantitative display of a perfusion curve or curve parameter for different points in the image.

[0036] The detection of epicardial borders is important to improve accuracy of stress echo exams and for detection of ischemia as well as to facilitate quantification of myocardial mass. However, accurate automatic detection of the epicardium has proven to be elusive. With contrast-enhanced imaging of thick slices, left ventricular opacification and myocardial perfusion improves the ability to detect both the epicardial and endocardial borders, allowing quantification of thickening and myocardial mass.

[0037] FIG. 8 illustrates an example of an ultrasound system display screen which depicts perfusion using a contrast agent in various ways. In the upper left area of the screen is a thick slice ultrasound image 92 in which the myocardium around the left ventricle has been perfused with a contrast agent as indicated by the light shading. The darker center of the image 92 is the heart chamber. The brighter the shading of the myocardium, the greater the concentration of contrast agent in that region of the myocardium and the better the perfusion of the tissue. To the right of the ultrasound image 92 are four parametric images 94 in which different parameters are displayed related to the perfusion of the myocardium and are depicted in color, with some colors indicating low perfusion and others indicating greater perfusion. Each color corresponds to a particular amount of perfusion depicted by the color bar located between the ultrasound image 92 and the parametric images 94. At the bottom of the screen is an area 96 displaying perfusion curves 98 at the regions marked by

the small circles on the right side myocardium in the thick slice ultrasound image 92. Each perfusion curve 98 represents the rate of reperfusion of a particular region of the myocardium as measured by the reperfusion of microbubbles into the region following a high energy flash disruption of the microbubbles.

[0038] Other variation of the present invention will readily occur to those skilled in the art. For example, the concepts of the present invention may be employed in an implementation which does not use multiline acquisition but acquires one receive line for every transmitted scanline. Various sequence of line acquisition may be employed other than successive acquisition of adjacent lines such as those shown in U.S. Pat. No. 5,438,994 (Starosta et al.) and U.S. Pat. No. 5,617,863 (Roundhill et al.) Higher order multiline may be employed than the illustrated 4X multiline, including a multiline order which acquires all of the component slices in one azimuthal scan sequence. Doppler modes other than colorflow may use the present invention including spectral Doppler, flow variance, and color M mode. M mode may use an implementation of the present invention which acquires and combines spatially distinct M lines into one display M line. The techniques of the present invention are applicable to both fundamental and harmonic imaging.

What is claimed is:

1. An ultrasonic diagnostic imaging system for the qualitative or quantitative analysis of tissue perfusion comprising: an array transducer adapted to transmit and receive scanlines over a volumetric region containing tissue which may have a perfusion defect; a beamformer, coupled to the array transducer, which acts to produce image data of a plurality of elevationally distinct slices of the volumetric region; a slice memory, coupled to the beamformer, which stores slice image data; a combiner, coupled to the slice memory, which combines slice image data in the elevation direction; a perfusion detector which operates on the combined slice image data to qualitatively depict perfusion by the concentration of microbubbles in tissue or to produce a quantified perfusion parameter for a region of tissue; and a display responsive to the perfusion detector for displaying at least one of a tissue image with perfusion depicted by color or brightness, or a quantified perfusion parameter for a region of tissue.
2. The ultrasonic diagnostic imaging system of claim 1, wherein the display displays an elevationally combined slice image of tissue with perfused areas indicated by brightness.
3. The ultrasonic diagnostic imaging system of claim 1, wherein the display displays a parametric image with different degrees of perfusion indicated by different colors.
4. The ultrasonic diagnostic imaging system of claim 1, wherein the display displays a perfusion curve for a particular region of an elevationally combined slice image of tissue.
5. The ultrasonic diagnostic imaging system of claim 1, further comprising a beamformer controller coupled to the beamformer which controls the number of slices to be scanned for an elevationally combined slice image.
6. The ultrasonic diagnostic imaging system of claim 5, wherein the array transducer is adapted to electronically focus and steer scanlines over a volumetric region.
7. The ultrasonic diagnostic imaging system of claim 6, wherein the beamformer further comprises a multiline beamformer.

8. The ultrasonic diagnostic imaging system of claim 7, wherein the beamformer controller further controls at least one of the number of transmit slices and the number of receive slices per transmit slice.

9. The ultrasonic diagnostic imaging system of claim 1, wherein the combiner further performs at least one of summing slice data in the elevation direction, averaging slice data in the elevation direction, weighting slice data in the elevation direction, or detecting the maximum value of slice data in the elevation direction.

10. The ultrasonic diagnostic imaging system of claim 1, further comprising a log detector having an input coupled to the beamformer and an output coupled to the slice memory.

11. An ultrasonic diagnostic imaging system for the diagnosis of tissue perfusion comprising:

an array transducer located in an ultrasound probe and adapted to transmit and receive scanlines over a volumetric region;

a microbeamformer located in the probe and coupled to the array transducer to control the steering and focusing of ultrasound signals over a plurality of adjacent slices in the volumetric region where contrast agent perfused tissue is present, the adjacent slices being parallel to each other in the elevation direction;

a detector, coupled to the microbeamformer, which detects image data of the slices;

a slice memory, coupled to the detector, which stores slice image data;

a combiner, coupled to the slice memory, which combines slice image data in the elevation direction;

a perfusion data processor, coupled to the combiner, which processes the combined slice image data to produce at least one of a qualitative or quantitative measure of perfusion; and

a display responsive to the perfusion data processor for displaying at least one measure of perfusion of tissue from combined slice image data.

12. The ultrasonic diagnostic imaging system of claim 11, wherein the display is responsive to the perfusion data processor for producing a combined slice image with differently perfused areas indicated by a range of brightness levels.

13. The ultrasonic diagnostic imaging system of claim 11, wherein the display is responsive to the perfusion data processor for producing a parametric image with differently perfused areas indicated by different colors.

14. The ultrasonic diagnostic imaging system of claim 1, wherein the display is responsive to the perfusion data processor for producing a perfusion curve or curve parameter for a particular region of contrast agent perfused tissue.

15. The ultrasonic diagnostic imaging system of claim 11, wherein the array transducer comprises an electronically steered and focused two dimensional array transducer.

16. The ultrasonic diagnostic imaging system of claim 15, wherein the array transducer acts to transmit beams, each of which insonifies a plurality of receive line locations, and acts to receive echoes from the receive line locations simultaneously.

17. The ultrasonic diagnostic imaging system of claim 16, wherein the array transducer acts to transmit beams, each of which insonifies receive line locations of a plurality of slices.

18. The ultrasonic diagnostic imaging system of claim 17, wherein the detector detects image data of the plurality of slices, and

wherein the slice memory operates to store the image data of the plurality of slices.

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专利名称(译)	超声厚切片成像定量灌注研究		
公开(公告)号	US20100056921A1	公开(公告)日	2010-03-04
申请号	US12/594906	申请日	2008-04-09
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V.		
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发明人	RAFTER, PATRICK G. THIELE, KARL BURNHAM, ROBERT L.		
IPC分类号	A61B8/14		
CPC分类号	A61B8/06 A61B8/0883 A61B8/463 A61B8/483 A61B8/5223 A61B8/5253 A61B8/5269 A61B8/481 G01S7/5208 G01S15/8925		
优先权	60/911598 2007-04-13 US		
其他公开文献	US9955941		
外部链接	Espacenet USPTO		

摘要(译)

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