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(54) **ULTRASOUND COLOR CHARACTERISTIC MAPPING**

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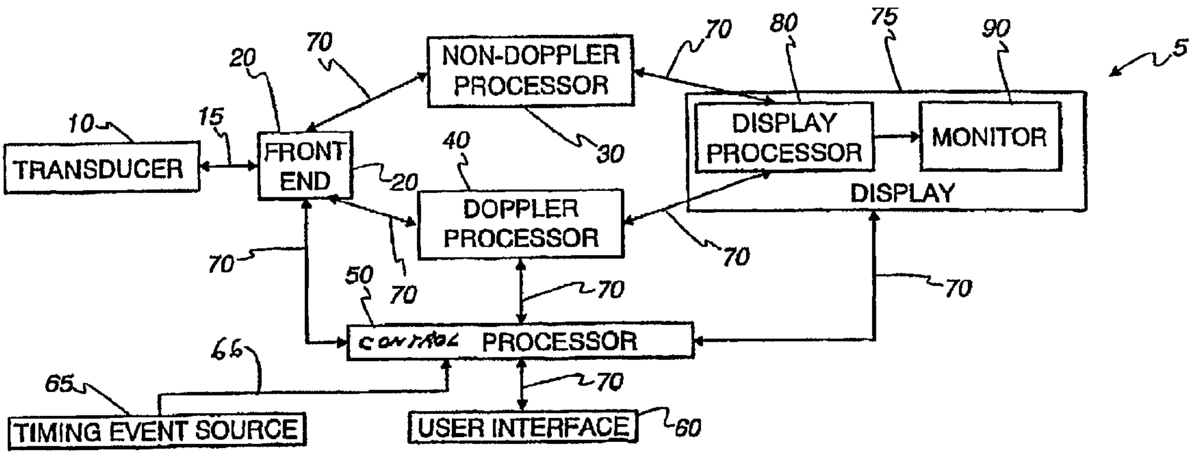
(52) **U.S. Cl.** **382/128**

(57) **ABSTRACT**

An ultrasound machine is disclosed that displays a color representation of moving structure, such as a cardiac wall tissue, within a region of interest on a monitor. The color representation is generated by displaying at least one color characteristic corresponding to a movement parameter of the structure, such as velocity or strain rate. The movement parameter is mapped to the color characteristic by apparatus comprising a front-end that generates received signals in response to ultrasound waves. A Doppler processor generates a set of parameter signals representing values of the movement parameter within the structure. A control processor adaptively generates a mapping function based on the distribution of the parameter signals to map the parameter signals to a set of color characteristic signals. A display processor applies the mapped values of the color characteristic legend to the values of the movement parameter representing the moving structure, to display a color representation on the monitor in response to the mapping function.



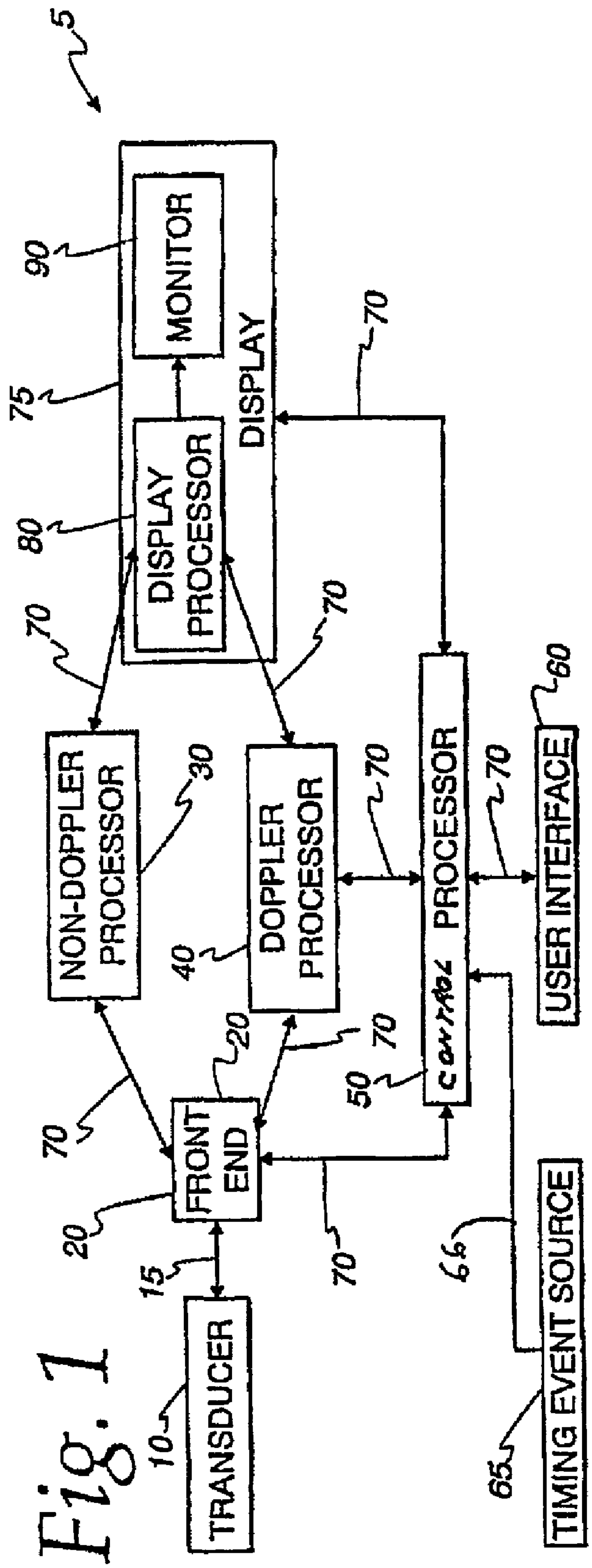

5
MONITOR
DISPLAY PROCESSOR
DISPLAY
NON-DOPPLER PROCESSOR
DOPPLER PROCESSOR
CONTROL PROCESSOR
USER INTERFACE
FRONT END
TRANSDUCER
TIMING EVENT SOURCE
10
15
20
30
40
50
60
65
66
70
75
80
90

Fig. 1

Fig. 2

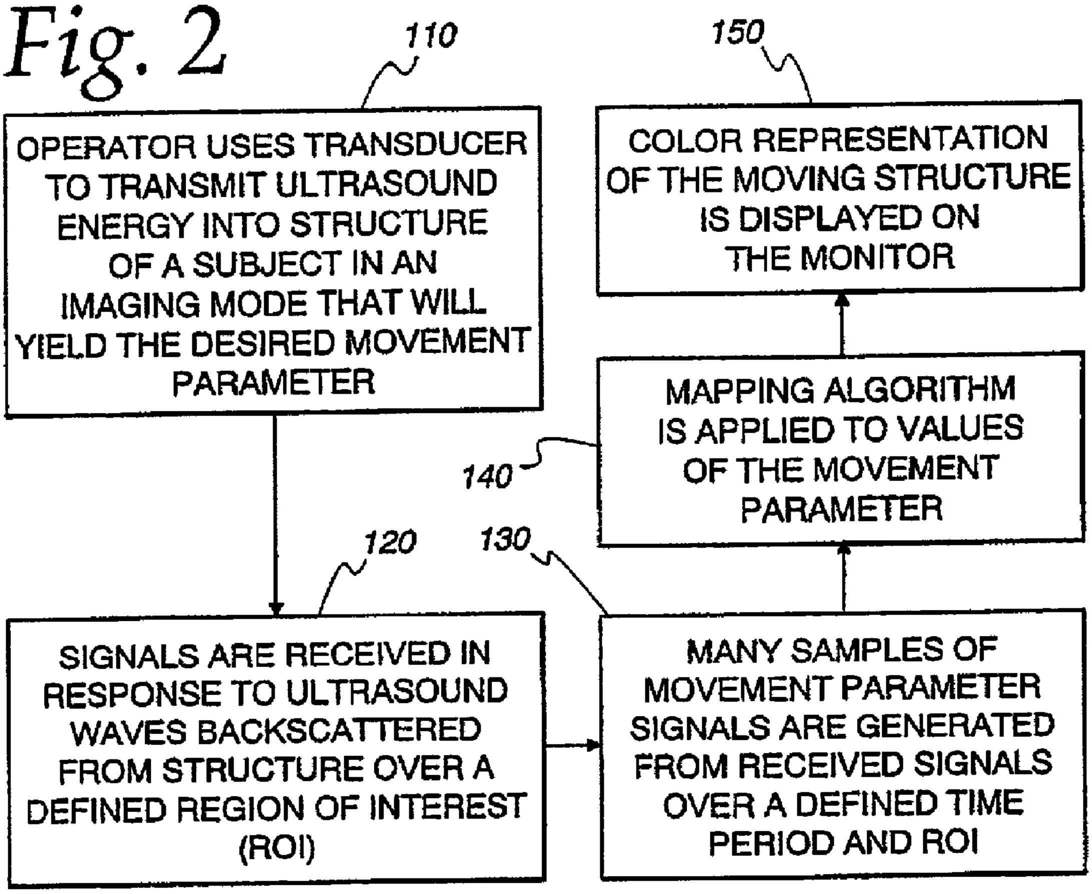

110
OPERATOR USES TRANSDUCER TO TRANSMIT ULTRASOUND ENERGY INTO STRUCTURE OF A SUBJECT IN AN IMAGING MODE THAT WILL YIELD THE DESIRED MOVEMENT PARAMETER
120
SIGNALS ARE RECEIVED IN RESPONSE TO ULTRASOUND WAVES BACKSCATTERED FROM STRUCTURE OVER A DEFINED REGION OF INTEREST (ROI)
130
MANY SAMPLES OF MOVEMENT PARAMETER SIGNALS ARE GENERATED FROM RECEIVED SIGNALS OVER A DEFINED TIME PERIOD AND ROI
140
MAPPING ALGORITHM IS APPLIED TO VALUES OF THE MOVEMENT PARAMETER
150
COLOR REPRESENTATION OF THE MOVING STRUCTURE IS DISPLAYED ON THE MONITOR

Fig. 3

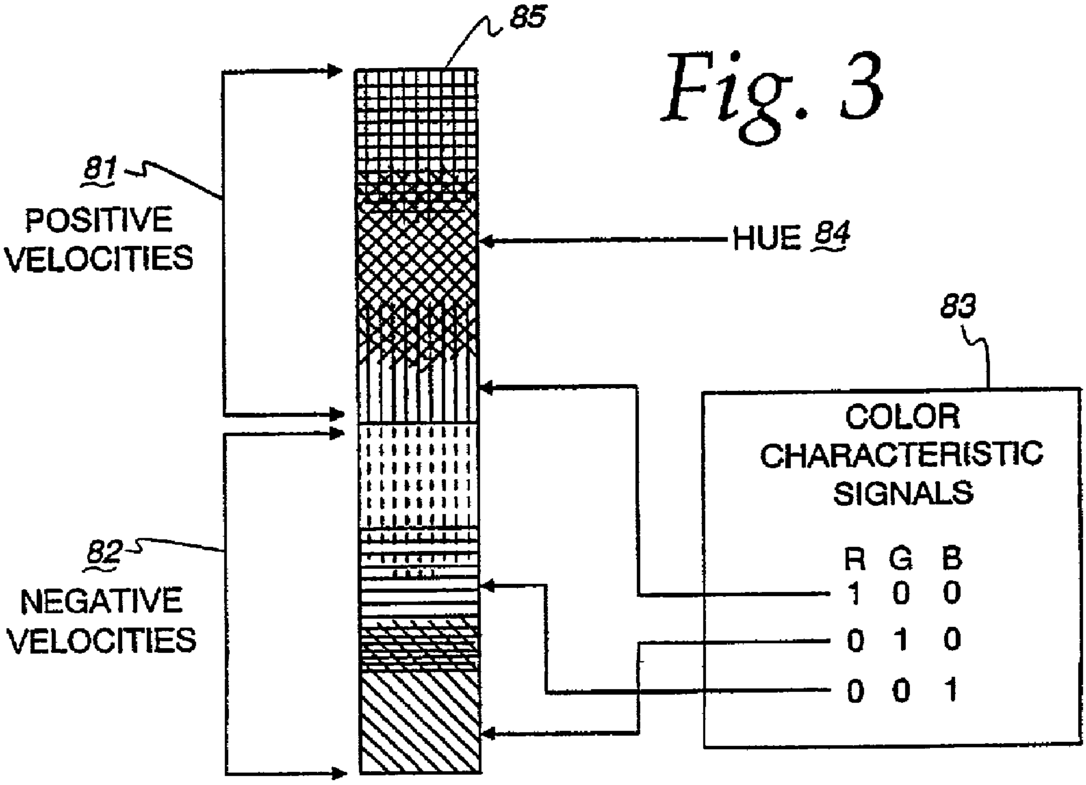

85
81
POSITIVE VELOCITIES
HUE 84
83
COLOR CHARACTERISTIC SIGNALS
R G B
1 0 0
0 1 0
0 0 1
82
NEGATIVE VELOCITIES

Fig. 4a

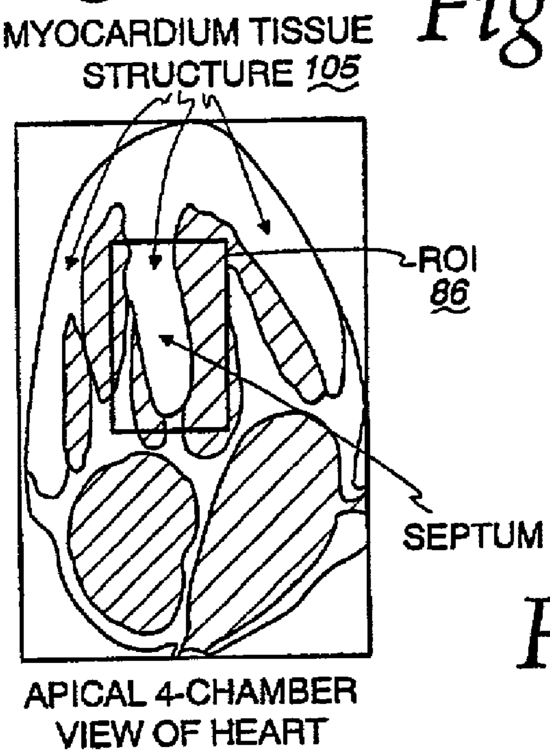


Fig. 4b

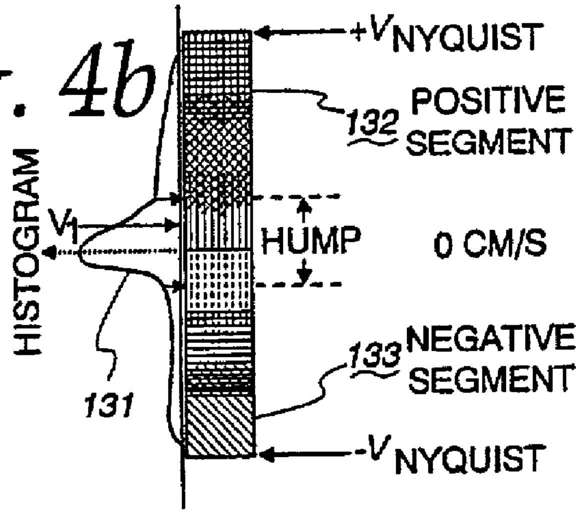


Fig. 4c

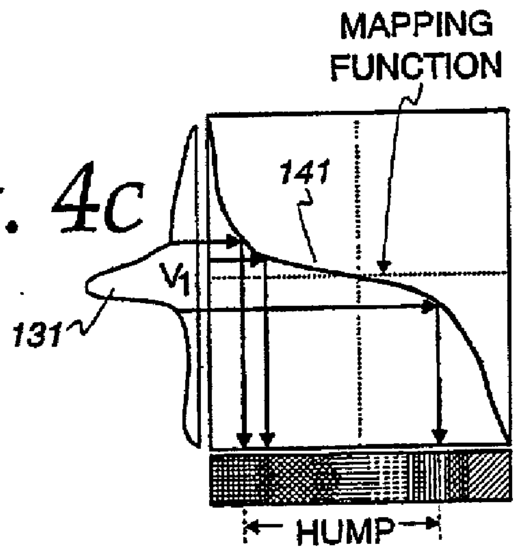


Fig. 5

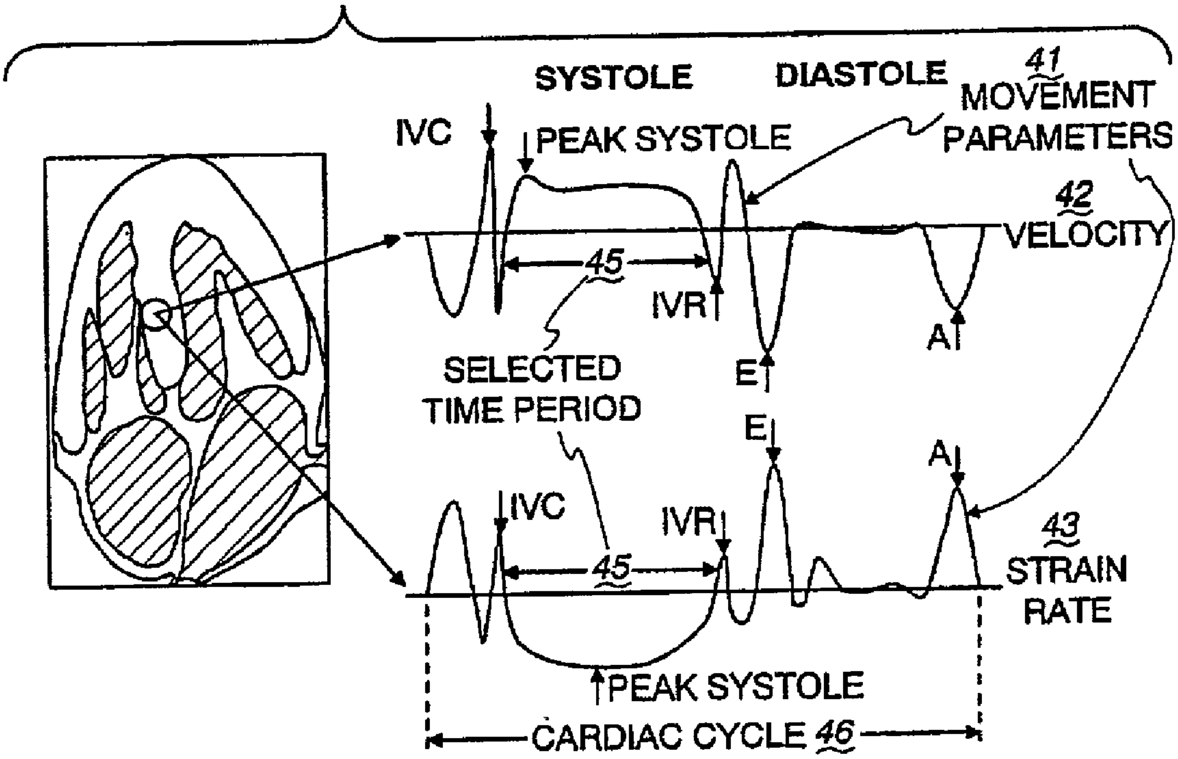


Fig. 6

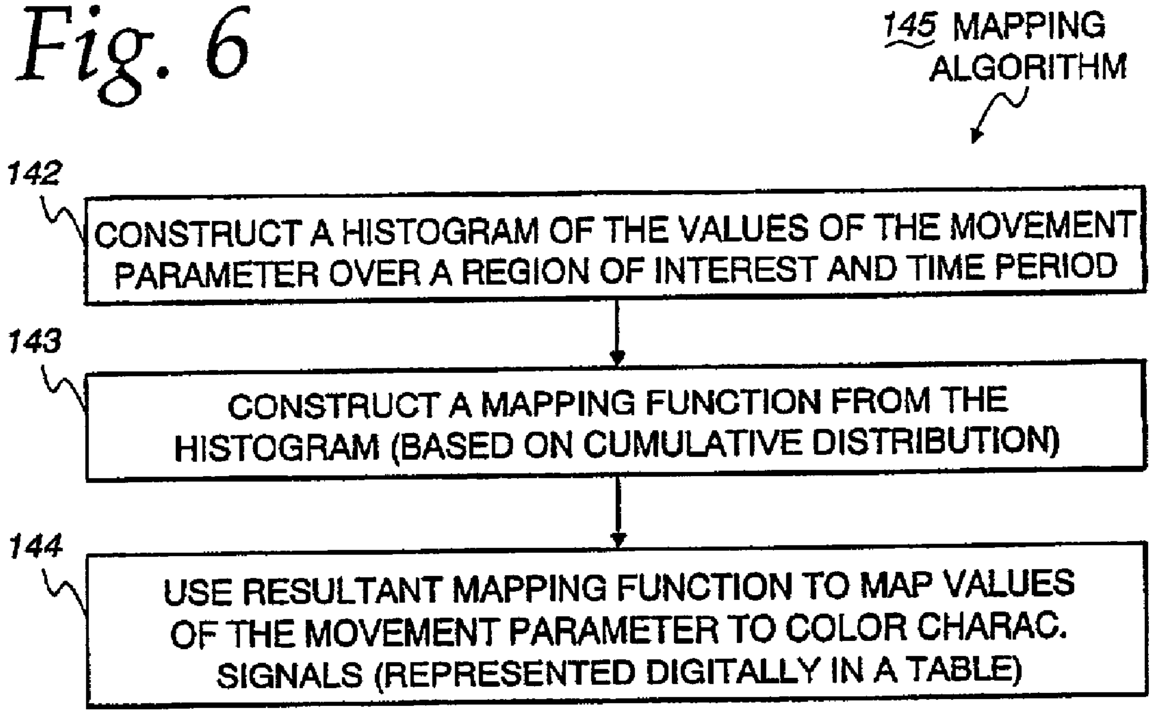
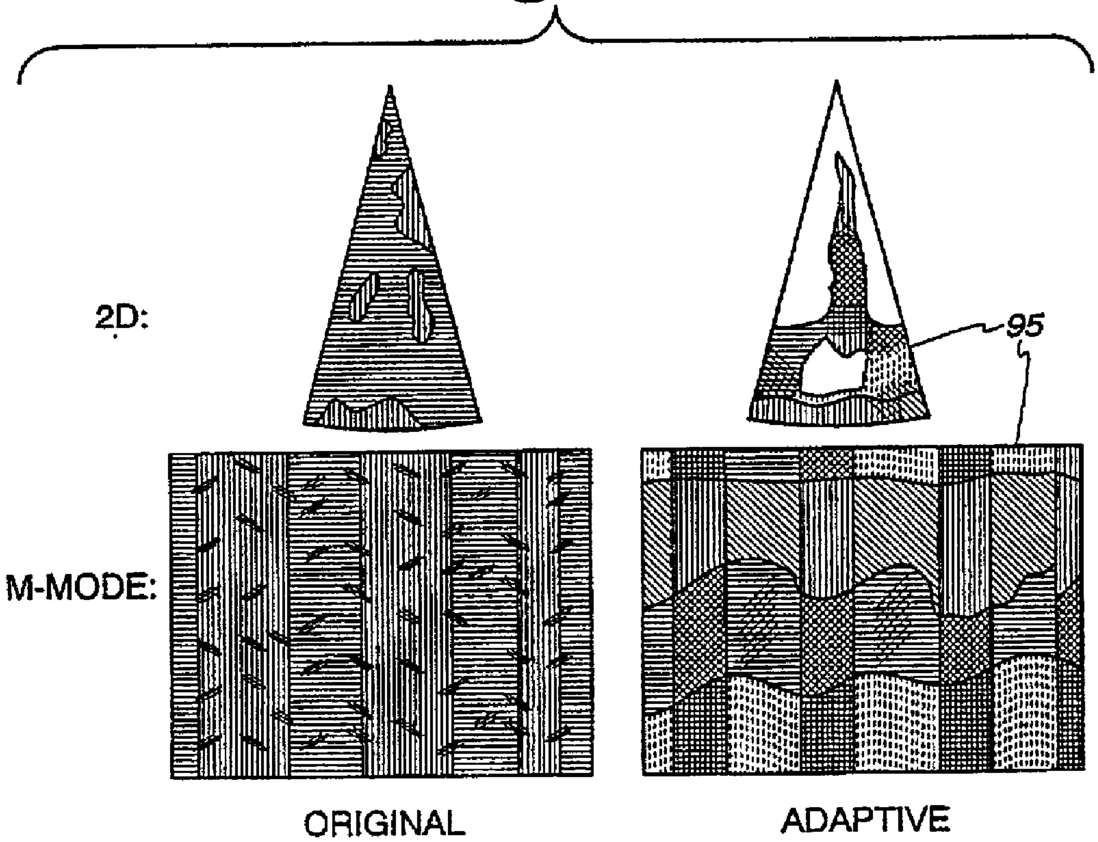

145 MAPPING ALGORITHM
142
CONSTRUCT A HISTOGRAM OF THE VALUES OF THE MOVEMENT PARAMETER OVER A REGION OF INTEREST AND TIME PERIOD
143
CONSTRUCT A MAPPING FUNCTION FROM THE HISTOGRAM (BASED ON CUMULATIVE DISTRIBUTION)
144
USE RESULTANT MAPPING FUNCTION TO MAP VALUES OF THE MOVEMENT PARAMETER TO COLOR CHARAC. SIGNALS (REPRESENTED DIGITALLY IN A TABLE)

Fig. 7


2D:
95
M-MODE:
ORIGINAL
ADAPTIVE

ULTRASOUND COLOR CHARACTERISTIC MAPPING

CROSS REFERENCE TO APPLICATIONS

[0001] The applicants claimed priority based on provisional application No. 60/297572 filed Jun. 12, 2001 in the names of Bjorn Olstad, Steinar Bjaerum, and Kjell Kristoffersen.

BACKGROUND OF THE INVENTION

[0002] Certain embodiments of the present invention relate to an ultrasound machine for generating and displaying an image of moving structure. More particularly, certain embodiments relate to adaptively color mapping an image of moving structure such as heart tissue.

[0003] Echocardiography is a branch of the ultrasound field that is currently a mixture of subjective image assessment and extraction of key quantitative parameters. Evaluation of cardiac wall function has been hampered by a lack of well-established parameters that may be used to increase the accuracy and objectivity in the assessment of, for example, coronary artery diseases. Stress echo is such an example. It has been shown that the subjective part of wall motion scoring in stress echo is highly dependent on operator training and experience. It has also been shown that inter-observer variability between echo-centers is unacceptably high due to the subjective nature of the wall motion assessment.

[0004] Much technical and clinical research has focused on the problem and has aimed at defining and validating quantitative parameters. Encouraging clinical validation studies have been reported, that indicate a set of new potential parameters that may be used to increase objectivity and accuracy in the diagnosis of, for instance, coronary artery diseases. Many of the new parameters have been difficult or impossible to assess directly by visual inspection of the ultrasound images generated in real-time. The quantification has typically required a post-processing step with tedious, manual analysis to extract the necessary parameters.

[0005] Much of the prior art describes techniques for non-adaptive color mapping of estimated imaging parameters such as tissue velocity and strain rate. A fixed mapping of a continuous range of color hues is typically used to indicate positive velocities or strain rates and a second fixed mapping of a continuous range of color hues is used to indicate negative velocities or strain rates. This type of color encoding makes it easy to identify reversals in velocities or strain rates. Timing information related to the velocity or strain rate reversals is also easy to extract from M-mode displays.

[0006] However, the non-adaptive color schemes in the prior art are not well suited for visual determination of other parameters, such as quantitative velocities or strain rates. Typically, a Nyquist velocity and associated pulse repetition frequency is set in order to avoid aliasing. Most of the actual velocities present are only a small fraction of the peak velocity which, in cardiac imaging from apex, typically may be measured at the mitral ring during the E-wave in diastole. As a result, most regions in the image are mapped with only small variations of the color hue mapped to lower positive and/or lower negative velocities. Quantitative assessment of parameters such as velocities or strain rates from 2-D images has been difficult, even in lucky situations, with a good spread of measured imaging parameters. It has, therefore, been necessary to resort to post-processing techniques and manual extraction of the digital information used in the color encoding for estimation of quantitative values.

[0007] Certain adaptive techniques have been previously applied to flow signals. For example, a method in U.S. Pat. No. 6,01 7,309 to Washburn et al. describes color coding of color flow data relating to fluid, such as blood. As explained in Col. 8, lines 25-54, an Auto Color Map Threshold/Compression Algorithm allows the stored color map threshold to be reset for better detection of low velocity or low power flow and allows the map to be re-mapped or compressed over the range of color flow data actually present. Two algorithms are provided: one for velocity mode and one for PDI mode. For the velocity mode, N frames of color flow data are collected from cine memory **28**C and formed into a composite histogram as shown in **FIG. 8**. The N frames are required to account for flow pulsatility. Then, the fixed map threshold is received by the algorithm from memory at a terminal **31** and is adjusted, if necessary, and the color map is re-created to apply more colors of the map across the full range of data in the composite histogram in a linear manner. As **FIG. 8** shows, the positive velocity data in the composite histogram does not cover the full range of 0 to 127, but instead covers some smaller range in-between. The algorithm calculates the statistics of the histogram data and sets the new map threshold to be x standard deviations below the mean. The value of x is determined per application to maximize low velocity flow detection while minimizing low velocity artifacts such as residual wall or tissue motion. The negative map threshold similarly is set for negative velocities based on the statistics of the negative velocity histogram. In this example of **FIG. 8**, the velocity color map is re-created (effectively linearly compressed) to apply more of its colors across the range of data in the composite histogram, taking into account the map threshold as a reference end point.

[0008] Methods in U.S. Pat. No. 6,071,241 to Washburn et al., U.S. Pat. No. 6,126,605 to Washburn et al., and U.S. Pat. No. 6,162,1 76 to Washburn et al., each describe an ultrasound color flow imaging system programmed to optimize display images of power and velocity by automatically adjusting thresholds by using histograms and samplings of color flow data.

[0009] A method in U.S. Pat. No. 6,120,451 to Washburn et al. describes an ultrasound color flow imaging system programmed to optimize display images of power and velocity by automatically adjusting thresholds by using histograms.

[0010] None of the foregoing patents, however, describe or suggest any color mapping technique for generating an ultrasound display of moving structure that uses the full dynamic range of the color map. The foregoing patents relate to displays representing moving fluid, such as blood and only perform simple linear compressions of the color map dynamic range or pre-determined non-linear compressions.

[0011] A need exists for a robust approach to more easily visualize tissue motion parameter information, such as strain rate, in a two-dimensional ultrasound image such that more of the tissue motion parameter information is broken out and is observed.

SUMMARY OF THE INVENTION

[0012] An embodiment of the present invention provides an ultrasound system for generating an image responsive to moving cardiac structure by adaptively generating a mapping function based on parameter signals and mapping the parameter signals to a set of color characteristic signals.

[0013] An apparatus is provided in an ultrasound machine for generating a display responsive to moving structure within a region of interest (ROI) of a subject by displaying at least one color characteristic corresponding to a movement parameter of the structure. In such an environment the apparatus for mapping the color characteristic preferably comprises a front-end arranged to generate transmitted signals into the structure and then to generate received signals in response to ultrasound waves backscattered from the structure in the ROI over a time period. A processor is responsive to the received signals to generate a set of parameter signals representing values of the movement parameter within the structure during at least a portion of the time period and is responsive to a distribution of the set of parameter signals and a mapping algorithm to generate a set of color characteristic signals representative of the values of the movement parameter. A display is arranged to display a color representation of the moving structure in response to the color characteristic signals. The resultant mapping is dependent, in part, on the distribution of values of the movement parameter and, therefore, the embodiment is adaptive.

[0014] A method is also provided in an ultrasound machine for generating a display responsive to moving structure within a region of interest of a subject by displaying at least one color characteristic corresponding to a movement parameter of the structure. In such an environment, the method preferably comprises transmitting signals into the structure and receiving signals in response to ultrasound waves backscattered from the structure in the region of interest over a time period. A set of parameter signals representing values of the movement parameter within the structure during the time period is generated in response to the received signals. A mapping function generates a set of color characteristic signals representative of the values of the movement parameter in response to a distribution of the set of parameter signals and a mapping algorithm. A color representation of the moving structure is displayed in response to the set of color characteristic signals. The resultant mapping is dependent, in part, on the distribution of values of the movement parameter and, therefore, the embodiment is adaptive.

[0015] Certain embodiments of the present invention afford an approach to more easily visualize tissue motion parameter information, such as tissue velocity and strain rate, in a two-dimensional ultrasound image such that more of the tissue motion parameter information is broken out and observed.

BRIEF DESCRIPTION OF DRAWINGS

[0016] **FIG. 1** is a schematic block diagram of an ultrasound machine made in accordance with an embodiment of the present invention.

[0017] **FIG. 2** is a flowchart of a method performed by the machine shown in **FIG. 1** in accordance with an embodiment of the present invention.

[0018] **FIG. 3** illustrates an exemplary color characteristic legend, comprising continuously varying hues of color, and is presented on the display shown in **FIG. 1** in accordance with an embodiment of the present invention.

[0019] **FIG. 4*a*** is a schematic cross-sectional view of the human heart including myocardium tissue bounded by a region of interest (ROI) that is designated by the machine shown in **FIG. 1** in accordance with an embodiment of the present invention.

[0020] **FIG. 4*b*** is an exemplary histogram representing the frequency of occurrence of estimated velocity values of samples of tissue within the ROI of **FIG. 4*a*,** generated by the machine shown in **FIG. 1** in accordance with an embodiment of the present invention.

[0021] **FIG. 4*c*** shows a resultant form of a mapping function that maps the histogram of **FIG. 4*b*** to an exemplary color characteristic legend according to a mapping algorithm executed by the machine shown in **FIG. 1** in accordance with an embodiment of the present invention.

[0022] **FIG. 5** is a schematic cross-sectional view of the heart shown in **FIG. 4*a*** also illustrating typical velocity and strain rate profiles as a function of time, measured longitudinally in an apical view in accordance with an embodiment of the present invention.

[0023] **FIG. 6** is a flowchart of a mapping algorithm for adaptive mapping of a set of color characteristic signals, resulting in the mapping function shown in **FIG. 4*c*** in accordance with an embodiment of the present invention.

[0024] **FIG. 7** shows sector and M-mode displays generated by the machine shown in **FIG. 1** and illustrates the effect of applying the resultant adaptive color characteristic mapping algorithm for a tissue velocity example in accordance with an embodiment of the present invention.

[0025] The foregoing summary, as well as the following detailed description of certain embodiments of the present invention, will be better understood when read in conjunction with the appended drawings. It should be understood, however, that the present invention is not limited to the arrangements and instrumentality shown in the attached drawings.

DETAILED DESCRIPTION

[0026] An embodiment of the present invention enables adaptive color mapping of moving tissue structure based on the distribution of movement parameter data. As used in this specification and claims, structure means non-liquid and non-gas matter, such as cardiac wall tissue. An embodiment of the present invention offers improved, real-time visualization and assessment of wall tissue function. The moving structure is characterized by a movement parameter, which means a parameter derived from movement of the structure, such as velocity or strain rate.

[0027] **FIG. 1** is a schematic block diagram of an embodiment of the present invention comprising an ultrasound machine **5**. A transducer **10** is used to transmit ultrasound waves into a subject by converting electrical analog signals to ultrasonic energy and to receive ultrasound waves backscattered from the subject by converting ultrasonic energy to analog electrical signals. A front-end **20** comprising a receiver, transmitter, and beamformer, is used to create the necessary transmitted waveforms, beam patterns, receiver filtering techniques, and demodulation schemes that are used for the various imaging modes. Front-end **20** performs the functions by converting digital data to analog data and vice versa. Front-end **20** interfaces at an analog interface **15** to transducer **10** and interfaces over a digital bus **70** to a non-Doppler processor **30**, a Doppler processor **40**, and a control processor **50**. Digital bus **70** may comprise several digital sub-buses, each sub-bus having its own unique configuration and providing digital data interfaces to various parts of the ultrasound machine **5**.

[**0028**] Non-Doppler processor **30** comprises amplitude detection functions and data compression functions used for imaging modes such as B-mode, B M-mode, and harmonic imaging. Doppler processor **40** comprises clutter filtering functions and movement parameter estimation functions used for imaging modes such as tissue velocity imaging (TVI), strain rate imaging (SRI), and color M-mode. The two processors, **30** and **40**, accept digital signal data from the front-end **20**, process the digital signal data into estimated parameter values, and pass the estimated parameter values to processor **50** and a display **75** over digital bus **70**. The estimated parameter values may be created using the received signals in frequency bands centered at the fundamental, harmonics, or sub-harmonics of the transmitted signals in a manner known to those skilled in the art.

[**0029**] Display **75** comprises scan-conversion functions, color mapping functions, and tissue/flow arbitration functions, performed by a display processor **80** which accepts digital parameter values from processors **30**, **40**, and **50**, processes, maps, and formats the digital data for display, converts the digital display data to analog display signals, and passes the analog display signals to a monitor **90**. Monitor **90** accepts the analog display signals from display processor **80** and the resultant image is displayed to the operator on monitor **90**.

[**0030**] A user interface **60** allows user commands to be input by the operator to the ultrasound machine **5** through control processor **50**. User interface **60** comprises a keyboard, mouse, switches, knobs, buttons, track ball, and on screen menus (not shown).

[**0031**] A timing event source **65** may be used to generate a cardiac timing event signal **66** that represents the cardiac waveform of the subject. The timing event signal **66** is input to ultrasound machine **5** through control processor **50**.

[**0032**] Control processor **50** is the main, central processor of the ultrasound machine **5** and interfaces to various other parts of the ultrasound machine **5** through digital bus **70**. Control processor **50** executes the various data algorithms and functions for the various imaging and diagnostic modes. Digital data and commands may be transmitted and received between control processor **50** and other various parts of the ultrasound machine **5**. As an alternative, the functions performed by control processor **50** may be performed by multiple processors, or may be integrated into processors **30**, **40**, or **80**, or any combination thereof. As a further alternative, the functions of processors **30**, **40**, **50**, and **80** may be integrated into a single PC backend.

[**0033**] Referring to **FIG. 2**, in step **110** an operator uses transducer **10** to transmit ultrasound energy into anatomical structure, such as cardiac tissue **105** (see **FIG. 4***a*), of the subject in an imaging mode, such as tissue velocity imaging (TVI), that will yield the desired estimated movement parameter values of the desired anatomical structure (typically a 2-dimensional apical cross section of the heart). Ultrasound energy is received into transducer **10** and signals are received into front-end **20** in response to ultrasound waves backscattered from the structure. The resultant estimated movement parameter values computed by Doppler processor **40** typically comprise longitudinal estimates of mean tissue velocity or strain rate.

[**0034**] In order to help the operator interpret the movement parameter, a color characteristic legend is displayed on monitor **90**. Referring to **FIG. 3**, in TVI mode, the color legend employs a fixed, continuous range of color hues to indicate positive velocities and a second fixed, continuous range of color hues is used to indicate negative velocities. Typically, red/yellow hues show anatomical motion towards the transducer **10** and blue/green hues show motion away from the transducer **10**. These color hues **84** are illustrated in the color characteristic legend **85** shown in **FIG. 3**. The various cross-hatchings and lines in the color characteristic legend **85** of **FIG. 3** represent a continuous range of color hues. Going from the top of the color characteristic legend **85** to the bottom, the colors transition from yellow to orange to red representing the positive velocity segment **81** of the color characteristic legend **85** and then violet to blue to green, representing the negative velocity segment of the color characteristic legend **85**. However, the color hues **84** that make up the color characteristic legend **85** may be any continuous or semi-continuous range of colors that provide good discrimination between levels of the movement parameter. The portions of **FIG. 3** in which cross-hatched lines intersect represent a blending of color hues.

[**0035**] The histogram **131** of **FIG. 4***b* illustrates how typical velocity measurements in the myocardium of the heart **105** will be distributed. Low positive and low negative velocities, compared to the peak velocities, dominate the frequency distribution as is seen by the hump in the histogram **131**. The peak velocities only occur for a short period of time. As illustrated in **FIG. 5**, typical velocity and strain rate values at specific points are plotted as a function of time. Apical images contain a large spatial gradient in the velocities. Peak velocities are both spatially and temporally localized and represent only a minor part of the histogram **131**.

[**0036**] In Step **120** of **FIG. 2**, ultrasound energy is received into transducer **10** and signals are received into front-end **20** in response to ultrasound waves backscattered from the structure **105** of a subject over an operator-defined region of interest (ROI) **86** (see **FIG. 4***a*). The operator brings up a scaleable ROI **86** on monitor **90** through the user interface **60** to select a spatial or anatomical region to process such as the septum of the heart (see **FIG. 4***a*). The ROI may be chosen to cover the entire displayed image if desired. Such a positioning of an ROI **86** forces the subsequent processing to segment and optimize the displayed image for that specific region.

[**0037**] In other similar embodiments, the ROI **86** may be selected automatically or as a combination of manual and automatic methods. For example, an algorithm for automatic positioning of an ROI **86** may be designed and embedded in the control processor **50** to separate the myocardium from cavities by using well-known segmentation and thresholding techniques operating on the data of the movement parameter.

[0038] In Step **130** of **FIG. 2**, received signals are sent from front-end **20** to Doppler processor **40** over digital bus **70**. Doppler processor **40** generates many samples of movement parameter signals, such as velocity or strain rate, using the well-known imaging modes of TVI and SRI over a segmented time period **45** (see **FIG. 5**) based on the received signals corresponding to the region designated by ROI **86**. The operator selects, through the user interface **60**, a desired time interval **45** to process, such as systole, which is a sub-interval of the cardiac cycle **46** (see **FIG. 5**). These time intervals are determined from well-known timing event sources **65 (FIG. 1)** and techniques such as electrocardiogram (ECG) techniques and/or from characteristic signatures in the profiles of the movement parameter data. Those skilled in ultrasound also know how to derive timing events from signals of other sources such as a phonocardiogram signal, a pressure wave signal, a pulse wave signal, or a respiratory signal. Ultrasound modalities such as spectral Doppler or M-modes may also be used to obtain cardiac timing information.

[0039] It may be advantageous to select a time interval **45** corresponding to a complete cardiac cycle **46** in order to optimize the display for the entire cardiac cycle **46**. Another possibility is to limit the time interval **45** to the systolic time period in order to display a color representation that is optimized for optimal systolic visualization. Other sub-intervals of the cardiac cycle **46** may also be applied. **FIG. 5** illustrates typical velocity **42** and strain rate **43** profiles which may be segmented into desired time periods based on profile features. For reference, the profiles in **FIG. 5** are annotated with the times corresponding to: IVC=isovolumetric contraction, IVR=isovolumetric relaxation, E=early diastolic velocity, and A=late diastolic velocity.

[0040] The time interval **45** may be selected automatically or as a combination of manual and automatic methods. For example, the time period may be determined automatically with an algorithm embedded in control processor **50**. The algorithm may use well-known techniques of analyzing estimated parameter profiles looking for key signature characteristics and defining a time period based on the characteristics or, similarly, analyzing the ECG signal. An automatic function may be implemented to recognize and exclude unwanted events from the selected time period, if desired, as well.

[0041] In Step **140** of **FIG. 2**, the values of the movement parameter are sent from Doppler processor **40** to control processor **50**, where a mapping algorithm **145** (see **FIG. 6**) is applied to the values of the movement parameter. **FIG. 6** is a flow chart of the mapping algorithm **145**.

[0042] In Step **142** of the mapping algorithm **145**, a histogram **131** is constructed from the many samples of the values of the movement parameter (see **FIG. 4*b***), restricted to those samples from the ROI **86** and the time interval **45**. This histogram **131** represents the frequency of occurrence of the values of the movement parameter. The histogram **131** may be constructed with or without weightings based on measurements of the values of the movement parameter (e.g. velocity or strain rate values). In one embodiment of the present invention, the positive **132** and negative **133** values of the movement parameter are processed separately, but in a similar manner, to construct the histogram **131**. An alternative is to construct a single histogram **131** for absolute values of the movement parameter instead of processing positive **132** and negative **133** values of the movement parameter separately. Such a single histogram **131** will make the final displayed color representation maintain visual separation of absolute differences between magnitudes of positive and negative movement relative to each other.

[0043] In Step **143** of the mapping algorithm **145**, a mapping function **141** is constructed by control processor **50** (see **FIG. 4*c***). This mapping function **141** is formed by generating a cumulative total of the frequency of occurrence of the values of the movement parameter **41** in the histogram **131**, and then normalizing the cumulative total to the domain of the color characteristic legend **85**. The result is a uniform distribution of the values of the movement parameter across the domain of the color characteristic legend **85**. As an option, the cumulative total may be weighted based on characteristics of the histogram **131**. Alternative transfer functions may be implemented as well, resulting in other distributions of the values of the movement parameter across the domain of the color characteristic legend **85**.

[0044] In Step **144** of the mapping algorithm **145**, the resultant mapping function **141** is used by control processor **50** as a non-linear transfer function between the values of the movement parameter (e.g. **42** or **43**) and the values of the color hues **84** in the color characteristic legend **85** (see **FIG. 4*c***). The process is illustrated by the arrows shown in **FIG. 4*c*,** for a particular estimated velocity value. It may be seen, in **FIG. 4*c*,** that the location within the color characteristic legend that the particular velocity value V_1 now gets mapped to is different from the location within the color characteristic legend V_1 was mapped to originally in **FIG. 4*b*,** before creation of the new mapping function **141**. The frequency of occurrence of the values of the movement parameter now have a proportional relationship to the number of color hues **84** in the color characteristic legend **85**.

[0045] For example, the center portion (hump) of the histogram **131**, which contains most of the samples of velocity estimates, is now mapped over a broader range of color hues. Also, each fixed proportion of the hues **84** of the color characteristic legend **85** will occupy roughly the same amount of spatial locations in the image (i.e results in a uniform distribution of the values of the movement parameter across the domain of the color characteristic legend). The relationship between the values of the movement parameter and the color hues **84** is typically represented in a digital table in the memory of control processor **50** and transferred to the memory in display processor **80** over digital bus **70**.

[0046] The color hues are typically represented in memory as red, green, blue (RGB) values as shown in **FIG. 3**. The RGB values constitute the color characteristic signals **83**. The RGB values may be represented as normalized values between 0 and 1, as shown in **FIG. 3**. Therefore, to represent a perfectly red hue, the RGB values are (1 0 0). For a perfectly green hue, the RGB values are (0 1 0), and for blue (0 0 1). Any other color hue may be represented by various combinations of RGB values. For example, if an RGB value is (0.5 0.8 0.3), the combination of unequal parts of red, green, and blue hues each with a different weighting results in some new color hue.

[0047] An RGB combination of (1 1 1) yields a perfectly white hue and an RGB combination of (0 0 0) yields a perfectly black hue.

[0048] Live imaging may be temporarily suspended for a short period of time (e.g. a couple seconds) while the values of the movement parameter are segmented and processed, depending on the exact architecture and capabilities of the ultrasound machine **5**.

[0049] In Step **150** of **FIG. 2**, live imaging resumes with the new color characteristic mapping (color-mapping table) being applied to new values of the movement parameter (e.g. **42** or **43**) in display processor **80**. A color representation **95** of the moving structure **105** is displayed on monitor **90** as seen in **FIG. 7**. The new mapping causes the color characteristic legend **85** to represent actual values of the movement parameters in a non-linear manner. However, movement parameter values are broken out from each other much better, allowing for better observation of the movement parameter values present in the ROI.

[0050] **FIG. 7** illustrates the effect of the adaptive color characteristic mapping function **141** for a tissue velocity imaging example. The original image on the left is dominated by red and blue color hues (represented by the vertical and horizontal lines) indicating lower velocities relative to the Nyquist velocity. The right hand side of the figure illustrates the same data set with an adaptively determined color-mapping table applied. It may be seen in **FIG. 7** that the images on the right contain many more color hues (represented by the various vertical, horizontal, and diagonal lines and the various cross-hatchings and dashed lines) compared to the images on the left, thus allowing for better visual quantification of the movement parameter by the operator.

[0051] Strain rate adaptive color mapping may follow exactly the same method as tissue velocity adaptive color mapping. In addition, it may be possible to reserve a unique color hue for small spatial deformations under a preset strain rate threshold. The described mapping algorithm **145** would then be limited to operate on the strain rate values exceeding the threshold value.

[0052] As an option, the mapping algorithm may be designed such that movement parameter values of zero, such as zero velocity and zero strain rate, are always mapped to a fixed color hue. Also, as a further option, the mapping algorithm may be designed such that the movement parameter of a tracked anatomical location is mapped to a fixed color hue. As a result, mapping an endocardial or epicardial location, for example, would generate a standardized color representation of cardiac wall thickening.

[0053] An embodiment of the method may be applied to other imaging modes of the ultrasound machine **5** for moving structure, for any estimated parameter (e.g. velocity, strain rate, power, amplitude, etc.).

[0054] In summary, certain embodiments of the present invention afford an approach to more easily visualize tissue motion parameter information, such as tissue velocity and strain rate, in a two-dimensional ultrasound image such that more of the tissue motion parameter information is broken out and observed. Adaptive mapping of movement parameter data to a color characteristic legend based on the distribution of the movement parameter data accomplishes the desired result.

[0055] While the invention has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from its scope. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

1. In an ultrasound machine for generating an image responsive to moving structure within a region of interest of a subject by displaying at least one color characteristic corresponding to a movement parameter of said structure, apparatus for mapping said color characteristic comprising:

- a front-end arranged to transmit ultrasound waves into said structure and to generate received signals in response to ultrasound waves backscattered from said structure in said region of interest over a time period;
- a processor responsive to said received signals to generate a set of parameter signals representing values of said movement parameter within said structure during said time period and responsive to a distribution of said set of parameter signals and a mapping algorithm to generate a set of color characteristic signals representative of said values of said movement parameter; and
- a display arranged to display a color representation of said moving structure in response to said set of color characteristic signals.

2. The apparatus of claim 1 wherein said moving structure comprises cardiac tissue.

3. The apparatus of claim 1 further comprising a user interface arranged to enable an operator to select said region of interest from said image on a monitor.

4. The apparatus of claim 1, wherein said movement parameter comprises one of velocity and strain rate.

5. The apparatus of claim 1, wherein said color characteristic comprises hue.

6. The apparatus of claim 1, wherein said time period comprises at least a portion of a cardiac cycle.

7. The apparatus of claim 1 wherein said distribution of said set of parameter signals comprises a histogram representing frequency of occurrence of said values of said movement parameter.

8. The apparatus of claim 7 wherein said mapping algorithm generates a mapping function comprising a cumulative total of the occurrence of said values of said histogram.

9. The apparatus of claim 8 wherein said mapping algorithm further comprises normalization of said cumulative total to a domain of a color characteristic legend.

10. The apparatus of claim 8 wherein at least one of said histogram and said mapping function is weighted.

11. In an ultrasound machine for generating an image responsive to moving structure within a region of interest of a subject by displaying at least one color characteristic corresponding to a movement parameter of said structure, a method of mapping said color characteristic comprising:

transmitting ultrasound waves into said structure and generating received signals in response to ultrasound waves backscattered from said structure in said region of interest over a time period;

generating a set of parameter signals representing values of said movement parameter within said structure during said time period in response to said received signals;

generating a set of color characteristic signals representative of said values of said movement parameter in response to a distribution of said set of parameter signals and a mapping algorithm; and

displaying a color representation of said moving structure in response to said set of color characteristic signals.

12. The method of claim 11 wherein said moving structure comprises cardiac tissue.

13. The method of claim 11 and further comprising enabling an operator to select said region of interest from said image.

14. The method of claim 11 wherein said movement parameter comprises one of velocity and strain rate.

15. The method of claim 11 wherein said color characteristic comprises hue.

16. The method of claim 11 wherein said time period comprises at least a portion of a cardiac cycle.

17. The method of claim 11 wherein said distribution of said set of parameter signals comprises a histogram representing frequency of occurrence of said values of said movement parameter.

18. The method of claim 17 wherein said mapping algorithm generates a mapping function comprising a cumulative total of the occurrence of values of said histogram.

19. The method of claim 18 wherein said mapping algorithm further comprises normalization of said cumulative total to a domain of a color characteristic legend.

20. The method of claim 18 wherein at least one of said histogram and said mapping function is weighted.

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摘要(译)

公开了一种超声机，其在监视器上的感兴趣区域内显示移动结构（例如心壁组织）的颜色表示。通过显示对应于结构的运动参数的至少一个颜色特性（例如速度或应变率）来生成颜色表示。通过包括前端的装置将运动参数映射到颜色特性，该前端响应于超声波产生接收信号。多普勒处理器生成表示结构内的运动参数的值的一组参数信号。控制处理器基于参数信号的分布自适应地生成映射函数，以将参数信号映射到一组颜色特征信号。显示处理器将颜色特征图例的映射值应用于表示移动结构的移动参数的值，以响应于映射功能在监视器上显示颜色表示。