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(54) **Title:** SYSTEM AND METHOD FOR SHEAR WAVE ELASTOGRAPHY BY TRANSMITTING ULTRASOUND WITH SUBGROUPS OF ULTRASOUND TRANSDUCER ELEMENTS

(57) **Abstract:** Systems and methods for performing shear wave elastography using push and/or detection ultrasound beams that are generated by subsets of the available number of transducer elements in an ultrasound transducer. These techniques provide several advantages over currently available approaches to shear wave elastography, including the ability to use a standard, low frame rate ultrasound imaging system and the ability to measure shear wave speed throughout the entire field-of-view rather than only those regions where the push beams are not generated.

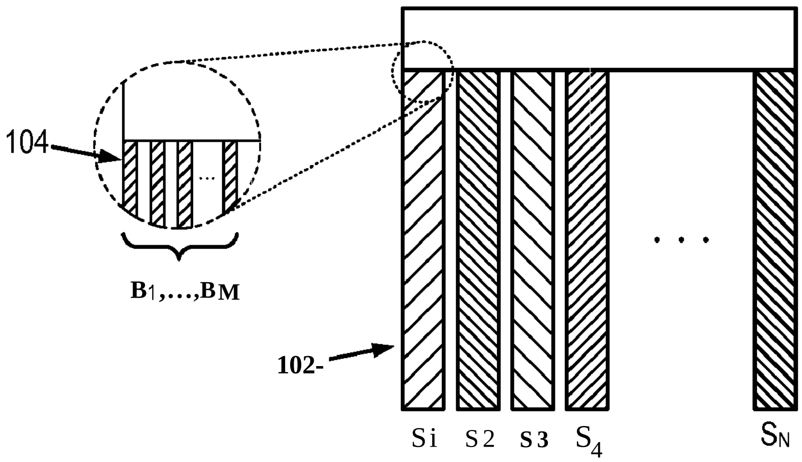


FIG. 1

WO 2014/055973 A1

SYSTEM AND METHOD FOR SHEAR WAVE ELASTOGRAPHY BY TRANSMITTING ULTRASOUND WITH SUBGROUPS OF ULTRASOUND TRANSDUCER ELEMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 61/710,744 filed on October 7, 2012, and entitled "SYSTEM AND METHOD FOR SHEAR WAVE ELASTOGRAPHY WITH LOW FRAME RATE IMAGERS."

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] This invention was made with government support under EB002167 and DK082408 awarded by the National Institutes of Health. The government has certain rights in the invention.

BACKGROUND OF THE INVENTION

[0003] The field of the invention is systems and methods for ultrasound imaging. More particularly, the invention relates to systems and methods for shear wave elastography using ultrasound.

[0004] Shear waves can be used to evaluate the viscoelastic properties of tissue, which are sensitive biomarkers of tissue pathology. To perform two-dimensional ultrasound shear wave elastography, an ultrasound imaging system with a frame rate of several kilohertz is required to capture the fast moving shear waves. This is not feasible with conventional ultrasound imaging systems, which typically have a frame rate of less than 100 Hz and where two-dimensional images are formed line by line. Thus, it would be desirable to provide a system and method capable of performing two-dimensional shear wave elastography with a conventional ultrasound imaging system.

SUMMARY OF THE INVENTION

[0005] The present invention overcomes the aforementioned drawbacks by providing a method for measuring a mechanical property of an object using an ultrasound system having an ultrasound transducer that includes a plurality of transducer elements. At least one shear wave is induced in the object, and elastography data is obtained from the object. The elastography data is obtained by dividing the transducer elements in the ultrasound transducer into a plurality of subgroups of transducer elements; successively transmitting a set of ultrasound beams using a different subgroup of transducer elements, thereby successively transmitting ultrasound to different regions in the object; and repeating that process at a pulse repetition frequency such that each set of ultrasound beams is effectively repeated at the pulse repetition frequency. From the obtained elastography data, a mechanical property of the object can then be calculated.

[0006] It is another aspect of the invention to provide a method for measuring a mechanical property of an object using an ultrasound system having an ultrasound transducer that includes a plurality of transducer elements. At least one shear wave is induced in the object by dividing the transducer elements in the ultrasound transducer into a plurality of subgroups of transducer elements and transmitting a plurality of focused ultrasound beams, each focused ultrasound beam being transmitted by a single subgroup of transducer elements. Elastography data is obtained from the object by transmitting a detection ultrasound beam into the object and receiving echo signals in response thereto. A mechanical property of the object can then be calculated using the obtained elastography data.

[0007] The foregoing and other aspects and advantages of the invention will appear from the following description. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown by way of illustration a preferred embodiment of the invention. Such embodiment does not necessarily represent the full scope of the invention, however, and reference is made therefore to the claims and herein for interpreting the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is an illustration of a plurality of ultrasound beam sets, each containing a plurality of ultrasound beams, being transmitted by an ultrasound transducer;

[0009] FIG. 2 is an example of a pulse timing diagram using the plurality of ultrasound beam sets of FIG. 1;

[0010] FIG 3 is an example of aligning the time grids of different ultrasound beam sets using interpolation;

[0011] FIG 4 is an example of a delay time in a shear wave front;

[0012] FIG. 5 is an example of another delay time in a shear wave front;

[0013] FIG. 6 is an illustration of a plurality of focused ultrasound push beams being simultaneously transmitted in a comb pattern;

[0014] FIG. 7 is an illustration of a focused ultrasound push beam that is rapidly translated along a lateral direction to generate shear waves; and

[0015] FIG. 8 is an illustration of a plurality of focused ultrasound push beams being simultaneously transmitted, in which each of the ultrasound push beams is generated with different sized subgroups of transducer elements.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Described here are systems and methods for performing shear wave elastography using push and/or detection ultrasound beams that are generated by subsets of the available number of transducer elements in an ultrasound transducer. These techniques provide several advantages over currently available approaches to shear wave elastography, including the ability to use a standard, low frame rate ultrasound imaging system and the ability to measure shear wave speed throughout the entire field-of-view rather than only those regions where the push beams are not generated.

[0017] High-end, conventional ultrasound imaging systems can image several lines from a single transmission using parallel beam forming. The pulse repetition frequency ("PRF"} and pulse repetition interval ("PRI"} for ultrasound imaging are determined by the maximum depth of the image. Assuming an imaging depth of 30 mm, the round-trip ultrasound travel time is

$$\frac{2\cdot 30[mm]}{1.54\left[\frac{mm}{\mu s}\right]}=39[\mu s] \qquad (1).$$

[0018] Adding beam forming and other overhead time delay, a PRI of 50 μs (PRF = 20 kHz] is feasible. The inventors have discovered that for two-dimensional shear wave elastography, the detection PRF at each spatial location can be less than 1 kHz. That is to say, using 1 kHz as an example, it is sufficient to perform shear wave elastography detection at the same spatial location only once every 1000 microseconds. Therefore, shear wave elastography can be performed using parallel beam forming detection at multiple locations sequentially while maintaining a PRF of 1 kHz at each location.

[0019] Referring now to FIG. 1, an example of a sequence of ultrasound beams generated by an ultrasound system to produce a desired PRF at each spatial location is illustrated. For example, the sequence of ultrasound beams includes N sets, $S_1,\ldots,S_N$ 102 each of M beams, $B_1,\ldots,B_M$ 104 formed in parallel. This sequence is then repeated at the pulse repetition frequency for a number, P , of desired repetitions.

[0020] By way of example, each set, S_n, of ultrasound beams may include a plurality of beams, B_m, that are formed in parallel. For example, each set of ultrasound beams may include four beams formed in parallel and twenty beam sets may be used for a total sampling of eighty different locations during each pulse sequence. Using this approach, shear wave motion can be detected within a two-dimensional region covered by the $M \cdot N$ spatial locations with an effective PRF of 1 kHz at each spatial location. Assuming a line spacing of 0.3 mm, which is typical for a 5 MHz linear array ultrasound transducer, two-dimensional shear wave elastography can be performed within an area that is 30 mm deep and 24 mm wide using this technique. In other implementations, each set of ultrasound beams may include only a single ultrasound beam. As a result, the region-of-interest in which mechanical properties can be measured will be smaller than with parallel beam forming.

[0021] An example pulse sequence timing for P repetitions of the pulse sequence illustrated in FIG. 1 is illustrated in FIG. 2. At time $t = 0\mu s$, transmission of beam set $S_{1,1}$ is used to track shear wave motion at beam locations defined by the beams, B_m, that form beam set $S_{1,1}$. For example, when beam set $S_{1,1}$ is composed of four beams, shear wave motion at four locations will be tracked. At a preset time after beam set $S_{1,1}$ is generated, beam set $S_{2,1}$ is generated to detect shear wave motion occurring at beam locations defined by the beams, B_m, that form beam set $S_{2,1}$. For example, the preset time may be 50 microseconds. In the next cycle of the transmission, the first beam set is again transmitted. This beam set, $S_{1,2}$, is therefore transmitted at time $t = 1000\mu s$ for a PRF of 1 kHz. The pulse sequence is repeated until the P^{th} repetition is performed at time $t = P \cdot 1000\mu s$.

[0022] The size of the two-dimensional shear wave elastography region is determined by the parallel beam forming capability of the ultrasound system and the required PRF at each spatial location. For example, six-beam parallel detection can allow a 36 mm image width if everything else does not change. It is contemplated that the required PRF may be higher in stiffer tissues. In this instance, the two-dimensional shear wave elastography region will be reduced in size in order to sustain the higher PRF. Therefore, implementations on traditional imagers may end up with a region-of-interest whose size changes with different applications. This result is similar to current two-dimensional color imaging methods in ultrasound scanners.

[0023] It is noted that although the descriptions provided above are made with respect to a one-dimensional array transducer, the concepts are also readily applicable to transducers with higher dimension, such as a two-dimensional array transducers.

[0024] It is noted that even though the PRF at each location is 1 kHz, different locations are sampled at different time grids. Referring to FIG. 2, the four beam locations in beam sets $S_{l,p}$ are sampled at times

$$t = 0, 1000, 2000, \ldots, P \cdot 1000\,\mu s.$$

[0025] The beams in beam sets $S_{2,p}$ are sampled at times,

$$t = 50,1050,2050,.\ \ldots,(P\ -1000) + 50\,\mu s.$$

[0026] This small time delay among locations needs to be accounted for in shear wave elastography reconstruction. Two example methods for accounting for this delay time are provided below.

[0027] One example method for compensating for the delay time noted above is to interpolate the time signal at each location from PRF to $N \cdot PRF$ (e.g., from 1 kHz to 20 kHz] and to use the same time grid for all locations. As shown in FIG. 3, the squares represent the time instances of ultrasound detection at locations covered by beam sets S_1 to S_N. Each beam is sampled at a PRF of 1 kHz, but there is a time shift of $50\mu s$ between adjacent beams. With interpolation back to 20 kHz for each beam, the time grids for each beam are aligned and synchronized. The interpolated points are represented by filled circles in FIG. 3.

[0028] Referring to FIG. 4, the triangular waves in (a] and (b) represent the shear wave signals detected at two locations x and y after interpolation such that both signals start at the same time. Direction $x \rightarrow y$ is the direction of shear wave propagation. The time delay, At, of the shear wave between (a] and (b) can be calculated using time-to-peak, cross-correlation, or other methods. The shear wave speed can therefore be calculated by

$$c_s = \frac{|y - x|}{\Delta t} \qquad (2);$$

[0029] where $|y - x|$ is the distance between location y and location x.

[0030] An example of another method for compensating for the delay time noted above is to account for the delay time when calculating the shear wave speed. Referring to FIG. 5, the triangular waves in (a] and (b) represent the shear wave signals detected at two locations, x and y, where the direction $x \rightarrow y$ is the direction of shear wave propagation. The time delay, At, of the shear wave between (a] and (b) can be calculated using time-to-peak, cross-correlation, or other methods. As explained above, the shear wave at different locations are detected at different time grids. Assuming that shear wave detection at location x starts at time $t = 0$ as shown in (a], and shear wave detection at location y starts at time $t = \delta$ as shown in (b), the actual delay, AT, between the shear wave at locations x and y is

$$AT = (At + \delta) \qquad (3).$$

[0031] By way of example, if x is located at one of the beams in beam set S_1, and y is located at one of the beams in beam set S_3, then

$$\delta = (3 - l) \quad -At = 2 \cdot 50 = 100\,\mu s \qquad (4).$$

[0032] The shear wave speed, c_s, can then be calculated by

$$c_s = \frac{|y - x|}{AT} \qquad (5);$$

[0033] where $|y - x|$ is again the distance between location y and location x.

[0034] It is noted that tracking beam sets $S_1, \ldots, S_N$ do not need to be in a spatially sequential order; instead, the tracking beam sets can be placed in different spatial orders. For example, tracking beams set S_1 can be placed on left end of the image, whereas tracking beam set S_2 can be placed at right end of the image, with odd-numbered beam sets following sequentially inward to the center of the image from beam set S_1 and even-numbered beam sets following sequentially inward to the center of the image from beam set S_2.

[0035] In addition, two or more beam sets can be transmitted simultaneously to reduce the number of transmit-detection events required to cover a two-dimensional region of desired size. This approach has the benefit of increasing the effective PRF of detection at each beam set location. For example, beam sets S_1 and S_{10} can be transmitted and detected simultaneously, followed by beam sets S_2 and S_{11} simultaneously, until all N beam sets are covered. This process can repeat again in time.

[0036] It is also noted that each of the beam sets will be transmitted by a group of transducer elements. Different beam sets may have same or different transducer elements. For example, in a linear array or curved array ultrasound transducer, elements 1 through 32 may be used for beam set S_1, and elements 8 through element 40 may be used for beam set S_2, and so on. In another example of a phase array transducer with 64 elements, the same 64 elements may be used to transmit all beam sets from S_1 to S_N by steering different beam sets to cover different regions.

[0037] The above teaching is for calculating the shear wave speed by measuring the time delay between shear waves detected at two or more locations along the shear wave propagation direction. The same concept can be applied for other methods of shear wave elasticity imaging, such as direct inversion and frequency dependent dispersion analysis. In addition, this method can be applied to shear waves produced by physiological motion, such as cardiac motion; mechanical vibration; and ultrasound radiation forces from single focused beams, single unfocused beams, multiple focused beams, or multiple unfocused beams.

[0038] Having described applications for transmitting ultrasound detection beams using subsets of the available transducer elements in an ultrasound transducer, techniques for using subsets of transducer elements to deliver ultrasound push beams are now discussed.

[0039] When an ultrasound push beam is transmitted into an object, shear waves are generated and propagate outward from the push beam in opposite directions. Consequently, shear waves are not generated in the push beam region, which means that shear wave speeds cannot be measured in the region where the push beam is generated. In addition, shear waves produced by an ultrasound push beam attenuate quickly over a short propagation distance. As a result, shear waves produced by a single push beam can only image a small region-of-interest; thus, in these instances, multiple push-detect acquisitions are required to piece together an image with large field-of-view ("FOV"}.

[0040] As described in co-pending PCT Application Publication WO2012/116364, entitled "Ultrasound Vibrometry with Unfocused Ultrasound," which is herein incorporated by reference in its entirety, a comb-shaped set of unfocused ultrasound beams can be used to provide a full FOV, two-dimensional shear wave speed map together with one rapid data acquisition. This method is referred to as comb-push ultrasound shear elastography ("CUSE"}.

[0041] In CUSE, multiple unfocused ultrasound push beams are used to produce shear waves within a tissue for shear wave elasticity imaging. Only one subset of transducer elements is used for each push beam; thus, multiple subsets of elements can be used for different spatial locations to simultaneously transmit multiple push beams. In CUSE, shear waves produced by each push beam can be treated as an independent realization of a single push beam.

[0042] Using CUSE, shear waves from different push beams interfere with each other and eventually fill the entire field-of-view ("FOV"}. To achieve robust shear wave speed estimation, a directional filter can be used to extract left-to-right ("LR"} propagating shear waves and right-to-left ("RL"} propagating shear waves from the interfering shear wave patterns. A time-of-flight based shear wave speed estimate method may be used to recover local shear wave speed at each pixel from both LR waves and RL waves. A final shear wave speed map may then be combined from the LR speed map and RL speed map. Because comb-push pulses produce shear wave motions with high amplitude at all image pixels, including at the push beam areas, both shear wave speed at the "source free" areas and shear wave speeds at the push beam areas can be recovered.

[0043] Thus, CUSE enables a full FOV two-dimensional reconstruction of a shear elasticity map with only one data acquisition. To improve acoustic radiation force penetration and generate stronger shear waves into deeper tissue (i.e., liver and kidney}, the previous CUSE method can be modified using focused ultrasound push beams. Using focused ultrasound push beams facilitates the generation of strong shear waves at locations deep within tissues. This ability to generate strong shear waves at deep tissue locations can lead to higher SNR for shear wave elasticity imaging compared to CUSE with unfocused beams.

[0044] In one configuration, illustrated in FIG. 6, the transducer elements are divided into a number of subgroups, such as four subgroups, that each simultaneously transmits a focused ultrasound beam. This technique is referred to as focused CUSE, or "F-CUSE." As noted, in F-CUSE, the transducer elements are divided into a number, N, of subgroups, with each subgroup containing one or more transducer elements.

[0045] As one example of the F-CUSE technique, a 128 element ultrasound transducer can be divided into four subgroups of 32 transducer elements each. In F-CUSE, all subgroups transmit focused ultrasound beams simultaneously to form a comb-push pattern ultrasound field. In one example, the duration of the push pulse beams can be on the order of 600 μs.

[0046] In another configuration, the transducer elements are divided into a number of subgroups with overlapping elements, and the subgroup that is used to transmit an ultrasound beam is rapidly changed along the lateral direction. The result of this "marching" of the subgroup of transducer elements being energized is to provide a focused ultrasound push beam at successively different horizontal locations. This technique may be referred to as marching CUSE, or "M-CUSE."

[0047] As one example of the M-CUSE technique, shown in FIG. 7, a 128 element ultrasound transducer can be divided into four, overlapping subgroups of 64 elements each. The first subgroup then transmits a single, focused push beam at a first time, tl. The duration of this push beam can be shorter than would be used in F-CUSE or traditional CUSE if it is desirable to control tissue or transducer heating due to repeated transmission using the overlapping transducer elements. As an example, the push beam duration in M-CUSE can be on the order of 200 μs. The push beam duration is selected based on considerations for how much overlap there is between subgroups of the transducer elements. For instance, the duration can be selected such that any given transducer element in overlapping subgroups is not energized for a consecutive duration that may lead to overheating in that element.

[0048] After the first push beam is transmitted, a second push beam is transmitted at a second time, t2, using the second subgroup of elements. This continues for the third and fourth subgroups. There is typically a small duration between consecutive push beams. For example, there can be a 15 μs delay between consecutive push beams. In this short duration of time, shear waves will propagate in soft tissue only about 0.45 mm, which is about 1.5 times the size of an individual transducer element in the transducer. Thus, in general, the amount of shear wave propagation between successive push beams is negligible for all subgroups after transmitting all of the focused push beams.

[0049] It is noted that each push beam of the F-CUSE or M-CUSE techniques may have a different number of transmit elements and may be focused at different depths. Additionally, each of the push events for the M-CUSE technique may include using more than one push beams. In the example shown in FIG. 8, push beams 1 (with less elements] and 2 (with more elements] are simultaneously transmitted at time ti, followed by push beams 3 and 4 transmitted simultaneously at time t2. This combination push will produce strong shear waves at all depths and all lateral positions for shear wave detection and processing. It is also noted that push beams in M-CUSE can have different push durations and can be transmitted in an arbitrary order (for example, in a different order 1→4→3→2 compared to the order 1→2→3→4 illustrated in FIG. 7]

[0050] Similar to the original CUSE method, both F-CUSE and M-CUSE can generate comb-patterned ultrasound push beams that induce a complicated shear wave field with interferences. Directional filtering described by Manduca et al. in "Spatio-Temporal Directional Filtering for Improved Inversion of MR Elastography Images," ***Medical Image Analysis,*** 2003; 7(4): 465-473, can thus be used to separate the shear waves into multiple directions without interference so that robust shear wave estimates can be achieved at each imaging pixel within the FOV.

[0051] After comb-push transmission, a plane wave imaging mode can be used with all transducer elements delivering ultrasound to detect the propagating shear waves. Alternatively, the detection scheme described above can also be used.

[0052] The present invention has been described in terms of one or more preferred embodiments, and it should be appreciated that many equivalents, alternatives, variations, and modifications, aside from those expressly stated, are possible and within the scope of the invention.

CLAIMS

1. A method for measuring a mechanical property of an object using an ultrasound system having an ultrasound transducer that includes a plurality of transducer elements, the step of the method comprising:

a] inducing at least one shear wave in the object;

b) obtaining elastography data from the object by:

    i) dividing the transducer elements in the ultrasound transducer into a plurality of subgroups of transducer elements;

    if) successively transmitting a set of ultrasound beams using a different subgroup of transducer elements, thereby successively transmitting ultrasound to different regions in the object;

    iii) repeating step ii] at a pulse repetition frequency such that each set of ultrasound beams is effectively repeated at the pulse repetition frequency; and

c) calculating a mechanical property of the object using the obtained elastography data.

2. The method as recited in claim 1, wherein step c) includes accounting for time offsets between the transmission of successive sets of ultrasound beams when calculating the mechanical property.

3. The method as recited in claim 2, wherein accounting for the time offsets includes interpolating data acquired using the same subset of ultrasound pulses, but in different repetitions of step b)ii) to a common time grid.

4. The method as recited in claim 2, wherein calculating the mechanical property in step c) includes calculating a shear wave speed by estimating a time delay between detection points in the at least one shear wave using at least one of a time-to-peak and a cross-correlation method.

5. The method as recited in claim 4, wherein calculating the time delay includes accounting for the time offset.

6. The method as recited in claim 1, wherein at least some of the plurality of different regions at least partially overlap.

7. The method as recited in claim 1, wherein each successively transmitted set of ultrasound beams is transmitted by a subgroup of transducer elements that is spatially adjacent to the subgroup of transducer elements that transmitted the previous set of ultrasound beams.

8. The method as recited in claim 1, wherein each set of ultrasound beams comprises a plurality of ultrasound beams that are formed in parallel.

9. The method as recited in claim 8, wherein each of the plurality of ultrasound beams is a focused ultrasound beam.

10. The method as recited in claim 8, wherein each of the plurality of ultrasound beams samples motion of the at least one shear wave at a different location in the object.

11. The method as recited in claim 1, wherein step b) is performed using an ultrasound system having a frame rate lower than one kilohertz.

12. The method as recited in claim 11, wherein the ultrasound system has a frame rate lower than 100 Hertz.

13. The method as recited in claim 1, wherein step a] includes transmitting a plurality of focused ultrasound beams into the object, each of the plurality of ultrasound beams being generated by a different subgroup of transducer elements.

14. The method as recited in claim 13, wherein the plurality of focused ultrasound beams are spaced apart evenly across a surface of the ultrasound transducer.

15. The method as recited in claim 14 in which step c) includes applying a directional filter to the elastography data acquired in step b) such that interference between shear waves propagating in different directions is substantially mitigated.

16. The method as recited in claim 13, wherein the plurality of focused ultrasound beams are transmitted by transmitting a focused ultrasound beam using a first subgroup of transducer elements at a first time and translating the focused ultrasound beam to spatially adjacent subgroups of transducer elements at successively different time points.

17. A method for measuring a mechanical property of an object using an ultrasound system having an ultrasound transducer that includes a plurality of transducer elements, the step of the method comprising:

a] inducing at least one shear wave in the object by:

i) dividing the transducer elements in the ultrasound transducer into a plurality of subgroups of transducer elements;

ii] transmitting a plurality of focused ultrasound beams, each focused ultrasound beam being transmitted by a single subgroup of transducer elements;

b) obtaining elastography data from the object by transmitting a detection ultrasound beam into the object and receiving echo signals in response thereto; and

c) calculating a mechanical property of the object using the obtained elastography data.

18. The method as recited in claim 17, wherein step a)ii) includes transmitting the plurality of focused ultrasound beams simultaneously.

19. The method as recited in claim 17, wherein step a)ii) includes transmitting one focused ultrasound beam at a time, and in which each successively transmitted focused ultrasound beam is generated by a subgroup of transducer elements spatially adjacent to the subgroup of transducer elements that generated the previous focused ultrasound beam.

20. The method as recited in claim 17, wherein step b) includes:

i) dividing the transducer elements in the ultrasound transducer into a plurality of subgroups of transducer elements;

if) successively transmitting a set of ultrasound beams using a different subgroup of transducer elements, thereby successively transmitting ultrasound to different regions in the object;

iii) repeating step ii] at a pulse repetition frequency such that each set of ultrasound beams is effectively repeated at the pulse repetition frequency.

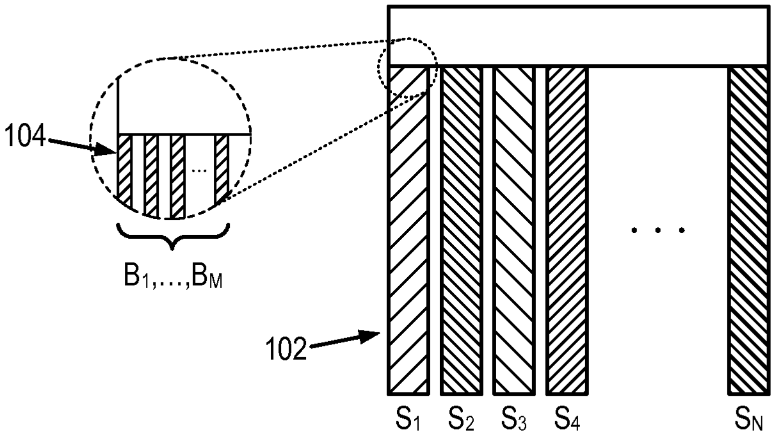
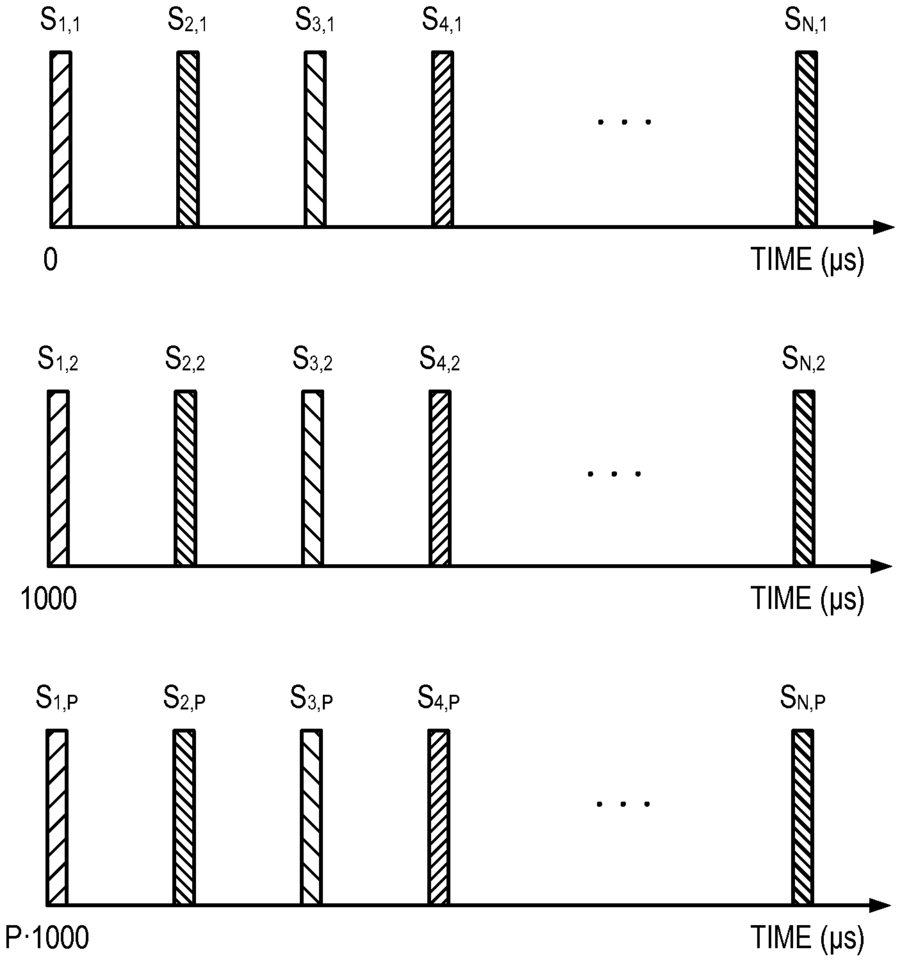

104
$B_1,\ldots,B_M$
102
S_1
S_2
S_3
S_4
S_N

FIG. 1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TIME (μs)

FIG. 2

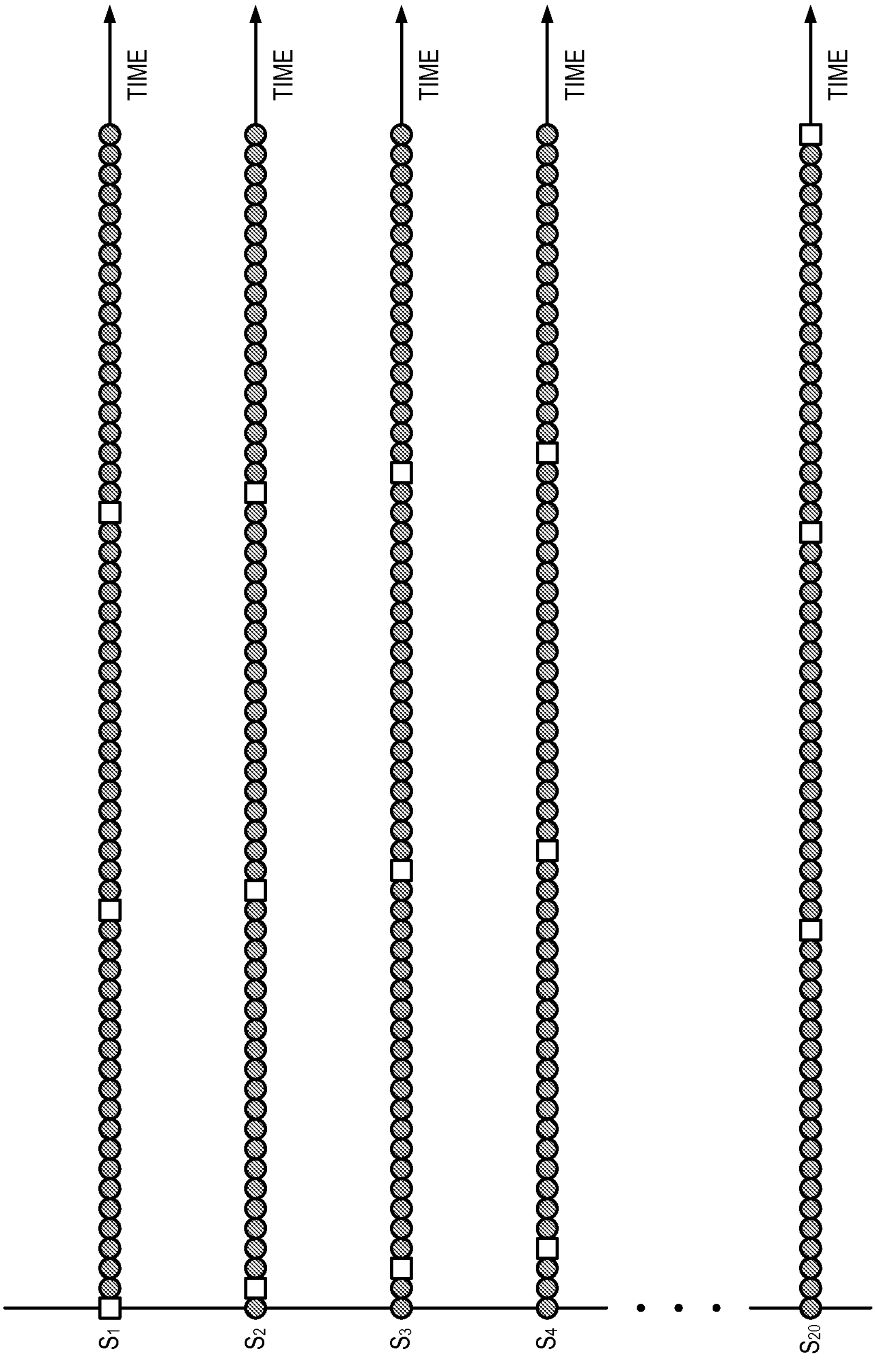

FIG. 3

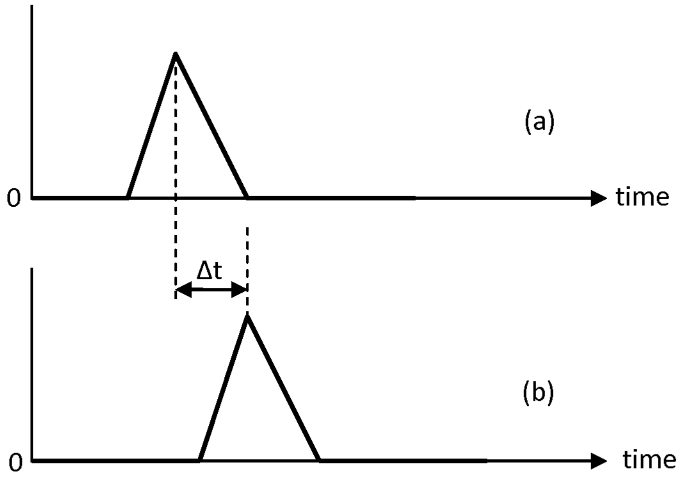

FIG. 4

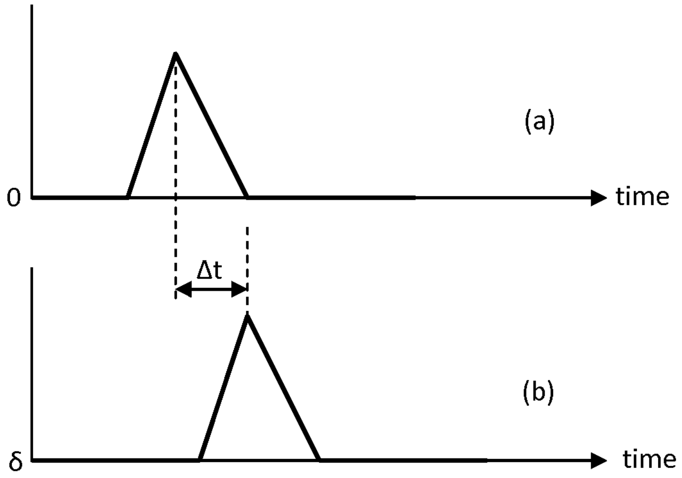

FIG. 5

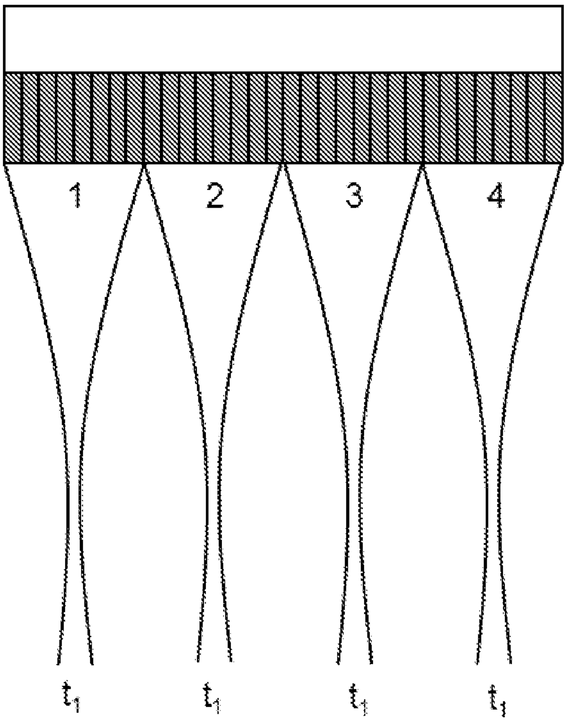

FIG. 6

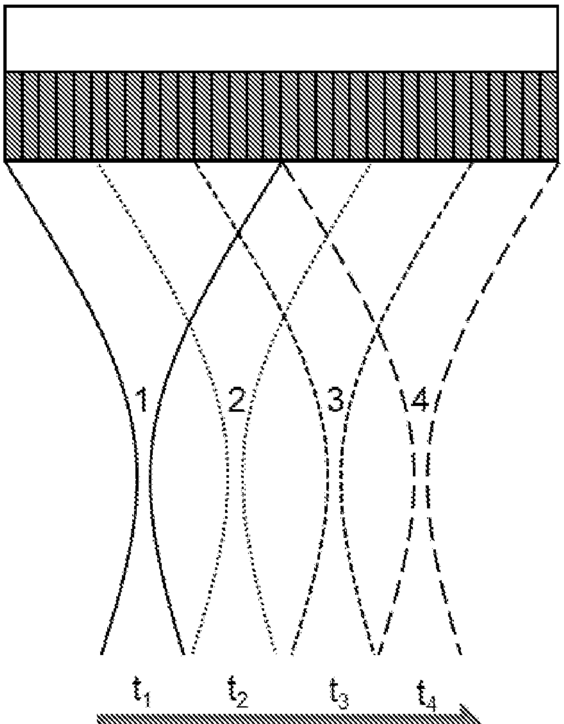

FIG. 7

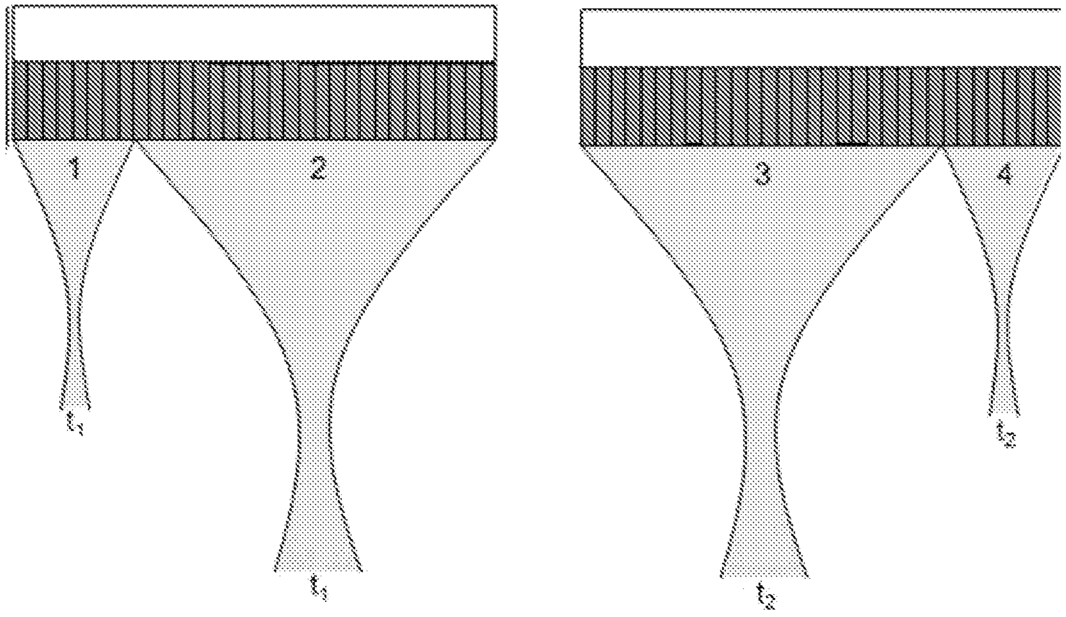

FIG. 8

PCT/US2013/063631 12.12.2013

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US13/63631

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61B 8/00; A61N 7/00 (2013.01)
USPC - 600/438; 601/2
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): A61B 8/00; A61N 7/00 (2013.01)
USPC: 600/438; 601/2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

MicroPatent (US-G, US-A, EP-A, EP-B, WO, JP-bib, DE-CB, DE-A, DE-T, DE-U, GB-A, FR-A); Google Scholar; ProQuest Dialog; Medline/PubMed; Search terms: beam, delay, elastography, focus, frame, group, hz, interval, overlap, rate, region, shear, speed, subgroup, time, transducer, ultrasonic, ultrasound, wave

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	WO 2012/116364 A1 (GREENLEAF, JF, et al.) August 30, 2012; claim 1; paragraphs [0014], [0029], [0041], [0042], [0050], [0056], [0065], [0068], [0070], [0073]	1, 6 ------- 2-5, 7-20
Y	US 2011/0263978 A1 (CHEN, S, et al.); October 27, 2011; figure 3; paragraphs [0029], [0049], [0059], [0060], [0064], [0078], [0084]	2-5, 7-10, 13-20
Y	US 2012/0095323 A1 (ESKANDARI, H, et al.) April 19, 2012; paragraph [0054]	11, 12
Y	US 2011/0063950 A1 (GREENLEAF, JF, et al.) March 17, 2011; paragraph [0052]	3
Y	US 2011/0066030 A1 (YAO, L) March 17, 2011; paragraph [0032]	3

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 06 December 2013 (06.12.2013)	Date of mailing of the international search report 12 DEC 2013
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Shane Thomas **PCT Helpdesk: 571-272-4300** **PCT OSP: 571-272-7774**

专利名称(译)	通过利用超声换能器元件的子组发射超声来进行剪切波弹性成像的系统和方法		
公开(公告)号	EP2833792A4	公开(公告)日	2016-07-06
申请号	EP2013844234	申请日	2013-10-07
[标]申请(专利权)人(译)	梅约医学教育与研究基金会		
申请(专利权)人(译)	梅奥基金会的医学教育和研究		
当前申请(专利权)人(译)	梅奥基金会的医学教育和研究		
[标]发明人	GREENLEAF JAMES F CHEN SHIGAO SONG PENGFEI		
发明人	GREENLEAF, JAMES, F. CHEN, SHIGAO SONG, PENGFEI		
IPC分类号	A61B8/00 A61N7/00 A61B8/08 G01N29/24 G01N29/34 G01S7/52 G01S15/89		
CPC分类号	A61B8/485 A61B8/08 A61B8/4488 A61B8/4494 A61B8/5223 G01N29/07 G01N29/262 G01N2291/011 G01N2291/02475 G01N2291/02827 G01N2291/0422 G01S7/52022 G01S7/52042 G01S7/5209 G01S15/8915 G01S15/8927		
优先权	61/710744 2012-10-07 US		
其他公开文献	EP2833792A1		
外部链接	Espacenet		

摘要(译)

使用由超声换能器中的可用数量的换能器元件的子集生成的推和/或检测超声波束来执行剪切波弹性成像的系统和方法。这些技术提供了超过目前可用的剪切波弹性成像方法的几个优点，包括使用标准的低帧率超声成像系统的能力以及在整个视野中测量剪切波速度的能力，而不仅仅是那些不产生推梁。