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Nikolov et al.

(54) **3-D ULTRASOUND IMAGING WITH MULTIPLE SINGLE-ELEMENT TRANSDUCERS AND ULTRASOUND SIGNAL PROPAGATION CORRECTION**

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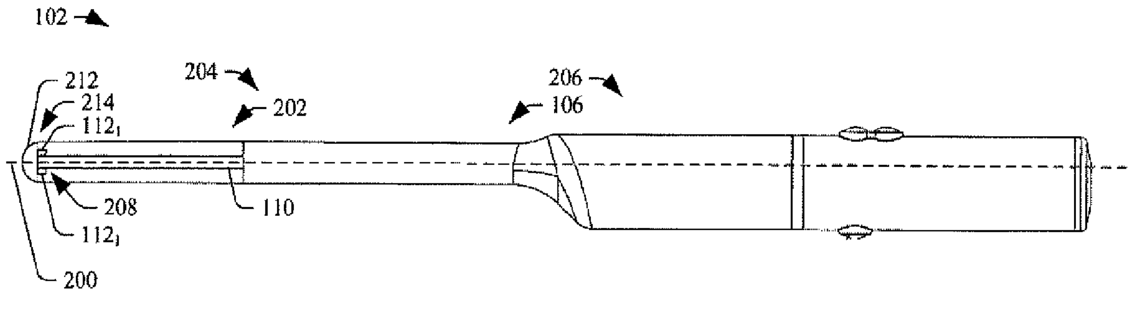
(57) **ABSTRACT**

A method includes receiving first electrical signals from a first single-element transducer ($\mathbf{112_1}$) and second electrical signals from a second single-element transducer ($\mathbf{112_2}$). The transducers are disposed on a shaft (**110**), which has a longitudinal axis (**200**), of an ultrasound imaging probe (**102**) with transducing sides disposed transverse to and facing away from the longitudinal axis. The transducers are angularly offset from each other on the shaft by a non-zero angle. The transducers are operated at first and second different cutoff frequencies. The shaft concurrently translates and rotates while the transducers receive the first and second ultrasound signals. The method further includes delay and sum beamforming, with first and second beamformers ($\mathbf{120_1}$, $\mathbf{120_2}$), the first and second electrical signals, respectively via different processing chains ($\mathbf{712_1}$, $\mathbf{712_2}$), employing an adaptive synthetic aperture technique, producing first and second images. The method further includes combining the first and second images, creating a final image, and displaying the final image.



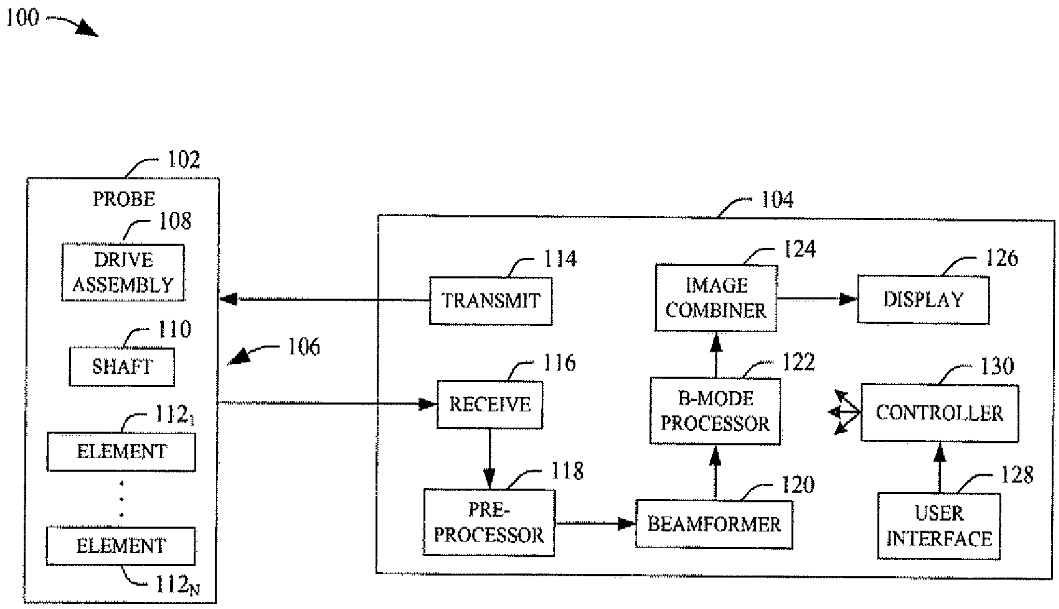

100
102
PROBE
108
DRIVE ASSEMBLY
110
SHAFT
112_1
ELEMENT
ELEMENT
112_N
106
104
114
TRANSMIT
116
RECEIVE
118
PRE-PROCESSOR
120
BEAMFORMER
122
B-MODE PROCESSOR
124
IMAGE COMBINER
126
DISPLAY
130
CONTROLLER
128
USER INTERFACE

FIGURE 1

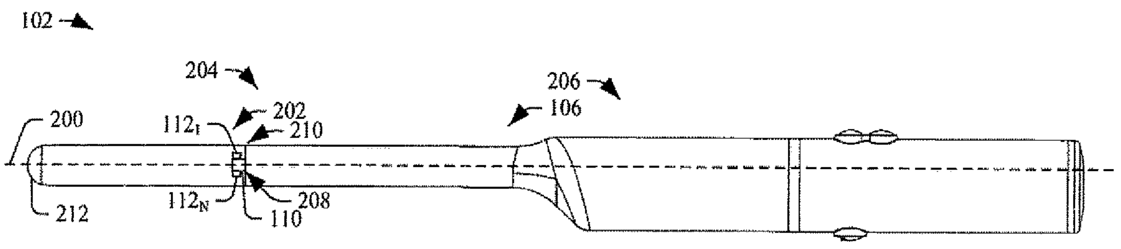


FIGURE 2

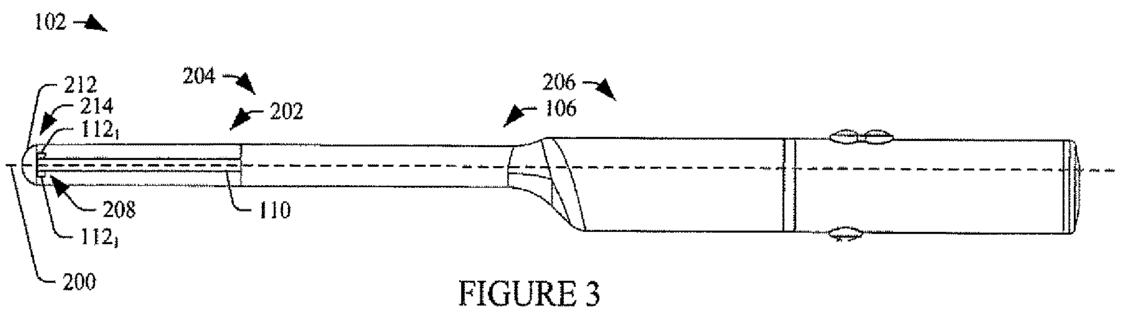


FIGURE 3

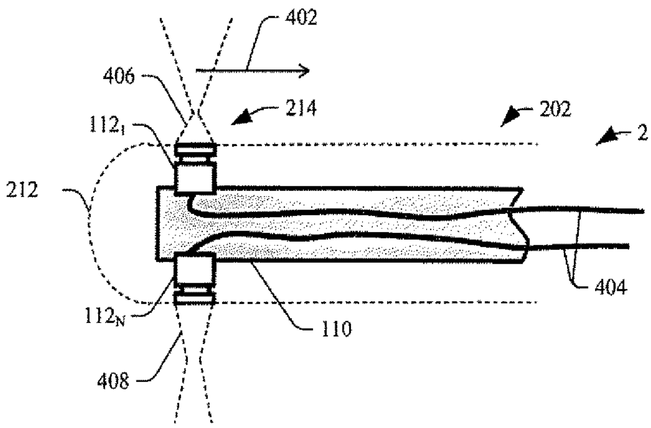


FIGURE 4

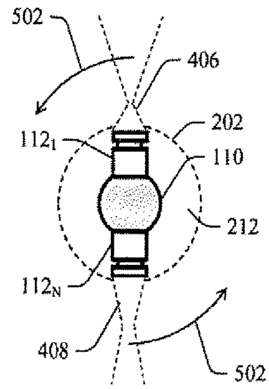


FIGURE 5

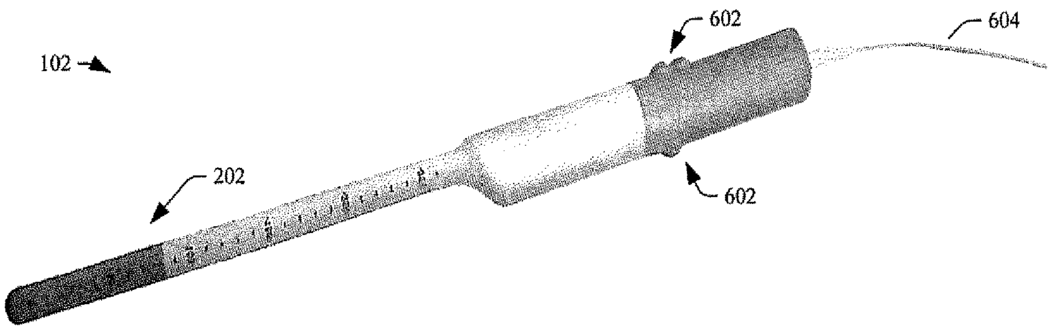


FIGURE 6

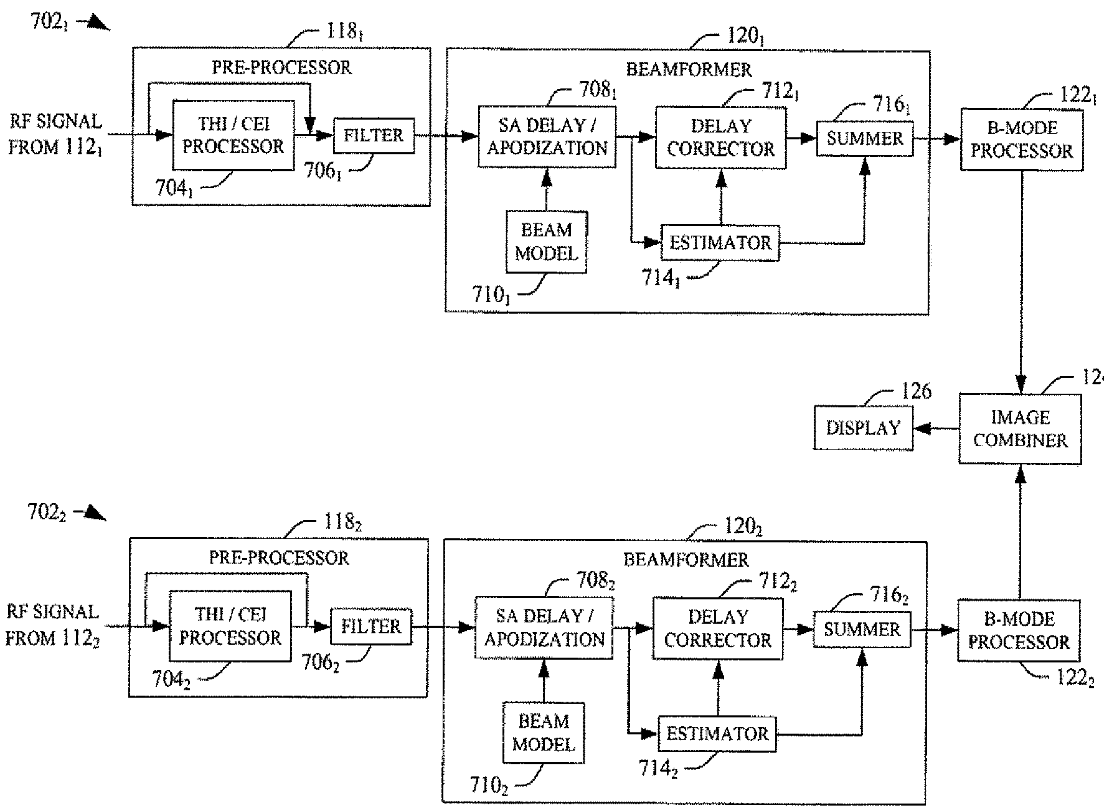
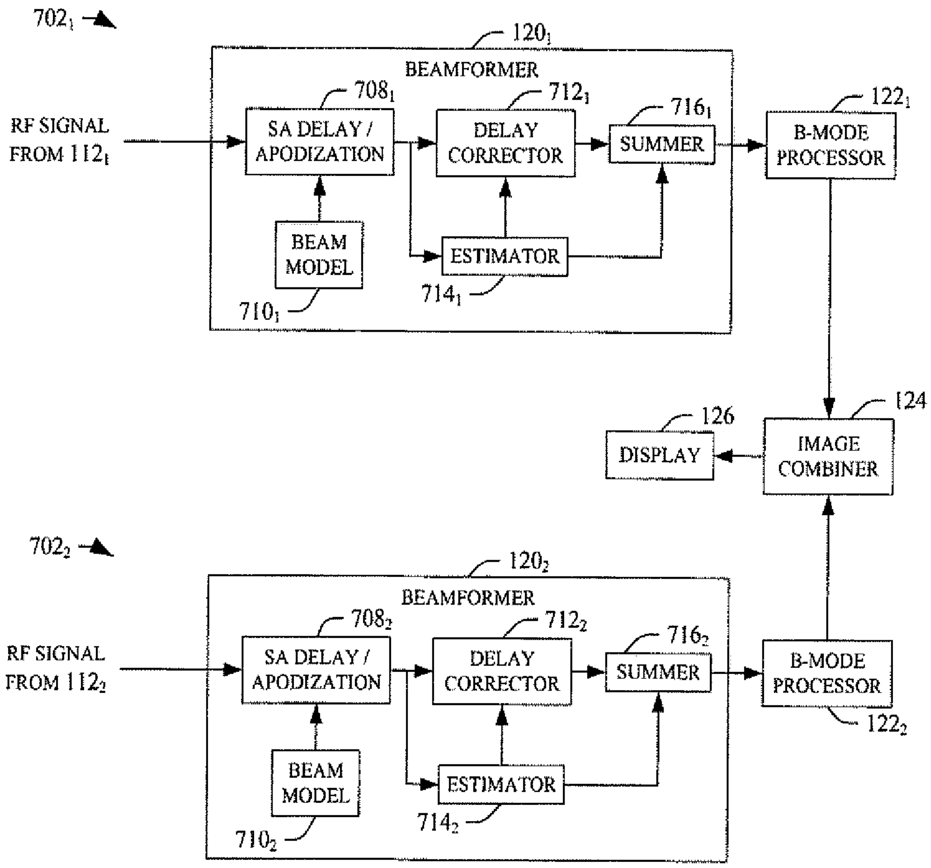
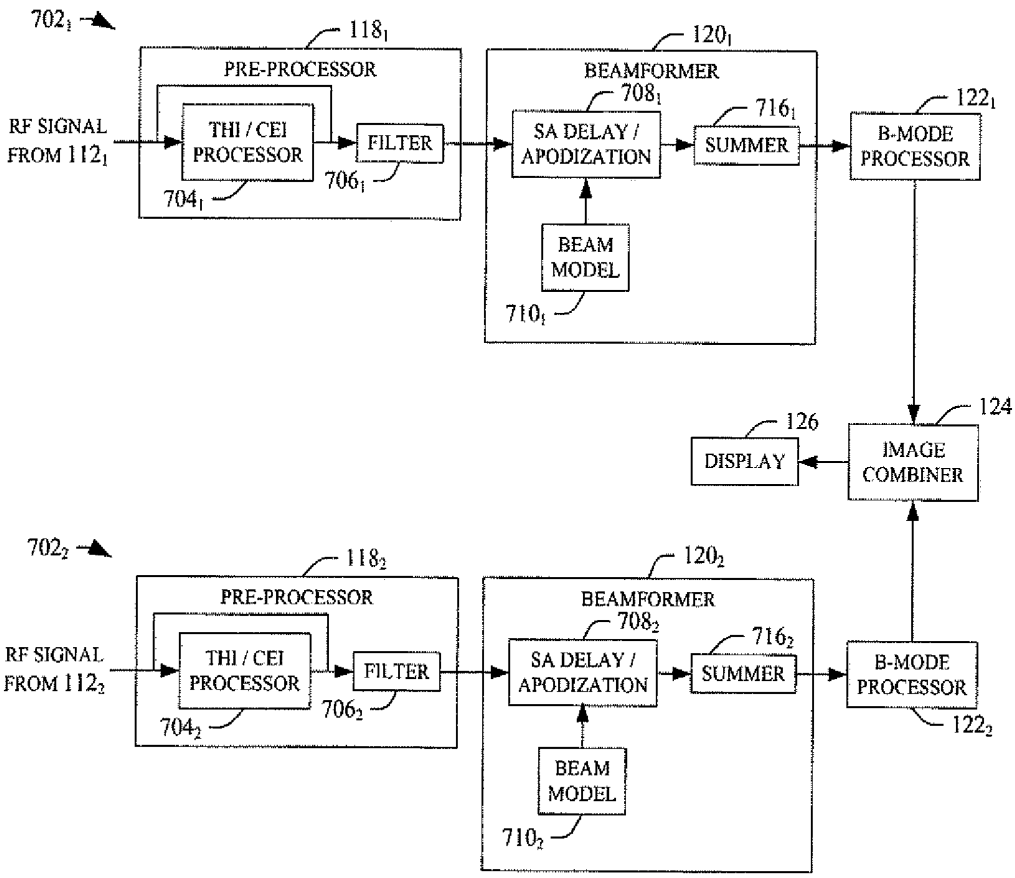

702_1
118_1
PRE-PROCESSOR
RF SIGNAL FROM 112_1
THI / CEI PROCESSOR
704_1
FILTER
706_1
120_1
BEAMFORMER
708_1
SA DELAY / APODIZATION
BEAM MODEL
710_1
712_1
DELAY CORRECTOR
ESTIMATOR
714_1
716_1
SUMMER
122_1
B-MODE PROCESSOR
126
DISPLAY
124
IMAGE COMBINER
702_2
118_2
PRE-PROCESSOR
RF SIGNAL FROM 112_2
THI / CEI PROCESSOR
704_2
FILTER
706_2
120_2
BEAMFORMER
708_2
SA DELAY / APODIZATION
BEAM MODEL
710_2
712_2
DELAY CORRECTOR
ESTIMATOR
714_2
716_2
SUMMER
B-MODE PROCESSOR
122_2

FIGURE 7



702_1
120_1
BEAMFORMER
708_1
712_1
716_1
122_1
RF SIGNAL FROM 112_1
SA DELAY / APODIZATION
DELAY CORRECTOR
SUMMER
B-MODE PROCESSOR
BEAM MODEL
ESTIMATOR
710_1
714_1
126
124
DISPLAY
IMAGE COMBINER
702_2
120_2
BEAMFORMER
708_2
712_2
716_2
RF SIGNAL FROM 112_2
SA DELAY / APODIZATION
DELAY CORRECTOR
SUMMER
B-MODE PROCESSOR
122_2
BEAM MODEL
ESTIMATOR
710_2
714_2

FIGURE 8



702_1
118_1
PRE-PROCESSOR
RF SIGNAL FROM 112_1
THI / CEI PROCESSOR
704_1
FILTER
706_1
120_1
BEAMFORMER
708_1
SA DELAY / APODIZATION
716_1
SUMMER
BEAM MODEL
710_1
122_1
B-MODE PROCESSOR
124
IMAGE COMBINER
126
DISPLAY
702_2
118_2
PRE-PROCESSOR
RF SIGNAL FROM 112_2
THI / CEI PROCESSOR
704_2
FILTER
706_2
120_2
BEAMFORMER
708_2
SA DELAY / APODIZATION
716_2
SUMMER
BEAM MODEL
710_2
B-MODE PROCESSOR
122_2

FIGURE 9

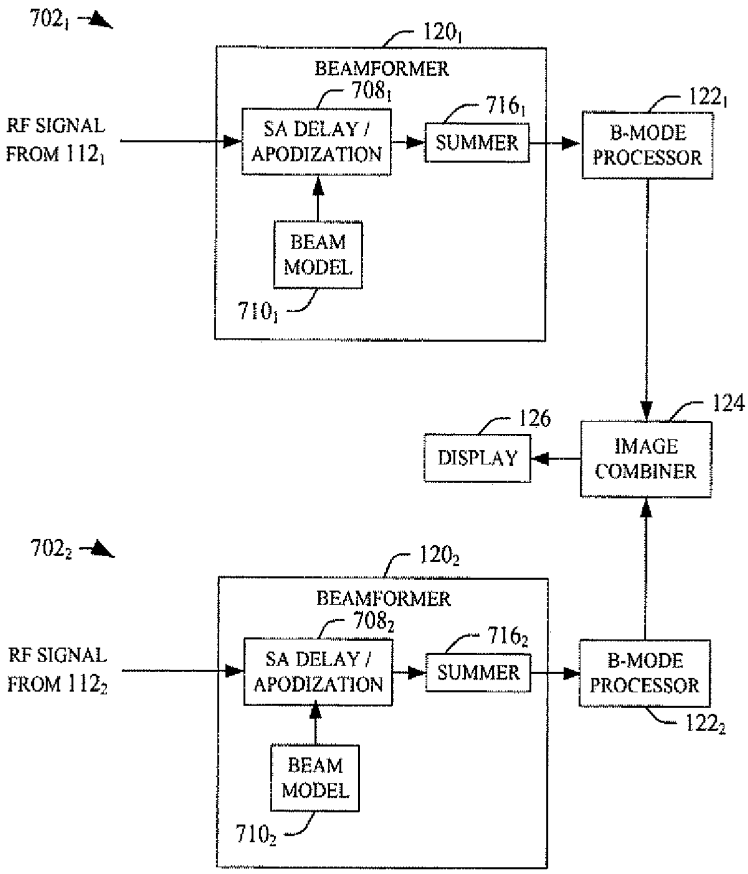

702₁
120₁
BEAMFORMER
708₁
716₁
122₁
RF SIGNAL FROM 112₁
SA DELAY / APODIZATION
SUMMER
B-MODE PROCESSOR
BEAM MODEL
710₁
126
124
DISPLAY
IMAGE COMBINER
702₂
120₂
BEAMFORMER
708₂
716₂
RF SIGNAL FROM 112₂
SA DELAY / APODIZATION
SUMMER
B-MODE PROCESSOR
122₂
BEAM MODEL
710₂

FIGURE 10

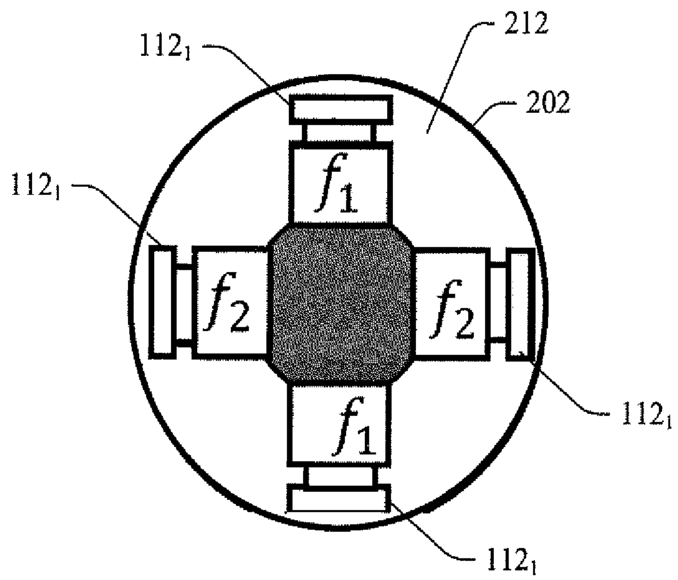


FIGURE 11

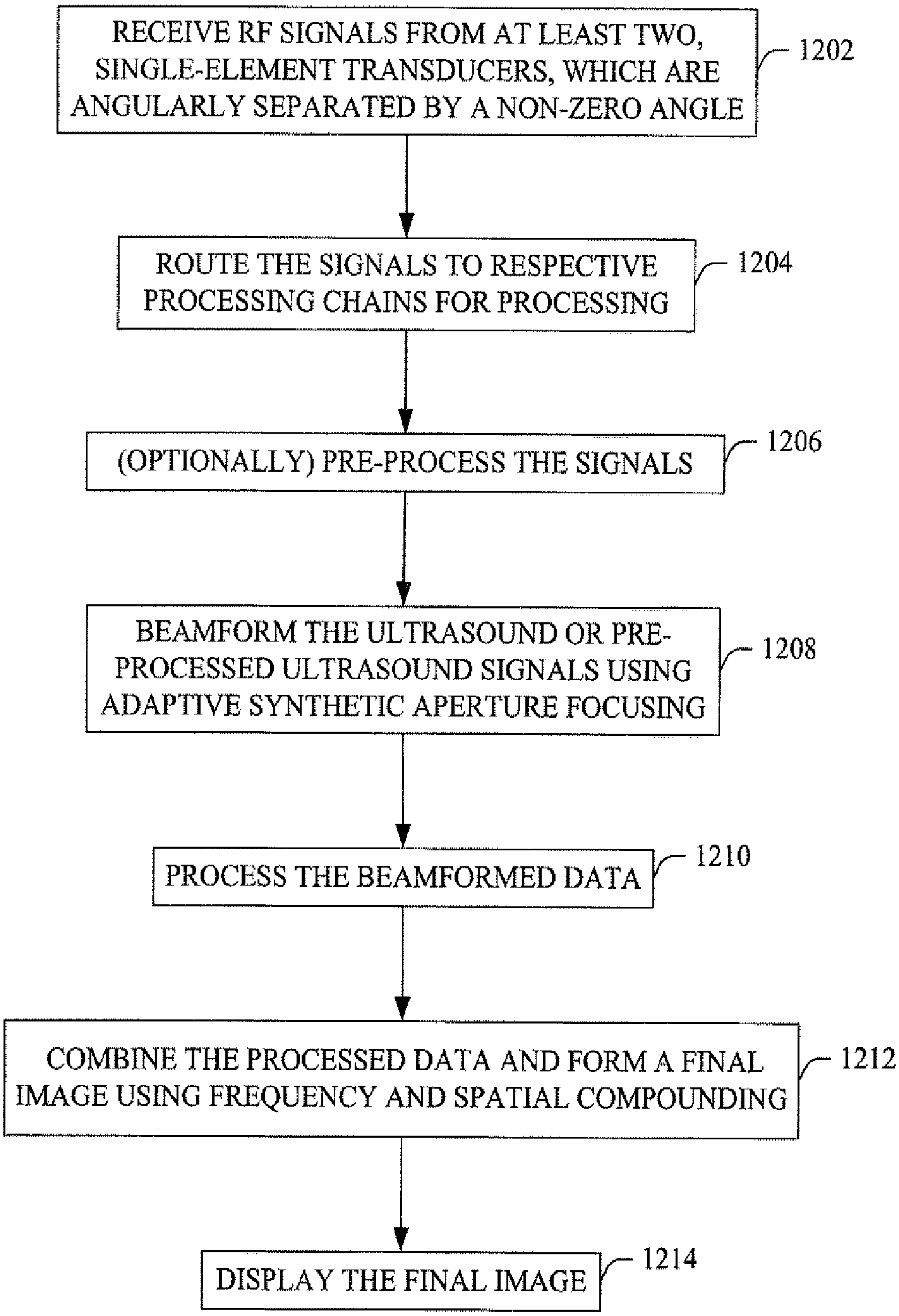

RECEIVE RF SIGNALS FROM AT LEAST TWO, SINGLE-ELEMENT TRANSDUCERS, WHICH ARE ANGULARLY SEPARATED BY A NON-ZERO ANGLE
1202
ROUTE THE SIGNALS TO RESPECTIVE PROCESSING CHAINS FOR PROCESSING
1204
(OPTIONALLY) PRE-PROCESS THE SIGNALS
1206
BEAMFORM THE ULTRASOUND OR PRE-PROCESSED ULTRASOUND SIGNALS USING ADAPTIVE SYNTHETIC APERTURE FOCUSING
1208
PROCESS THE BEAMFORMED DATA
1210
COMBINE THE PROCESSED DATA AND FORM A FINAL IMAGE USING FREQUENCY AND SPATIAL COMPOUNDING
1212
DISPLAY THE FINAL IMAGE
1214

FIGURE 12

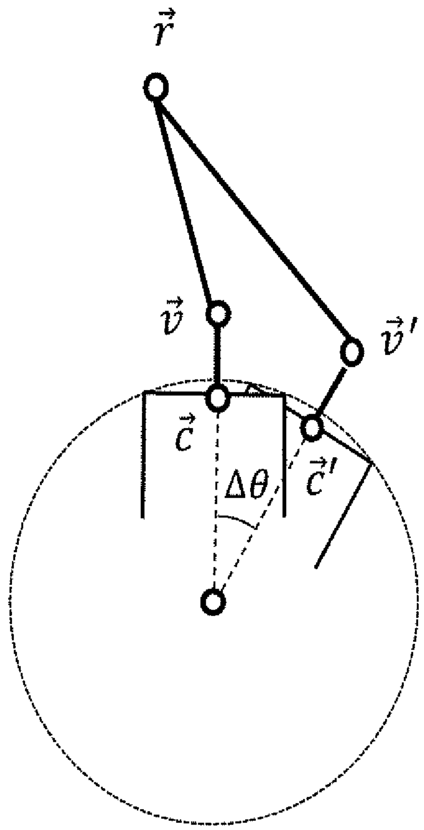


FIGURE 13

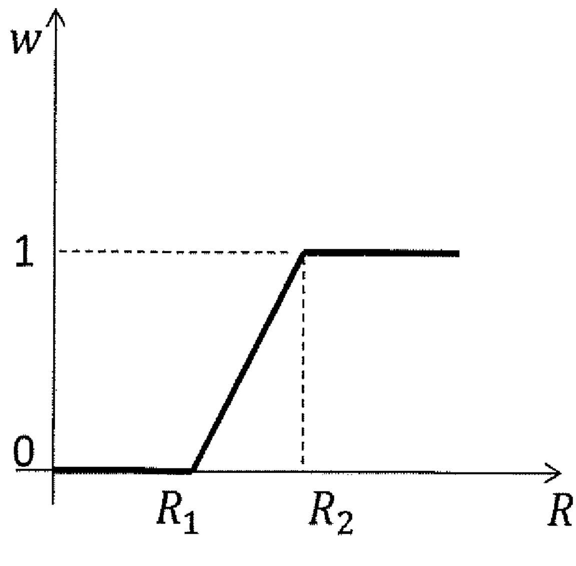


FIGURE 14

3-D ULTRASOUND IMAGING WITH MULTIPLE SINGLE-ELEMENT TRANSDUCERS AND ULTRASOUND SIGNAL PROPAGATION CORRECTION

TECHNICAL FIELD

[0001] The following generally relates to ultrasound imaging and more particularly to three-dimensional (3-D) ultrasound imaging with multiple, single-element transducers and ultrasound signal propagation correction.

BACKGROUND

[0002] Ultrasound imaging can be used to provide one or more real-time images of information about the interior of a subject, such as an organ, tissue, blood, etc., or an object. This includes two-dimensional and/or three-dimensional images. Three-dimensional probes acquire data that can be processed to generate three-dimensional images. One such probe includes two, single-element transducers disposed on a shaft one hundred and eighty degrees apart. The shaft is configured to translate and rotate, which translates and rotates the two, single-element transducers. Concurrently translating and rotating the shaft moves the two, single-element transducers along a helix trajectory during data acquisition, collecting data for three-dimensional imaging.

[0003] When the two, single-element transducers are operated at two different center frequencies and focused at two different depths, a sonographer can choose whether to use the higher frequency for nearer field imaging, or the lower frequency for farer field imaging. Synthetic aperture focusing has been used to increase image quality of images acquired with a single-element transducer. However, the mechanical movement of the two, single-element transducer probe gives rise to jitter, and jitter and along with transducer acceleration result in a calculated transducer position that is different from the actual transducer position. Unfortunately, this difference introduces error in the delay in delay and sum beamforming, which can degrade image quality.

SUMMARY

[0004] Aspects of the application address the above matters, and others.

[0005] In one aspect, a method is for ultrasound imaging with a first single-element transducer and a second single-element transducer. The first and second single-element transducers are disposed on an ultrasound probe shaft, which has a longitudinal axis, with transducing sides disposed transverse to and facing away from the longitudinal axis. The first and second single-element transducers are angularly offset from each other on the shaft by a non-zero angle. The method includes operating the first and second single-element transducers at first and second different cutoff frequencies, and concurrently translating and rotating the shaft, moving the first and second single-element transducers along a helical path while the first and second single-element transducers acquire first and second echo signals. The method further includes receiving first electrical signals from the first single-element transducer, wherein the first electrical signals are indicative of the first echo signals, and receiving second electrical signals from the second single-element transducer, wherein the second electrical signals are indicative of the second echo signals. The method further includes delay and sum beamforming, with first and second adaptive synthetic aperture focusing beamformers, the first and second electrical signals, respectively via different processing chains, employing adaptive synthetic aperture focusing, producing first and second images. The method further includes combining the first and second images, creating a final image and displaying the final image.

[0006] In another aspect, an ultrasound imaging system includes a probe with an elongate shaft, a drive assembly coupled to the elongate shaft and configured to translate and rotate the shaft, and at least first and second single-element transducers disposed at an end region of the shaft angularly separated from each other by an angle in a range between 60 and 180 degrees. The at least first and second single-element transducers transmit and receive in a direction transverse to the elongate shaft and have different center frequencies, and respectively generate first and second electrical signals. The ultrasound imaging system further includes a console with delay and sum beamformer configured to process the first and second electrical signals respectively through different processing chains, wherein the different processing chains respectively include first and second adaptive synthetic aperture focusing beamformers configured to employ adaptive synthetic aperture focusing to produce first and second images. The ultrasound imaging system further includes an image combiner that combines the first and second images and displays the combined image on a display.

[0007] In another aspect, an apparatus includes a delay and sum beamformer configured to process first and second electrical signals respectively through different processing chains, wherein the different processing chains respectively include first and second adaptive synthetic aperture focusing beamformers configured to employ adaptive synthetic aperture focusing to produce first and second images. The first electrical signals are received from a first single-element transducer. The first electrical signals are indicative of first ultrasound signals, and receiving second electrical signals are received from a second single-element transducer. The second electrical signals are indicative of second ultrasound signals. The first and second single-element transducers are disposed on a shaft, which has a longitudinal axis, of an ultrasound imaging probe with transducing sides disposed transverse to and facing away from the longitudinal axis. The first and second single-element transducers are angularly offset from each other on the shaft by a non-zero angle. The first and second single-element transducers are operated at first and second different cutoff frequencies. The shaft concurrently translates and rotates while the first and second single-element transducers receive the first and second ultrasound signals. The apparatus further includes an image combiner that combines the first and second images and displays the combined image on a display.

[0008] Those skilled in the art will recognize still other aspects of the present application upon reading and understanding the attached description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The application is illustrated by way of example and not limited by the figures of the accompanying drawings, in which like references indicate similar elements and in which:

[0010] FIG. **1** schematically illustrates an example three-dimensional ultrasound probe with at least two, single-element transducers and an ultrasound imaging system configured for synthetic aperture focusing;

[0011] FIG. **2** schematically illustrates an example of the three-dimensional ultrasound probe with the at least two, single-element transducers in a retracted position;

[0012] FIG. **3** schematically illustrates an example of the three-dimensional ultrasound probe with the at least two, single-element transducers in an extended position;

[0013] FIG. **4** schematically illustrates an example of the three-dimensional ultrasound probe with the at least two, single-element transducers translating from the extended position to the retracted position;

[0014] FIG. **5** schematically illustrates an example of the three-dimensional ultrasound probe with the at least two, single-element transducers rotating;

[0015] FIG. **6** illustrates an example of the three-dimensional ultrasound probe;

[0016] FIG. **7** illustrates an example processing chain for a two, single-element transducer configuration, including pre-processing, adaptive beamforming, post-beamforming processing, and final image construction;

[0017] FIG. **8** illustrates a variation of FIG. **7** in which the pre-processing is omitted;

[0018] FIG. **9** illustrates a variation of FIG. **7** in which standard delay and sum beamforming is utilized;

[0019] FIG. **10** illustrates a variation in which the pre-processing is omitted and standard delay and sum beamforming is utilized;

[0020] FIG. **11** schematically illustrates a variation including more than two, single-element transducers;

[0021] FIG. **12** schematically illustrates a method in accordance with an embodiment disclosed herein;

[0022] FIG. **13** depicts effects of mechanical jitter; and

[0023] FIG. **14** shows derivation of weight coefficients for adaptive sum from the magnitude of the cross-correlation function.

DETAILED DESCRIPTION

[0024] FIG. **1** illustrates an example imaging system **100** such as an ultrasound imaging system. The imaging system **100** includes a transducer probe **102** and an ultrasound console **104**, which interface through suitable complementary hardware and/or wireless interfaces (not visible).

[0025] The transducer probe **102** includes an elongate tubular portion **106**, a drive assembly **108**, an elongate shaft **110**, and a plurality of single-element transducers $\mathbf{112}_1$, . . . , $\mathbf{112}_N$ (collectively referred to herein as single-element transducers **112**), where N is a positive integer. FIG. **2** shows a non-limiting example of the transducer probe **102**. In the example of FIG. **2**, the elongate tubular portion **106** extends in a direction away from a handle region **206** and along a longitudinal axis **200** of the probe **102** and includes a first end region **202** and a second region **204**, which is between the first end region **202** and the handle region **206**. The first end region **202** includes an acoustic window.

[0026] A first end (not visible) of the shaft **110** is coupled to the drive assembly **108** (not visible), which is configured to rotate and/or translate the shaft **110**. The drive assembly **108** can be in the shaft **110**, the handle **206**, and/or elsewhere. A second end **208** of the shaft **110** is in the first end region **202**. The single-element transducer $\mathbf{112}_1$ is coupled to the second end **208**, with its transducing region perpendicular to and away facing away from the longitudinal axis **200**. With a two, single-element transducer configuration (N=2), the single-element transducer $\mathbf{112}_N$ is likewise coupled to the second end **208**, but angularly shifted or offset relative to the single-element transducer $\mathbf{112}_1$.

[0027] For instance, in the illustrated instance, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ are diametrically opposed, or offset one hundred and eighty degrees (180°) around the shaft **110**. In another instance, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ are perpendicular, or offset ninety degrees (90°) around the shaft **110**. In another instance, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ are offset sixty degrees (60°) around the shaft **110**. In general, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ are angularly offset or separated by a single angle in a range from sixty (60) to one hundred and eighty (180) degrees. More than two, single-element transducers (i.e., N>2) are contemplated herein and can increase the frame rate. Smaller non-zero angles are also contemplated herein.

[0028] In FIG. **2**, the shaft **110** is in a retracted position **210** with the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ closer to the second region **204** than a tip **212** of the first region **202**. In FIG. **3**, the shaft **110** is in an extended position **214** with the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ closer to the tip **212** than the second region **204**. The shaft **110** is configured to translate between the retracted and extended positions **210** and **214** and, concurrently and/or independently, rotate. The rotation can be less than three hundred and sixty degrees (360°), equal to 360° (i.e., one revolution), or greater than 360° (i.e., more than one revolution). The single-element transducers **112** can acquire data for 3-D imaging while translating and rotating.

[0029] FIG. **4** shows translational movement **402** from the extended position **214** towards the retracted position **210**. FIG. **4** also shows conductive paths **404** configured to route signals to and from the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$. FIG. **5** shows rotational counter-clockwise movement **502**. Clockwise movement is also contemplated herein. Continuous combined translation along the sagittal plane and rotation in the transverse plan provides a helical trajectory. FIGS. **4** and **5** also show individual field of views **406** and **408** with different center frequencies, one for a nearer field (higher center frequency) and one a farer field (lower center frequency).

[0030] Returning to FIG. **1**, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ convert an excitation electrical (e.g., pulsed) signal to an ultrasound pressure field, and receive echo signals and generate radio frequency (RF) signals indicative thereof. The echo signals, e.g., are generated in response to the transmitted pressure field interacting with structure, stationary and/or moving. The single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ can concurrently or independently transmit and receive. Transmit circuitry **114** generates the excitation electrical signal and controls the center frequency. Receive circuitry **116** receive the RF signals and, optionally, amplifies and/or digitizes them. The transmit and receive circuitry **114** and **116** transmit and receive so that data suitable for adaptive synthetic aperture focusing is acquired.

[0031] A suitable frequency range for the transducers **112** is from three (3) MHz to fifty (50) MHZ, such as eight (8) to ten (10) MHZ, or higher or lower, with a bandwidth of 60 to 75%. In one instance, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ respectively transmit with a center frequency at five (5) megahertz (MHz) and fifteen (15) MHz, with no overlap in their frequency bands. In this configuration, with a bandwidth of 60%, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ transmit in bands of 3.5 to 6.5 MHz and 10.5 to

19.5 MHz. In another instance, the frequency bands overlap less than 50%. For example, with center frequencies at 10 and 15 MHz, and a bandwidth of 70%, the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_N$ respectively transmit in bands of 6.5 to 13.5 MHz and 9.75 to 20.25 MHz.

[0032] A non-limiting example of the probe **102** is the 20R3 Transducer, which is a product (#9052) of BK Ultrasound, a company of Analogic Corporation, which is headquartered in Peabody, Mass., USA. FIG. **6** shows the 20R3 Transducer, including the first region **202** in which the shaft **110** (not visible) and single-element transducers **112** translate and rotate. FIG. **6** also shows control buttons **602** (e.g., forward/in, backwards/out, start/stop/capture, etc.) and a sub-portion of a cable interface **604**, which includes an electro-mechanical interface (not shown), which connects to a complementary electro-mechanical interface (not shown) of the console. This probe is further discussed in BK Ultrasound, 20R3 Transducer, User Guide, February 2015.

[0033] Returning to FIG. **1**, a pre-processor **118** pre-processes the RF signal. In this example, the pre-processer **118** is configured to provide standard signal conditioning for RF signals. In one instance, this includes one or more of band-pass filtering as a function of depth, separation of harmonic frequencies, shifting the center frequency to 0 (generation of in-phase and quadrature-phase (IQ) baseband signals). This may also include generating IQ data by converting the RF-signal to the complex-value IQ domain. This can be achieved, e.g., by multiplying the RF-signal by a complex sinusoid signal, e.g., I=RF×cos (wt), and Q=RF×−sin (wt). The data can be further processed, e.g., low pass filtered, decimated, etc. This processing is optional, and can be turned on or off. In a variation, the pre-processor **118** is omitted.

[0034] A beamformer **120** is configured to beamform the signals. In one instance, this includes, e.g., delay and weighting, and summing the delayed and weighted signals. As described in greater detail below, the beamformer **120**, in one instance, includes a synthetic aperture beamformer configured to perform adaptive synthetic aperture focusing. In general, this beamformer corrects calculated delays, which are subject to errors due to jitter from the mechanical movement of the shaft **110**, employs the corrected delays, and adaptively sums the weighted and delayed signals based on a correlation of the signals. The adaptive synthetic aperture focusing described herein can mitigate error in the position of the transducer from jitter and transducer acceleration, improving image quality.

[0035] A B-mode processor **122** processes the output of the beamformer **120**. In one instance, this includes detecting the envelope of the signal and/or applying dynamic range compression (DRC) to the envelope, including thresholding. The B-mode processor **122** can process RF data and/or IQ data for generating envelope data. The DRC applied by the B-mode processor **122** can follow a linear law, a quadratic law, a logarithmic law, a μ-law and/or other DRC algorithm. The B-mode processor **122** can log compress the envelope data into a grayscale format, downscale the compressed data, and/or otherwise processes the data.

[0036] An image combiner **124** combines images from B-mode processor **122**, which includes an image generated with data acquired by each of the transducer elements $\mathbf{112}_1$, . . . , $\mathbf{122}_N$. As described in greater detail below, the image combiner **124**, in one instance, frequency compounds or blends these images from B-mode processor **122**. Such compounding may first include aligning/registering the images and then combing aligned/registered images, which are acquired at different frequencies and at different spatial positions. This reduces speckle. The effect of the operation is a combined spatial and frequency compounding. The frequency compounding stems from the different bands at which the transducers operate, and the spatial compounding stems from different positions that the two transducers (relative to each other) scan the same tissue. A display **126** displays the compounded image.

[0037] A user interface (UI) **128** includes one or more input devices (e.g., a button, a knob, a slider, a touch pad, a mouse, a trackball, a touch screen, etc.) and/or one or more output devices (e.g., a display screen, a light, an audio generator, etc.), which allow for interaction between a user and the ultrasound imaging system **100**. This includes allowing the sonographer to select adaptive synthetic aperture focusing. An example of monostatic synthetic aperture focusing is discussed at least in Andresen et al., "Synthetic aperture focusing for a single element transducer undergoing helical motion," IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 58(5):935-43, May 2011.

[0038] A system controller **130** is configured to control one or more of the components of the console **104**, the transducer elements **112**, and/or other device. For example, in one instance, the system controller **130** controls the transmit circuitry **114** and/or received circuitry **116** to control the transmit angles, transmit energies, transmit frequencies, transmit and/or receive delays, weights, etc. The system controller **130** also controls beamformer **120** to perform adaptive synthetic aperture focusing and/or frequency compounding. Such control can be based on configuration files, user input, a selected mode of operation, etc.

[0039] One or more of the components of the console **104** can be implemented via one or more processors (central processing unit (CPU), graphics processing unit (GPU), microprocessor, controller, etc.) executing one or more computer readable instructions encoded or embedded on computer readable storage medium, which is a non-transitory medium such as physical memory or other non-transitory medium, and excludes transitory medium. Additionally, or alternatively, at least one of the instructions can be carried by a carrier wave, a signal, or other transitory medium.

[0040] The ultrasound imaging system **100** can be part of a portable system on a stand with wheels, a system residing on a tabletop, and/or other system in which the transducer elements **112** is housed in a probe or the like, and the console **104** is housed in an apparatus separate therefrom such as a standard and/or other computer. In another instance, the transducer elements **112** and the console **104** can be housed in a same apparatus such as within a single enclosure hand-held ultrasound scanning device.

[0041] FIG. **7** illustrates an example of the beamformer **120** (in connection with various other components of the system **100**) for a two, single-element transducers **112** configuration. Configurations for 3, 4, 5, 6, etc. single-element transducer embodiments are also contemplated herein with some examples provided below.

[0042] A first processing chain $\mathbf{702}_1$ processes signals from the transducer element $\mathbf{112}_1$, and a second processing chain $\mathbf{702}_2$ processes signals from the transducer element $\mathbf{112}_2$. A **3**, **4**, **5**, **6**, etc. transducer configuration will have 3, 4, 5, 6, etc. processing chains, or a different processing chain for each of the single-element transducers **112**. The first processing chain **702**$_1$ is described in detail herein. It is to be appreciated that the second (and 3, 4, 5, 6, etc.) processing chain(s) **702**$_2$ is identical to the first processing chain **702**$_1$ but processes an input signal from a different single-element transducer **112**.

[0043] The first processing chain **702**$_1$ includes a pre-processor **118**$_1$, a beamformer **120**$_1$, and a B-mode processor **122**$_1$. The second processing chain **702**$_2$ includes a pre-processor **118**$_2$, a beamformer **120**$_2$, and a B-mode processor **122**$_2$. The pre-processor **118** comprises the pre-processors **118**$_1$ and **118**$_2$, the beamformer **120** comprises the beamformers **120**$_1$ and **120**$_2$, the B-mode processor **122** comprising the B-mode processors **122**$_1$ and **122**$_2$. Alternatively, these can be separate and distinct components. The processing chains **702**$_1$ and **702**$_2$ share the image combiner **124**.

[0044] The illustrated pre-processer **118**$_1$ includes a tissue harmonic imaging (THI)/contrast enhanced imaging (CEI) processor **704**$_1$. The THI/CEI processor **704** implements one or more existing and/or other approaches to separate harmonic frequencies, e.g., pulse inversion, amplitude modulation, and two filters, one for the fundamental and another for the harmonic frequencies. The output signal can be either a real signal or a complex (IQ) signal, centered around a frequency in the MHz range, or around 0 Hz (baseband). In general, the signal contains both magnitude and phase information for the received echoes.

[0045] The pre-processer **118**$_1$ additionally or alternatively includes a filter **706**$_1$. In this example, the filter **706**$_1$ is a bandpass/sliding filter. The bandpass/sliding filter **706**$_1$ is used to increase signal-to-noise ratio and to separate signals with different frequency contents. The filter coefficients are updated as of function of depth to change the center frequency and the bandwidth of the filter. The output signal can be either a real signal or a complex signal. In general, the signal contains both magnitude and phase information and can be used for beamforming.

[0046] The beamformer **120**$_1$ includes a synthetic aperture (SA) delay/apodization processor **708**$_1$, a beam model **710**$_1$, a delay corrector **712**$_1$, an estimator **714**$_1$, and a summer (adder) **716**$_1$.

[0047] The SA delay/apodization processor **708**$_1$ processes the RF signal and/or the pre-processed signal, producing delayed signals $y_n(\vec{r})$ as shown in Equation 1:

$$y_n(\vec{r})=a_n(\vec{r})s_n(T_n(\vec{r})), \quad \text{Equation 1:}$$

where $s_n(\ )$ is a signal recorded at emission n, $T_n(\vec{r})$ is a propagation time from a surface of the single-element transducer **112**$_1$ to a point $\vec{r}$ and back to the single-element transducers **112**$_1$, and $a_n(\vec{r})$ is a weight (apodization) applied on the signal, e.g., to minimize side lobes and eliminate regions that are not illuminated by the beam. The signal $s_n(t)$ is discrete, and if T_n falls between samples, then $\hat{s}_n(T_n)$ is generated by interpolation. The interpolation can be linear, spline, polynomial, based on fractional delay filters, etc.

[0048] The beam modeler **710**$_1$ calculates the propagation times $T_n(\vec{r})$ and the weight coefficients $a_n(\vec{r})$. The calculation of T_n and a_n can be based on a virtual source model, a semi-analytic model, simulated or measured data, etc. A virtual source model is discussed in Andresen et al., "Synthetic aperture focusing for a single element transducer undergoing helical motion," IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 58(5):935-43, May 2011, and Frazier et al., "Synthetic aperture techniques with a virtual source element," IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, 45(1):196-207, 1998, etc.

[0049] A semi-analytic model is discussed in Jensen et al., "Spatial filters for focusing ultrasound images," IEEE Ultrasonics Symposium, Proceedings, An International Symposium (Cat. No. 01CH37263), Volume 2, pp. 1507-1511. IEEE, 2001. A semi-analytic model is discussed in Hansen et al. "Synthetic aperture imaging using a semi-analytic model for the transmit beams," Medical Imaging 2015: Ultrasonic Imaging and Tomography, volume 1, page 94190K, March 2015, and Nikolov et al. "Synthetic aperture imaging using a semi-analytic model for the transmit beams," IEEE International Ultrasonics Symposium (IUS), pages 1-4. IEEE, October 2015.

[0050] SA delay/apodization processor **708**$_1$ outputs the delayed signal y_n and/or the input signal s_n and the delay and weight information T_n, and a_n. The delay corrector **712**$_1$ and the estimator **714**$_1$ correct the delay T_n. The mechanical movements of the single-element transducers **112** gives rise to imprecisions and jitter, which introduce error in the propagation times T_n. The delay corrector **712**$_1$ interpolates a desired sample at time instance $T_n(\vec{r})+\delta_n(\vec{r})$, where $\delta_n(\vec{r})$ is a delay adjustment determined by the estimator **714**$_1$. An example of a suitable interpolation is discussed in Lakso et al., "Splitting the unit delay," IEEE Sig. Proc. Mag., 13(1):30-60, 1996. Other interpolation approaches are also contemplated herein.

[0051] The estimator **714**$_1$ determines differences between the calculated time of flights and generates the correction value $\delta_n(\vec{r})$ based thereon. An example of generating the correction value is described in connection with FIG. **13**. FIG. **13** illustrates the effects of mechanical jitter for a rotational component of motion. A difference in the angular position of the transducer is $\Delta\theta$ between the expected and the actual angle. For sharply focused transducers, the virtual source model predicts that the propagation of the sound from the transducer surface to a point in the image $\vec{r}$ follows the path $\vec{c}\rightarrow\vec{v}\rightarrow\vec{r}$, where $\vec{c}$ is the geometric center of the circular transducer and $\vec{v}$ is the focus point.

[0052] The propagation time from the transducer surface to a point P and back is defined (the subscript n for emission number is omitted for conciseness) as shown in Equation 2:

$$T(\vec{r}) = \frac{2}{c}\cdot(|\vec{v}-\vec{c}|+|\vec{r}-\vec{v}|), \quad \text{Equation 2}$$

where c is the speed of sound, and $|\vec{v}-\vec{c}|$ and $|\vec{r}-\vec{v}|$ are the lengths of the line segments connecting the respective points.

[0053] The real propagation time is as shown in Equation 3:

$$T(\vec{r}) = \frac{2}{c}\cdot(|\vec{v}'-\vec{c}'|+|\vec{r}-\vec{v}'|), \quad \text{Equation 3}$$

where $\vec{c}'$ and $\vec{v}'$ are the actual positions of the transcducer center and focus points, respectively. The actual propagation time can be expressed as shown in Equation 4:

$$T'(\vec{r})=T(\vec{r})+\delta_n(\vec{r}), \qquad \text{Equation 4:}$$

where $\delta_n(\vec{r})$ is the difference in arrival time due to the jitter in mechanical position, which in FIG. **13**, is due to difference in angle $\Delta\theta$. The received complex signal s(t) from a point scatterer can be expressed as shown in Equation 5:

$$s(t)=A(t)\cdot e^{(-j2\pi f_0 t)}, \qquad \text{Equation 5:}$$

where A(t) is an envelope function such as Gaussian, f_0 is a carrier frequency, and t is time. The duration of A(t) is several periods of the carrier signal. For mathematical convenience, it is often approximated with a rectangular window as shown in Equation 6:

$$A(t)=\begin{cases} 1, & -T_p/2<t<T_p/2 \\ 0, & \text{otherwise,} \end{cases} \qquad \text{Equation 6}$$

where T_p is the duration of a pulse.

[0054] After delaying the signals with a delay calculated using the beam model, the signal can be expressed as shown in Equation 7:

$$\begin{aligned} y(\vec{r}) &= s\left(t-T'^{(\vec{r})}+T(\vec{r})\right) \\ &= s(t-\delta_n(\vec{r})) \\ &= A(t-\delta_n(\vec{r}))e^{\left(-j2\pi f_0\left(t-\delta_n(\vec{r})\right)\right)} \end{aligned} \qquad \text{Equation 7}$$

The signal y( ) whose direction (assumed direction) coincides with the line in the image that is currently beamformed (the line on which the point $\vec{r}$ is located), is used as a reference signal $y_0(\vec{r})$. This signal, for this line, is assumed not to have any jitter (all $\_\delta_0(\vec{r})$ are set to zero). All other signals are aligned to it.

[0055] To find the deviation in propagation, the cross correlation between the central signal $y_o(\vec{r})$ and the other signals $y_n(\vec{r})$ that are used in the synthetic aperture focusing are calculated at lag 0. The signals are first delayed according to the beam model, and then, their delayed versions are correlated as shown in Equation 8:

$$\begin{aligned} R_n(0,\vec{r}) &= \frac{\langle y_0(\vec{r})y_n(\vec{r})\rangle}{\|y_0(\vec{r})\|\|y_n(\vec{r})\|} \\ &= |R_n(0)|e^{\left(-j2\pi f_0\delta_n(\vec{r})\right)}, \end{aligned} \qquad \text{Equation 8}$$

where y_o is a central beam, y_n is a beam for which a weight has been calculated, $\langle\cdot;\cdot\rangle$ is an inner product, and $\|\cdot\|$ is a norm.

[0056] The delay $\_\delta_n(\vec{r})$ is derived from the angle of the correlation function $R_n(0,\vec{r})$ as shown in Equation 9:

$$S_n(\vec{r}) = \frac{1}{2\pi f_0}\angle(R_n(0,\vec{r})). \qquad \text{Equation 9}$$

This estimation procedure is based on a phase-shift technique, used in color flow imaging, and discussed in Kasai et al., "Real-Time Two-Dimensional Blood Flow Imaging Using an Autocorrelation Technique," IEEE Trans. Son. Ultrason., SU-32(3):458-464, 1985.

[0057] An alternative approach is to calculate the cross-correlation $R_n(k,\vec{r})$ for a series of lags k and search for the location of the peak of $|R_n(0,\vec{r})|$. This the approach is used for combined motion compensation and motion estimation in Nikolov et al., "Velocity estimation using recursive ultrasound imaging and spatially encoded signals," In 2000 IEEE Ultrasonics Symposium, Proceedings, An International Symposium (Cat. No. 00CH37121), volume 2, pages 1473-1477. IEEE, 2000.

[0058] The difference in the current context is that the deviations $\_\delta_n(\vec{r})$ are due to difference in transducer position. This means that $\_\delta_n(\vec{r})$ is a systematic error for a given set of acquisitions. It is possible to find the deviation in position $\vec{c}'-\vec{c}$, as least squares fit from the beam model and the estimated deviations $\_\delta_n$. This procedure makes the estimator robust to deviations due to speckle artifacts. The procedure is further enhanced by estimating the signal to noise ratio (SNR), and using only the portions with high SNR in the least squares fit.

[0059] The summer **716**$_1$ adaptively adds the delay corrected signals, which reconstructs a signal $p(\vec{p})$ at a point at a location $\vec{r}=[x,y,z]^T$. In one instance, this is achieved as shown in Equation 10:

$$p(\vec{p}) = \sum_{n=0}^{N-1} a_n(\vec{r})w_n(\vec{r})s_n(T_n(\vec{r})+\delta_n(\vec{r})), \qquad \text{Equation 10}$$

where N is a total number of contributing emissions, and $w_n(\vec{r})$ is a weighting coefficient. The adaptive sum ensures that the summed signals are in phase. The adaptive weight coefficient $w_n(\vec{r})$ can be computed from the magnitude of the normalized cross correlation function at lag 0 as shown in Equation 11:

$$w_n(\vec{r})=F(|R_n(0,\vec{r})|), \qquad \text{Equation 11:}$$

where F( ) is a function, and R_n( ) is calculated using Equation 8. An example of a suitable function F( ) is shown in FIG. **14** and Equation 12:

$$w_n(\vec{r}) = \begin{cases} 1 & |R_n(0,\vec{r})| \geq R_2 \\ \dfrac{|R_n(0,\vec{r})-R_1|}{R_2-R_1} & R_1 < |R_n(0,\vec{r})| < R_2\,. \\ 0 & |R_n(0,\vec{r})| \leq R_1 \end{cases} \qquad \text{Equation 12}$$

For signals highly correlated signals, w_n is closer to one (1), relative to less corrected signals. The function can also be sigmoid or another empirically determined relation. The calculated values of $w_n(\vec{r})$ are smoothed with a low pass filter or a polynomial fit prior to use in the adaptive sum to avoid discontinuities and/or fluctuations in the image brightness.

[0060] The B-mode processor $\mathbf{122}_1$ processes the image generated by the summer $\mathbf{716}_1$. As briefly discussed herein, this may include detecting the envelope and applying dynamic range compression (DRC), including thresholding. For example, the B-mode processor **122** can use IQ data for generating envelope data by computing the amplitude of the (complex) IQ signal. In another instance, the B-mode processor **122** filters the RF-data with a filter such as a finite impulse response (FIR), an infinite impulse response (IIR) filter, or other filter. The B-mode processor **122** then runs the filtered RF-data through an envelope detector.

[0061] The image combiner **124** generates a final image by (non-coherently) compounding the images from the B-mode processors $\mathbf{122}_1$ and $\mathbf{122}_2$. The images are misaligned due to the mechanic motion of the probe **102**. The image combiner **124** aligns the images (e.g., via registration) and then adds/blends the images to create the final image. Examples of suitable compounding techniques are discussed in Gehlbach et al., "Frequency diversity speckle processing," Ultrasonic Imaging, 9(2):92-105, April 1987, and Magnin et al., "Frequency compounding for speckle contrast reduction in phased array images," Ultrasonic Imaging, 4(3):267-281, July 1982.

[0062] The image is displayed via the display **126**. The approach described herein, in one instance, can achieve a uniform image before and after the focus point in the transverse plane, improve focusing in the sagittal plane, and/or reduce speckle noise. In general, this is achieved using an adaptive synthetic aperture focusing algorithm and frequency/spatial compounding. The approach is described in detail for N=2 single-element transducers, and is extended to more such as three, four (as described below), five, etc. single-element transducers **112**.

[0063] Variations are described next.

[0064] FIG. **8** is identical to FIG. **7** except the preprocessors **118** are omitted. In this instance, the beamformers **120** directly process the RF signal (or the IQ signal). This variation corrects for jitter and transducer acceleration and reduces speckle, as discussed herein and/or otherwise.

[0065] FIG. **9** is identical to FIG. **7** except the delay corrector **712** and the estimator **714** are omitted. In this instance, the delays are not corrected before compounding. This variation reduces speckle as discussed herein. The beamformer **120** processes the input signal and reconstructs a signal $p(\vec{r})$ as shown in Equation 4:

$$p(\vec{r})=\Sigma_{n=0}^{N-1}a_n(\vec{r})s_n(T_n(\vec{r})).$$

[0066] FIG. **10** is identical to FIG. **7** except the preprocessor **118**, the delay corrector **712**, and the estimator **714** are omitted. Similar to FIG. **8**, the beamformer **120** processes the RF signal (or the IQ signal). Similar to FIG. **9**, the delays are not corrected before compounding, and speckle is reduced as discussed herein and/or otherwise.

[0067] FIG. **11** schematically illustrates an example in which N=4.

[0068] In this example, the transducer probe **102** includes the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_2$ and single-element transducers $\mathbf{112}_3$ and $\mathbf{112}_4$. The single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_2$ and disposed 180° apart, similar to the configuration of FIGS. **2**-**5**. However, both of the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_2$ in this example, operate with the same center frequency, f_1. The single-element transducers $\mathbf{112}_3$ and $\mathbf{112}_4$ are disposed 180° apart, an angularly offset from the single-element transducers $\mathbf{112}_1$ and $\mathbf{112}_1$ by 90°. Both of the single-element transducers $\mathbf{112}_3$ and $\mathbf{112}_4$ operate with a same center frequency, f_2, which is different than f_1. Each of the single-element transducers **112** is focused. The cross-talk between the single-element transducers **112** is eliminated by their spatial position and by the different frequencies f_1 and f_2 at which they operate.

[0069] In the two, single-element transducers version described herein, the two, single-element transducers operate at two different frequency f_1 and f_2 and are focused at two different depths z_1 and z_2. In other words, there are two pairs of frequency and depth (f_1, z_1) and (f_2, z_2). In the four, single-element transducers version configuration, there are four pairs of frequency and depth parameters (f_1, z_1), (f_2, z_1), (f_1, z_2), and (f_2, z_2). The spatial and frequency separation makes it possible to acquire two or four simultaneous images with the same transmit event. The different focus depths and the different frequencies give different realizations of the speckle. The non-coherent summation of the images results in speckle reduction.

[0070] An alternative configuration is to use separate and distinct probes, each having one or more single-element transducers **112**, where probes that operate at the same frequency are placed at angles of 180°.

[0071] FIG. **12** schematically illustrates a method in accordance with an embodiment disclosed herein.

[0072] It is to be understood that the following acts are provided for explanatory purposes and are not limiting. As such, one or more of the acts may be omitted, one or more acts may be added, one or more acts may occur in a different order (including simultaneously with another act), etc.

[0073] At **1202**, ultrasound signals from at least two, single-element transducers are received. As described herein, the at least two, single-element transducers operate at different center frequencies with field of views at different spatial positions (e.g., 180° apart).

[0074] At **1204**, the ultrasound signals from the at least two, single-element transducers are input to respective processing chains.

[0075] At **1206**, the ultrasound signals are pre-processed in their respective processing chains. In a variation, this act is omitted.

[0076] At **1208**, the ultrasound or pre-processed ultrasound signals are beamformed using adaptive synthetic aperture focusing, as described herein and/or otherwise.

[0077] At **1210**, the beamformed data is processed via a B-mode processor, as described herein and/or otherwise.

[0078] At **1212**, the output of the B-mode processor is combined to form a final image using frequency and spatial compounding, as described herein and/or otherwise.

[0079] At **1214**, the final image is displayed.

[0080] At least a portion of one or more of the methods discussed herein may be implemented by way of computer readable instructions, encoded or embedded on computer readable storage medium (which excludes transitory medium), which, when executed by a computer processor (s), causes the processor(s) to carry out the described acts. Additionally or alternatively, at least one of the computer readable instructions is carried by a signal, carrier wave or other transitory medium.

[0081] The embodiments disclosed herein can be used in applications such as pelvic, prostate and/or other imaging.

[0082] The application has been described with reference to various embodiments. Modifications and alterations will occur to others upon reading the application. It is intended that the invention be construed as including all such modifications and alterations, including insofar as they come within the scope of the appended claims and the equivalents thereof.

1. A method for ultrasound imaging with a first single-element transducer and a second single-element transducer, wherein the first and second single-element transducers are disposed on an ultrasound probe shaft, which has a longitudinal axis, with transducing sides disposed transverse to and facing away from the longitudinal axis, the first and second single-element transducers are angularly offset from each other on the shaft by a non-zero angle, the method, comprising:

operating the first and second single-element transducers at first and second different cutoff frequencies;

concurrently translating and rotating the shaft, moving the first and second single-element transducers along a helical path while the first and second single-element transducers acquire first and second echo signals;

receiving first electrical signals from the first single-element transducer, wherein the first electrical signals are indicative of the first echo signals, and receiving second electrical signals from the second single-element transducer, wherein the second electrical signals are indicative of the second echo signals;

delay and sum beamforming, with first and second adaptive synthetic aperture focusing beamformers, the first and second electrical signals, respectively via different processing chains, employing adaptive synthetic aperture focusing, producing first and second images;

combining the first and second images, creating a final image, which has reduced speckle noise and higher contrast resolution relative to the first and second images; and

displaying the final image.

2. The method of claim 1, wherein the adaptive synthetic aperture focusing corrects calculated first and second delays for transducer position errors with first and second corrections, weights and delays the first and second electrical signals with first and second weights and the corrected calculated first and second delays, and adaptively sums the weighted and delayed first and second electrical signals respectively with first and second correlation coefficients, producing the first and second images.

3. The method of claim 2, wherein the delay and sum beamforming includes:

computing the first weights and the calculated first delays and the second weights and the calculated second delays with one of a virtual source model, a semi-analytic model, simulated data, or measured data.

4. The method of claim 2, wherein the delay and sum beamforming includes:

determining the first corrections for the calculated first delays by determining differences between the calculated first delays and adding the first corrections to the calculated first delays; and

determining the second corrections for the calculated second delays by determining differences between the calculated second delays and adding the second corrections to the calculated second delays.

5. The method of claim 2, further comprising:

determining first levels of coherence between the first corrected calculated delayed signals;

generating the first correlation coefficients with the first levels of coherence;

determining second levels of coherence between the second corrected calculated delayed signals; and

generating the second weighting correlation coefficients with the second levels of coherence.

6. The method of claim 2, wherein the combining of the first and second images includes frequency compounding the first and second images.

7. The method of claim 6, wherein the combining of the first and second images includes registering the first and second images and then the frequency compounding of the first and second images.

8. The method of claim 7, wherein the combining of the first and second images includes spatially compounding the first and second images.

9. The method of claim 2, further comprising:

band-pass filtering the first electrical signals as a function of depth and band-pass filtering the second electrical signals as a function of depth and beamforming the filtered first and second electrical signals.

10. The method of claim 2, further comprising:

deriving first and second In-phase/Quadrature data respectively from the first and second electrical signals and beamforming the first and second In-phase/Quadrature data.

11. The method of claim 2, further comprising:

separating a first set and a second set of harmonic frequencies respectively from the first and second electrical signals and beamforming the first and second sets of harmonic frequencies.

12. The method of claim 2, further comprising:

shifting the first and second different cutoff frequencies and beamforming the first and second electrical signals with the shifted different cutoff frequencies.

13. The method of claim 2, further comprising:

detecting a first envelope and a second envelope respectively from the first and second beamformed signals and combining the first and second envelopes to produce the final image.

14. The method of claim 13, further comprising:

compressing the first and second envelopes and combining the first and second compressed envelopes to produce the final image.

15. An ultrasound imaging system, comprising:

a probe, including:

an elongate shaft;

a drive assembly coupled to the elongate shaft and configured to translate and rotate the shaft;

at least first and second single-element transducers disposed at an end region of the shaft angularly separated from each other by an angle in a range between 60 and 180 degrees, wherein the at least first and second single-element transducers transmit and receive in a direction transverse to the elongate shaft and have different center frequencies, and respectively generate at least first and second electrical signals; and a console, including:

a delay and sum beamformer configured to process the at least first and second electrical signals respectively through different processing chains, wherein the different processing chains respectively include at least first and second adaptive synthetic aperture focusing beamformers configured to employ adaptive synthetic aperture focusing to produce at least first and second images; and

an image combiner that combines the at least first and second images and displays the combined image on a display.

16. The system of claim **15**, wherein the delay and sum beamformer computes and corrects expected signal propagation times of the at least first and second electrical signals for errors due to mechanical movement of the at least first and second single-element transducers, weights and delays the at least first and second electrical signals using the corrected expected signal propagation times, and adaptively sums the weighted and delayed at least first and second electrical signals respectively with at least first and second correlation coefficients, producing the at least first and second images.

17. The system of claim **16**, wherein the delay and sum beamformer includes an estimator that determines differences between first signal propagation times and determines first corrections based thereon and uses the first corrections to correct the expected signal propagation time of first electrical signals, and determines differences between second signal propagation times and determines second corrections based thereon and uses the second corrections to correct the expected signal propagation time of second electrical signals.

18. The system of claim **16**, wherein estimator includes an estimator that determines the first and second corrections based on phases of the first and second correlations.

19. The system of claim **16**, wherein the delay and sum beamformer includes a delay corrector that interpolates a desired sample at a propagation time corresponding to a summation of an expected signal propagation time and a corresponding propagation time correction.

20. The system of claim **16**, wherein the delay and sum beamformer includes an estimator that finds a first level of correlation between the first delayed and weighted signals and determines the first correlation coefficients based on the first level of correlation and finds a second level of correlation between the second delayed and weighted signals and determines the second correlation coefficients based on the second level of correlation.

21. The system of claim **20**, wherein estimator finds the at least first and second levels of correlations by estimating deviations in the at least first and second delays using a lag-0 correlation between at least first and second center signals and at least first and second other delayed and weighted signals.

22. The system of claim **15**, wherein the image combiner combines the at least first and second images by frequency compounding the at least first and second images.

23. The system of claim **22**, wherein the image combiner registers the at least first and second images and then combines the at least first and second images by frequency compounds the at least first and second images.

24. The system of claim **23**, wherein the image combiner spatially compounds the at least first and second images.

25. The system of claim **23**, further comprising:

at least one additional single-element transducer, wherein the image combiner combines images generated by adaptive synthetic aperture focusing beamformers with electrical signal from the at least first and second single-element transducers and the at least one additional single-element transducer.

26. An apparatus, comprising:

delay and sum beamformer configured to process first and second electrical signals respectively through different processing chains, wherein the different processing chains respectively include first and second adaptive synthetic aperture focusing beamformers configured to employ adaptive synthetic aperture focusing to produce first and second images;

wherein the first electrical signals are received from a first single-element transducer, wherein the first electrical signals are indicative of first ultrasound signals, and receiving second electrical signals are received from a second single-element transducer, wherein the second electrical signals are indicative of second ultrasound signals,

wherein the first and second single-element transducers are disposed on a shaft, which has a longitudinal axis, of an ultrasound imaging probe with transducing sides disposed transverse to and facing away from the longitudinal axis, wherein the first and second single-element transducers are angularly offset from each other on the shaft by a non-zero angle,

wherein the first and second single-element transducers are operated at first and second different cutoff frequencies, and wherein the shaft concurrently translates and rotates while the first and second single-element transducers receive the first and second ultrasound signals; and

an image combiner that combines the first and second images and displays the combined image on a display.

* * * * *

专利名称(译)	具有多个单元件传感器和超声信号传播校正的三维超声成像		
公开(公告)号	US20190072671A1	公开(公告)日	2019-03-07
申请号	US16/081228	申请日	2016-03-01
[标]申请(专利权)人(译)	B-K医疗公司		
申请(专利权)人(译)	B-ķ医疗APS		
当前申请(专利权)人(译)	B-ķ医疗APS		
[标]发明人	NIKOLOV SVETOSLAV IVANOV HANSEN JENS MUNK		
发明人	NIKOLOV, SVETOSLAV IVANOV HANSEN, JENS MUNK		
IPC分类号	G01S15/89 A61B8/00 G01S7/52		
CPC分类号	G01S15/8993 A61B8/4477 G01S15/894 G01S15/8945 G01S15/8952 G01S15/8997 G01S7/52077 G01S7/52052 A61B8/12 G01S7/52046 G01S7/5205		
外部链接	Espacenet USPTO		

摘要(译)

一种方法包括接收来自第一单元件换能器（ 112 1 ）的第一电信号和来自第二单元件换能器的第二电信号（ 112 2 ）。换能器设置在轴（ 110 ）上，该轴具有超声成像探头（ 102 ）的纵轴（ 200 ）。换能侧横向于和背向纵向轴线设置。换能器在轴上彼此成角度地偏移非零角度。换能器以第一和第二不同的截止频率操作。当换能器接收第一和第二超声信号时，轴同时平移和旋转。该方法还包括利用第一和第二波束形成器（ 120 1 ，120 2 ）的延迟和求和波束形成，第一和第二电信号分别通过不同的处理链（ 712 1 ，712 2 ），采用自适应合成孔径技术，产生第一和第二图像。该方法还包括组合第一和第二图像，创建最终图像，以及显示最终图像。