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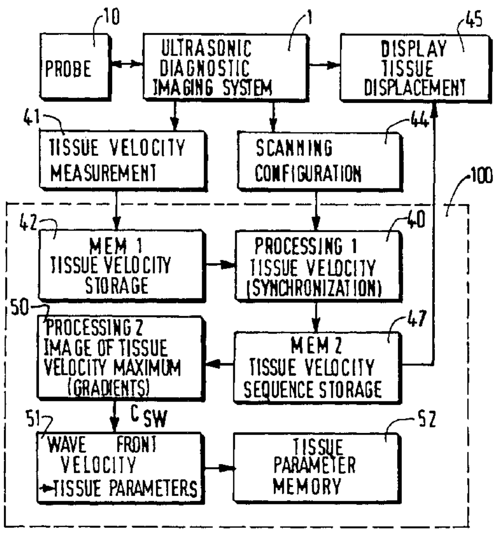
(54) Title: ULTRASONIC METHOD AND SYSTEM FOR SHEAR WAVE PARAMETER ESTIMATION



(57) Abstract: The invention relates to an ultrasonic diagnostic imaging method for determining propagation parameters of transient shear wave front, comprising steps of forming transient shear waves in a tissue (5), acquiring ultrasonic image data (S,S*) of the tissue, along image lines (*l*) during a time delay (T_{SW}) for a transient shear wave front to propagate over a depth (z) in said tissue, estimating the tissue velocity (V) for each line, constructing a tissue velocity image sequence [I(V)] from the ultrasonic data (S,S*) and the tissue velocities (V) on the lines, and deriving the velocities (C_{SW}) of the shear wave front at instants of the sequence. Tissue parameters such as elasticity are then calculated from said front velocity. The invention also relates to an ultrasonic diagnostic imaging system having processing means (100, PROCESSING1, PROCESSING2) for carrying out this method. The processing means may be a computer program product having instruction to this end.

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Ultrasonic method and system for shear wave parameter estimation

FIELD OF THE INVENTION

The invention relates to a an ultrasonic method and an ultrasonic system for determining local propagation velocity of transient shear waves in a tissue, for displaying a sequence of velocity images of the transient shear waves and for determining tissue elasticity information.

The invention finds its application in using this information as a tool to diagnose abnormalities, such as tumors or edemas, in a patient tissue. These abnormalities are known to show changes of their mechanical properties with respect to sound background tissue. Shear wave propagation information permits of localizing said abnormalities.

BACKGROUND OF THE INVENTION

A method for determining tissue elasticity in various parts of a body is already known from Sarvazyan, U.S. Pat.N°5,606,971. According to this known method, ultrasonic waves are focussed at different location of a tissue, using a focused ultrasonic source that transmits said ultrasonic waves to its focal region. The focused ultrasonic source is preferably an ultrasound transducer of the phased array kind. Said focussed ultrasonic waves are amplitude modulated for generating shear waves at said different locations of the tissue. Said shear waves are further detected by measuring their amplitude and phase on the surface of the tissue. At least one propagation parameter of the shear waves in the tissue is determined from the phase and amplitude measures such as shear wave velocity, attenuation coefficient, amplitude and velocity of shear displacement of tissue particles in the propagating shear wave. A calculation, based on these measures, is performed and at least one mechanical parameter of tissue is determined such as the shear elasticity modules, Young modulus, dynamic shear viscosity, using known relations. The steps of the method are repeated for all amplitude modulated focused ultrasound waves, which are focused at said various locations. The calculated values of dynamic shear viscosity and elasticity modulus are displayed in function of the coordinates of said locations.

This known method of producing shear waves necessitates the use of focussed ultrasonic sources such as phased array transducers, for transmitting a great amount of ultrasonic energy to the locations where shear waves are produced in the tissue. Focussed ultrasonic sources may have destructive effects on the patient tissue due to the necessary amount of ultrasonic energy that is locally applied.

SUMMARY OF THE INVENTION

The present invention has for an object to provide a method, and a system to carry out the method, which do not use a focused ultrasonic source, in order to avoid possible secondary effects in the patient tissue. According to the invention, shear waves are generated in a tissue using an external mechanical vibration source. The shear waves produce displacements of tissue particles. According to the invention, a standard ultrasonic diagnostic system measures the velocity of the tissue particles and the velocity of the front of the shear waves. This ultrasonic diagnostic system also has means to display a sequence of images of the shear wave front propagation.

A problem is that the shear waves propagate at about 1 m. per s. over several centimeters in the tissue, for instance 4 cm. In this case, the propagation time is about 40 ms (milliseconds). This velocity is much too high and the propagation time delay much too small to permit of visualizing the effect of shear waves on the tissue using a standard sequence of ultrasonic images produced by a standard ultrasonic diagnostic imaging system. The image frame rate of such a system is not adapted to visualizing the shear wave propagation because it is of the order of 15 images per second whereas an image frame rate of about 1 image per ms (1000 images per second) is needed for shear wave visualization.

The present invention provides, as claimed in Claim 1, an ultrasonic diagnostic imaging method for determining propagation parameters of transient shear wave front, comprising steps of forming transient shear waves in a tissue, acquiring ultrasonic image data (S,S*) of the tissue, along image lines, during a time delay for a transient shear wave front to propagate over a depth (z) in said tissue, estimating the tissue velocity (V) for each line, constructing a tissue velocity image sequence [I(V)] from the ultrasonic data (S,S*) and the tissue velocities (V) on the lines, and deriving the velocities (C_{SW}) of the shear wave front at instants of the sequence. The invention also provides an ultrasonic diagnostic imaging method, as claimed in claim 7, for determining tissue local mechanical parameters of a tissue from the transient shear wave front velocity (C_{SW}).

The present invention further provides a system, as claimed in claim 8 for carrying out said methods.

The invention allows the visualization of sequences of tissue moving under the influence of shear wave, using a standard ultrasound diagnostic imaging system with a standard transducer emitting and receiving standard ultrasound and echo signals respectively. The invention further allows the localization of tissue regions having contrasting mechanical properties with respect to a background, and the determination of the mechanical parameters of said tissue regions.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is described in detail thereafter in connection with the schematic drawings in which :

FIG. 1A is a block diagram of an ultrasonic diagnostic imaging system having means for producing shear waves in a tissue, for processing echo signals and displaying corresponding images; FIG.1B illustrates the scanning of ultrasonic lines in one image; and FIG.1C illustrates the formation of an ultrasonic full-image sequence;

FIG.2 is a block diagram of an ultrasonic diagnostic imaging system for processing ultrasonic signals of a tissue region under the influence of shear wave, for measuring the wave front velocity, and tissue mechanical local parameters;

FIGs.3A and 3B illustrate respectively the formation of sequences of ultrasonic sub-images and the formation of corresponding sequences of tissue velocity sub-images;

FIG.4 illustrates the construction of a sequence of tissue velocity full-images;

FIG.5 illustrates an image constructed from the tissue velocity full-image sequence to provide the shear wave front velocity measure.

DETAILED DESCRIPTION

FIG.1A shows a block diagram representing a standard ultrasonic diagnostic imaging system 1 connected to a transducer 10 denoted probe and to a vibration generator 2. The ultrasonic diagnostic system is connected to a processing system 100 for the determination of local propagation velocity of transient shear waves, for the display of a sequence of images the transient shear wave front and for the determination of tissue parameters such as tissue elasticity.

Referring to FIG.1B, the probe 10 is positioned in ultrasonic contact with a tissue 5 to be examined and emits ultrasonic pulses through said tissue. The probe comprises transducer elements disposed in an arrangement parallel to the surface of the tissue and to an axis OX, denoted X-axis. The transducer elements permit of emitting several ultrasonic beams of ultrasonic pulses parallel to an axis OZ denoted Z-axis, orthogonal to the X-axis. The total number ℓ_{IM} of ultrasonic beams may be for example $\ell_{IM} = 128$ or $\ell_{IM} = 256$. Each beam is hereafter referred to as an ultrasonic line parallel to the Z-axis and has an abscissa on the X-axis from x_1 to $x_{\ell IM}$. As the ultrasonic pulses propagate through the tissue 5, along one line, at an abscissa x_i with the index i such as $1 \leq i \leq \ell_{IM}$, corresponding echoes are generated by tissue particles encountered along said line. These echoes are received by the probe at instants that are function of the depth z of the echo formation on said line parallel to the Z-axis. The combination of all echoes generated from reflection along one line at an abscissa x_i forms a line of ultrasonic data of the tissue, which data are complex data and are denoted S and S*. The scanning of one line over a depth z of about 4 cm takes a time of less than or about $T_\ell = 100\,\mu s$; for the simplicity of explanation, it is supposed thereafter that this time is $T_\ell = 100\,\mu s$. The scanning of the ℓ_{IM} lines is performed one line after the other and forms a full 2-D image of ultrasonic data (S and S*), referred to as ultrasonic image, which ultrasonic image comprises ℓ_{IM} lines (128 or 256 lines) parallel to the Z-axis disposed at regular intervals ($x_1, x_2, \ldots x_{\ell IM}$). The lines are about 4 cm long measured along the Z-axis. With the hypothesis set above, it takes about a time $T_{IM} = \ell_{IM} 100\,\mu s$ to form one 2-D ultrasonic image over a depth of 4 cm:

$T_{IM} = 12{,}8$ ms for one ultrasonic image of 128 lines,

or $T_{IM} = 25{,}6$ ms for one ultrasonic image of 256 lines.

Referring to FIG.1A, the ultrasonic diagnostic imaging system 1 is connected to a vibration generator 2 that is an external mechanical pulse generator 2. This external mechanical pulse generator presents the advantages of being very armless for the patient and very easy to use for the practitioner. Each mechanical pulse is applied to the tissue 5 by means of a contact body 4 and generates shear waves that propagates in tissue 5 over a depth z of about 4 cm at a velocity that has been A PRIORI estimated and that is:

$$C_{SW} = \text{about } 1\text{m/s}$$

With this estimated velocity C_{SW}, the shear waves propagates in the tissue over said depth of 4 cm taking a time that is about :

$$T_{sw} = 40 \text{ ms.}$$

The invention proposes a method and a system for the visualization of the transient shear wave front on a display 45 connected to the standard ultrasonic diagnostic system 1. To that end, the ultrasonic diagnostic system of FIG.1A comprises the processing system 100 associated to the standard ultrasonic diagnostic system 1, to the vibration generator 2 and to the probe 10. The probe 10 may be positioned with respect to the vibration generator 2 in any way appropriate for the standard ultrasonic diagnostic system 1 to form ultrasonic images of the tissue region 5 where the shear wave propagate.

For visualizing the transient shear wave front, first a temporal sequence of ultrasonic images is formed during the time delay of the shear wave front propagation. Referring to FIG.1C, for visualizing correctly this propagation, it is proposed to form a temporal sequence of a number N of ultrasonic images, for instance N = 10 to 50 images. In an example described thereafter, it is chosen to form a temporal sequence of :

$$N = 40 \text{ ultrasonic images}$$

denoted I_1, I_2 to I_N regularly acquired during the time delay :

$$T_{SW} = 40 \text{ ms.}$$

So, with the previous hypothesis related to scanning time $T\ell$ of one line, the ultrasonic diagnostic imaging system must supply one ultrasonic image every 1ms to allow the visualization of the shear wave, whereas the standard ultrasonic diagnostic imaging system is able to supply only one ultrasonic image every 12,8 ms or every 25,6 ms, which is the time T_{IM}. So, such a standard ultrasonic diagnostic system is not adapted to supply an image frame rate appropriate to construct the temporal ultrasonic image sequence that is required to visualize the transient shear wave front propagation. The processing system 100 permits of solving this problem.

FIG.2 shows a block diagram representing the system 100 having processing means for acquiring sequences of temporal ultrasonic sub-images, for estimating the local velocity of tissue particles under the action of the shear waves, for constructing a sequence of tissue velocity full-images, for estimating the shear wave front velocity and for visualizing the displacement of tissue under the influence of the transient shear wave propagation.

Referring to FIG.3A, at a first instant α_1, the vibration generator generates a first shear wave in the tissue 5, and, using the scanning configuration 44 of the ultrasonic diagnostic system 1, at the same instant α_1, the probe 10 that is coupled to tissue 5 begins scanning a first line at the abscissa x_1 in order to provide a first line of ultrasonic data denoted S and S*. It takes $T\ell = 100\,\mu s$ to the system to scan one line, and said system disposes of $T_{SW} = 40$ ms to scan 4 cm, over which the shear wave propagates, and must supply N = 40 temporal ultrasonic images at the rate of 1 ultrasonic image per ms. So, the system has time to scan a number $1 < \ell_K \leq 10$ adjacent lines of the first ultrasonic image I_1, disposed at abscissa $x_1, x_2, \ldots x_{10}$, thus forming a first band of lines of ultrasonic data (S and S*), which band is denoted K_1 (I_1) in said first ultrasonic image I_1. For example, $\ell_K = 10$ lines.

Referring to FIG.3A, the system further scans a number $\ell_K = 10$ adjacent lines of the second temporal ultrasonic image I_2, disposed at the same abscissa $x_1, x_2, \ldots x_{10}$, thus forming a first band of lines of ultrasonic data (S and S*), denoted $K_1(I_2)$ of $\ell_K = 10$ lines at the same abscissa in the second ultrasonic image I_2.

Referring to FIG.3A, the system further scans $\ell_K = 10$ adjacent lines of each temporal ultrasonic image including I_{40}, forming in each temporal ultrasonic image I_1 to I_{40} only one band K_1 of $\ell_K = 10$ lines disposed at the abscissa x_1 to x_{10}. The first band K_1 is denoted first sub-image K_1 of each completed ultrasonic image of 128 or 256 lines to be performed. It takes $T_{SW} = 40$ ms for the system to perform $N = 40$ temporal ultrasonic sub-images $K_1(I_1)$ to $K_1(I_{40})$ of ultrasonic data S and S*. This forms a first sequence of ultrasonic sub-images of the ultrasonic data (S and S*).

As it may be understood of those skilled in the art, the number of lines of the ultrasonic sub- image is calculated : by determining the total number ℓ_{SW} of lines that are possibly scanned during the time propagation T_{SW} of the shear wave, knowing the time $T\ell$ for scanning one line, by fixing the number N of ultrasonic images of the sequence that is appropriate to visualize the shear wave front displacement, which gives the number ℓ_K of lines possibly scanned per ultrasonic image, from I_1 to I_N, during the time of one pulse of the vibration generator 2:

$$\ell_K = \ell_{SW} / N$$

At a second instant α_2, the vibration generator 2 generates a second shear wave in the same region of tissue 5, and, using the scanning configuration 44, at the same instant α_2, the probe 10, that is coupled to tissue 5, begins scanning a first line at the abscissa x_{11}, which forms the first line of ultrasonic data (S and S*) of a second band $K_2(I_1)$ of the first temporal ultrasonic image I_1. So, now, the system scans $\ell_K = 10$ lines at the abscissa x_{11} to x_{20}, thus forming the second band of ultrasonic data (S and S*), which band is denoted $K_2(I_1)$ and is composed of $\ell_K = 10$ lines in the first temporal ultrasonic image I_1.

Then as previously described in reference to FIG.3A, the system further scans $\ell_K = 10$ adjacent lines of each temporal ultrasonic image I_1 to I_{40}, disposed at the abscissa x_{11} to x_{20}, forming the bands of temporal ultrasonic sub-images $K_2(I_1)$ to $K_2(I_{40})$.

At further instants α_3 to α_k, the vibration generator 2 provides a mechanical pulse that generates a shear wave propagating in the same region of tissue 5 and, using the scanning configuration 44, at the same instant, the probe 10 that is coupled to the tissue 5 begins scanning a first line of $\ell_K = 10$ lines to form the ultrasonic image of a corresponding band K of the temporal ultrasonic images I_1 to I_{40}.

This scanning operation is performed until a number k of bands or ultrasonic sub-images K_1 to K_k are constructed for each ultrasonic image I_1 to I_{40}. The number k of ultrasonic sub-images and the number ℓ_K of lines in each ultrasonic sub-images are chosen appropriately by the user in function of the number of lines ℓ_{IM} of each full image. At the instant α_k, the last sequence of ultrasonic sub-images is constructed.

Referring to FIG.2, the ultrasonic data of the sequences of ultrasonic sub-images are used to construct corresponding sequences of tissue velocity sub-images. The velocities of tissue particles under the action of shear waves are measured along each scanning line of the ultrasonic sub-image sequence. The measure of velocity of displacement of tissue is an operation well known of those skilled in the art, which is usually performed using the standard ultrasonic system 1 that has means 41 for tissue velocity measurement.

The ultrasonic diagnostic imaging system 1 may perform the tissue velocity measurement on each scanning line at the abscissae x_1 to x_ℓ of the ultrasonic sub-images of the sequences respectively K_1 to K_k using different methods. A known method is for example the "phase shift method" according to which the tissue velocity $[V(n,\ell,z)]$ is supplied by the processing means 41, from the ultrasonic data S and S* of the lines of the sequences of ultrasonic sub-images, according to the formula :

$$V(n,\ell,z) = \frac{C}{4\pi(\ell_K\, T_\ell\, fo)} \operatorname{Arg} \sum_{m=n-p}^{m=n+p} S(m,\ell,z)\, S^*(m+1,\ell,z)$$

where n is the image number in the sequence of N ultrasonic sub-images, with $1 \le n \le N-1$, where ℓ is the line number in the considered ultrasonic sub-image among the ℓ_K total number of lines in said ultrasonic sub-image K_1 to K_k of a given ultrasonic sub-image n in which the velocity of tissue is estimated, T_ℓ is the scanning time of one line, fo is the mean frequency of the echo signal, S and S* are the values of the complex ultrasonic signals, z is the depth of the point where the velocity is estimated and C is the velocity of ultrasounds in the tissue (in the present example, $1 \le n \le 39$, $\ell_K = 10$ and $T_\ell = 100\,\mu s$). In the above formula, p is the number of data that are averaged in order to calculate the velocity; p may be taken equal to 2 for example; m is calculated from n and p.

Referring to FIG.3B, with this method, sequences of tissue velocity sub-images are constructed, that are composed of a number N-2p (for example N-2p = 40 – 4 =

36) of sub-images, which is different from the number N of sub-images (N = 40) of the sequences of ultrasonic sub-images. However the number k of sequences of tissue velocity sub-images is the same as the number of sequences of ultrasonic sub-images.

In a variant, the tissue velocity may be measured by a well known "temporal shift method", or other methods that are the choice of the user.

Then, the sequences of tissue velocity sub-images are stored in a first memory means 42, denoted MEM1, and notably the tissue velocity values are stored as a function of their locations, denoted P(x,z,t) where x is the abscissa of the scanning line along the X-axis, t is the instant, which is different from n, corresponding to said image number n and z is the depth along the Z-axis. So P(x,z,t) is a point in a tissue velocity sub-image at an instant t corresponding to n at the abscissa x and depth z, and in a sub-image $K_1[V(n,\ell,z)]$ to $K_k[V(n,\ell,z)]$ of the k sequences of (N-2p) tissue velocity sub-images.

Referring to FIG.2, the k tissue velocity sub-images $K_1[V(n,\ell,z)]$ to $K_k([V(n,\ell,z)]$ are further processed in order to be assembled for constructing a temporal sequence of N-2p tissue velocity full-images, denoted $I_1[V(n,\ell,z)]$ to $I_{N-2p}[V(n,\ell,z)]$.

This operation is performed using a first processing means 40 denoted PROCESSING1 of the processing system 100. The PROCESSING1 operates a synchronization of the lines of all tissue velocity sub-images for forming tissue velocity full-images. In this operation, all the first lines of all the k tissue velocity first sub-images, which are adjacent, are synchronized to the first line of the first sub-image formed at the first instant α_1, in order to cover a first full-image, and all the lines of all the k tissue velocity sub-images corresponding to said given full-image are synchronized on said first line, taking into account the time delay between the formation of each image line. Then, all the adjacent sub-images of the tissue velocity sequences are processed in the same way with respect to the instant of formation of the first sub-images among the adjacent sub-images, for covering tissue velocity full-images.

Referring to FIG.4, the resulting tissue velocity sequence is then constituted by the number N – 2p = 36 tissue velocity full-images $I_1[V(n,\ell,z)]$ to $I_{N-2p}[V(n,\ell,z)]$ that are so constructed. By this operation of synchronization, each tissue velocity full-image $I_1[V(n,\ell)]$ to $I_{N-2p}[V(n,\ell)]$ of the tissue velocity sequence corresponds to a respective instant t of shear wave propagation in the tissue, t being function of n previously defined.

In order to perform the synchronization operation, the velocity values related to the lines, which are stored in MEM1 are extracted and input to the synchronization means PROCESSING1, which has for a function to correct the time delay produced by the scanning operation. First, in order to construct one full-image at one instant t of the tissue velocity sequence, the lines of each tissue velocity sub-image of the k tissue velocity sequences must be synchronized to the first line of the first tissue velocity sub-image corresponding to said tissue velocity full-image. Second, the point on the lines of said full-image must be synchronized to corresponding tissue velocity values estimated from the sequences of tissue velocity sub-images, taking into account that the sequences of ultrasonic sub-images comprise N ultrasonic sub-images presented at instants n whereas the sequences of tissue velocity sub-images comprise N-2p tissue velocity sub-images presented at instants t. It is to be noted that the real time delay between instants t_ℓ and $t_{\ell+1}$ corresponding to the velocities on two adjacent lines at the same depth z, respectively V(n, ℓ,z) and V(n, ℓ+1,z), is T_ℓ, which is the time delay for scanning one line. It is also to be noted that the time necessary to scan one ultrasonic sub-image is $\ell_K T_\ell$. So, the time delay between the instants t1 and t_ℓ corresponding to the velocities V(n,1,z) and V(n, ℓ,z) is :

$$t_\ell - t1 = (\ell - 1)T_\ell .$$

For the above-described reasons, finding the actual velocity on a given line numbered ℓ in the tissue velocity sub-image is performed by using an interpolation function, denoted I, of the velocity data in function of time t, according to the formula:

$$f_\ell\ (t) = I\,[\ V(n, \ell, z)]\ \text{from } n = p \text{ to } N\text{-}2p$$

where $t = [n+(\ell-1)]\ \ell$ that is smaller than $\ell_K T_\ell$.

This function f_ℓ (t) is a filtering function applied on the velocity data that provides the actual tissue velocity on a considered line of the tissue velocity image to be constructed. This filtering function may be of a kind that is known by those skilled in the art, for example a cubic spline function or a sinus cardinal function.

The number k of sub-images K, the number N of temporal ultrasonic images and the number ℓ of lines to form a temporal ultrasonic image are the choice of the user. At the end of this phase 3, a temporal sequence of a number N-2p = 40-2p of tissue velocity full-images has been constructed from the k acquired sequences of N ultrasonic sub-images and the estimation of the tissue velocity.

Referring to FIG.2, the data issued of PROCESSING1 are stored in a second memory means 47 denoted MEM2. The full-images are tissue velocity images of the region 5 where the shear waves propagate, and are displayed in sequence using the display means 45 of system 1. At this stage of the process, the display shows the tissue regions moving under the action of the mechanical pulse supplied by the vibration generator 2.

Referring to FIG.2, in a further phase, the data of the tissue velocity image sequence are extracted from MEM2 and supplied to a second processing means 50, denoted PROCESSING2. From the data of the tissue velocity sequence, which comprise the tissue velocity values at each point of each image, and at each instant t of the shear wave propagation, one further image, referred to as I_{MAX}, is constructed in PROCESSING2.

Referring to FIG.5, in PROCESSING2, this new image I_{MAX}, called image of the maximum velocities, is build by writing, at points on lines of said image, the instants, referred to as t_{MAX}, among t_1 to t_{N-2p}, when the velocities of the tissue are maximum, denoted V_{MAX}. The different points of the image I_{MAX} that correspond to maximum of tissue velocities at the same instant t_{MAX} are joined by lines denoted L_t: all the points on a same line are points of maximum velocities for a same instant t: the lines are equal-levels of velocities. So, these lines show the instants of propagation of the shear wave front. The estimation of the gradients of time in this image I_{MAX} permits of determining the velocity of said shear wave front. The wave front velocity, denoted C_{SW} is estimated in PROCESSING2, in function of the gradients in said new image I_{MAX}, by the following formula :

$$C_{SW} = \left(\frac{dt_{MAX}^2}{dx} + \frac{dt_{MAX}^2}{dz}\right)^{-\frac{1}{2}}$$

The propagation front velocity data extracted from PROCESSING2 are further processed in a calculation means 51 for estimating the tissue parameters such as for example the elasticity of tissue regions from formulae known of the document cited in the introductory part. The tissue parameters are stored in memory means 52 in order to be further used as diagnostic tools for helping to the diagnostic of tumors or other diseases.

This ultrasonic diagnostic imaging system may be a standard ultrasonic apparatus 1,10 associated to a processing means 100 comprising a suitably programmed computer, a processor of a workstation, or a special purpose processor having circuit means such as LUTs, Memories, Filters, Logic Operators, that are arranged to perform the functions of the method steps according to the invention. The workstation may also comprise a keyboard, a screen 45 and a mouse. The processing system may be connected to supplementary storing means to store medical images.

CLAIMS:

1. An ultrasonic diagnostic imaging method for determining propagation parameters of transient shear wave front, comprising steps of:

- forming transient shear waves in a tissue (5),
- acquiring ultrasonic image data (S,S*) of the tissue, along image lines (ℓ), during a time delay (T_{SW}) for a transient shear wave front to propagate over a depth (z) in said tissue,
- estimating the tissue velocity (V) for each line,
- constructing a tissue velocity image sequence [I(V)] from the ultrasonic data (S,S*) and the tissue velocities (V) on the lines,
- and deriving the velocities (C_{SW}) of the shear wave front at instants of the sequence.

2. A method as claimed in Claim 1, comprising for the acquisition of ultrasonic data, steps of:

- estimating the time delay (T_{SW}) for a transient shear wave to propagate over a given depth (z) of tissue, calculating the number of scan lines (ℓ_{SW}) that can be ultrasonically scanned during said time delay, setting a predetermined number (N) of full-images for an ultrasonic full-image sequence, each ultrasonic full-image comprising a predetermined number of scan lines (ℓ_{IM}), calculating the number of lines (ℓ_{K}) that can be possibly scanned in each full-image of the ultrasonic image sequence,
- estimating a number (k) of adjacent sub-images (K_k) in each ultrasonic full-image, each sub-image being formed of said number of possibly scanned lines (ℓ_{K}), in order to cover each full-image of the sequence by the estimated number of adjacent sub-images,
- and determining an ultrasonic scanning configuration (44) for scanning the corresponding sub-images of the sequence images like as many sequences of sub-images as the estimated number of adjacent sub-images.

3. A method as claimed in Claim 2, comprising steps of:

- scanning the tissue according to the scanning configuration while initiating one shear wave each time one sequence of ultrasonic sub-images is started.

4. A method as claimed in Claim 3, comprising for the estimation of the sequence of tissue velocity images, steps of:

- estimating the tissue velocities (V) on the scan lines from the ultrasonic data (S,S*), in function of the number of lines (ℓ_K) in the ultrasonic sub-images and in function of the image number (n) of the sub-image in the sequences of ultrasonic sub-images,
- forming sequences of tissue velocity sub-images [K(V)] corresponding to the sequences of ultrasonic sub-images [K(I)],
- considering the adjacent sub-images appropriate to cover respectively full-images in order to construct one sequence of velocity full-images [I(V)] during the propagation of one shear wave, and synchronizing the lines of the adjacent tissue velocity sub-images, relating to each full-image, with the first line of the corresponding sub-image of the first sequence for forming said sequence of velocity full-images.

5. A method as claimed in Claim 4, comprising for estimating the shear wave front velocities, steps of:

- in the sequence of tissue velocity images [I(V)], determining the points, on the image lines, for which the tissue velocities are maximum (V_{MAX}) in function of the instant (t_{MAX}) of formation of the considered tissue velocity image,
- from said tissue velocity image sequence, forming a further image, referred to as image (I_{MAX}) of the maximum velocities, which image is formed of points having respectively the locations on said image lines and being attributed the values of the instants (t_{MAX}) for which the tissue velocities (V_{MAX}) are maximum in said tissue velocity image sequence,
- linking the points having the same instant values for forming an image of the transient shear wave fronts at said instant values.

6. A method as claimed in Claim 5, comprising for estimating the shear wave front velocities, steps of:

- in said image of the maximum velocity (t_{MAX}, V_{MAX}) determining the time gradient values in function of the image point locations (x,z),

- estimating the transient shear wave front velocities (C_{SW}) from the gradient values of said image of the maximum.

7. An ultrasonic diagnostic imaging method for determining mechanical parameters of a tissue (5) by the determination of propagation parameters of transient shear wave front, comprising steps of:

- estimating the transient shear wave front velocity (C_{SW}) according to the method of one of Claims 1 to 6,
- and estimating the tissue local mechanical parameters from the transient shear wave front velocities.

8. An ultrasonic diagnostic imaging system, for determining mechanical parameters of a tissue by the determination of propagation parameters of transient shear wave front, comprising:

- a vibration generator (2,4) for producing transient shear waves in a tissue (5) using external mechanical pulses,
- and a standard ultrasonic imaging system (1,10,44,41) for acquiring ultrasonic data (S, S*) of the tissue, along image lines, during a time delay (T_{SW}) for a transient shear wave front to propagate over a depth (z) in said tissue, and for estimating the tissue velocities for each line,

and a processing system (100) having:

- a first processing means (PROCESSING1) for constructing a tissue velocity image sequence from the ultrasonic data and the tissue velocities on the lines,
- a second processing means (PROCESSING2) for deriving the velocities of the shear wave front at instants of the sequence,
- and a calculating means (51) for estimating the tissue local mechanical parameters from the transient shear wave front velocities (C_{SW}).

9. A system as claimed in Claim 8, comprising for acquiring image data, scanning configuration means (44), which is defined by:

- estimating the time delay (T_{SW}) for a transient shear wave to propagate over a given depth of tissue, calculating the number of scan lines that can be ultrasonically scanned during said time delay, setting a predetermined number (N) of full-images for an ultrasonic full-image sequence, each ultrasonic full-image comprising a predetermined number (ℓ_{IM}) of scan lines, calculating the number (ℓ_K) of lines that can be possibly scanned in every full-image of the ultrasonic image sequence,

- estimating a number (k) of sub-images in each ultrasonic full-image, each sub-image being formed of said number of possibly scanned lines, in order to cover each full-image of the sequence by the estimated number of adjacent sub-images,
- which scanning configuration means (44) is for scanning the tissue so as corresponding ultrasonic sub-images of the sequence images are scanned like as many sequences of ultrasonic sub-images as the estimated number of adjacent ultrasonic sub-images, and so as one sequence of ultrasonic sub-images is started each time one shear wave is initiated.

10. A system as claimed in Claim 9, comprising:

- velocity measurement means (41) for estimating the tissue velocities on the scan lines from the ultrasonic data, in function of the number of lines in the ultrasonic sub-images and in function of the number of images in the sequences of ultrasonic sub-images, and for forming sequences of tissue velocity sub-images corresponding to the sequences of ultrasonic sub-images.

11. A system as claimed in Claim 10, wherein the first processing means (PROCESSING1) receives the sequences of tissue velocity images, processes the adjacent sub-images appropriate to cover respectively full-images in order to construct one sequence of velocity full-images during the propagation of one shear wave, by synchronizing the lines of the adjacent tissue velocity sub-images relating to each full-image with the first line of the corresponding sub-image of the first sequence for forming said sequence of tissue velocity full-images.

12. A system as claimed in Claim 11, wherein the second processing means (PROCESSING2) receives the sequence of tissue velocity full-images

- determines the points, on the image lines, for which the tissue velocities are maximum in function of the instant of formation of a considered tissue velocity image,
- forms a further image, referred to as image of the maximum, which image is formed of points having respectively the locations on said image lines and being attributed the values of the instants for which the tissue velocities are maximum in said tissue velocity image sequence,

- and links the points having the same instant values for forming an image of the transient shear wave fronts at said instant values.

13. A system as claimed in one of Claims 8 to 12, comprising display means (45) for displaying the sequence of tissue velocity images and the images of front propagation.

14. An apparatus having means (1,10) to acquire medical ultrasonic data and having a system (100), having access to said medical ultrasonic data, to process the data as claimed in one of claims 8 to 13, and having means (45) to display the processed images.

15. A computer program product comprising a set of instructions for carrying out a method as claimed in one of Claims 1 to 7.

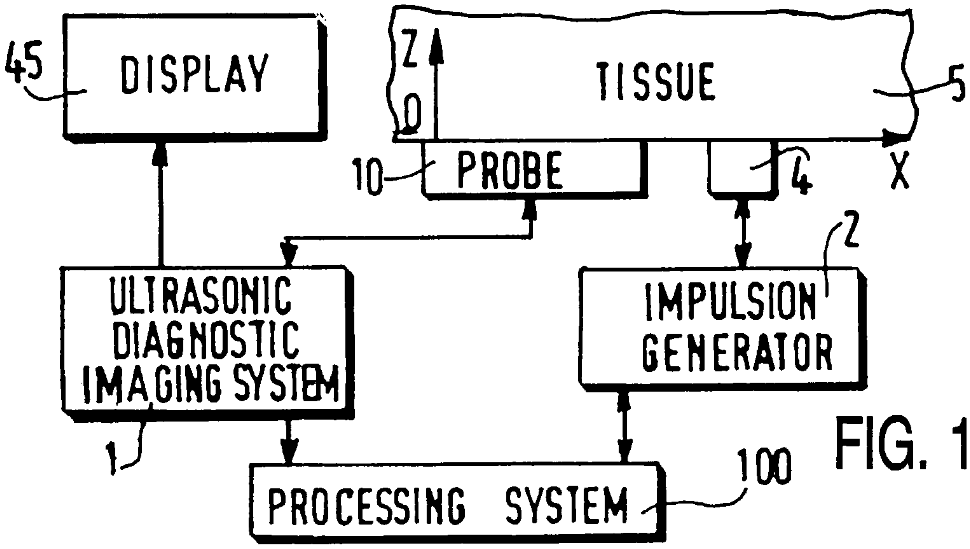

FIG. 1A

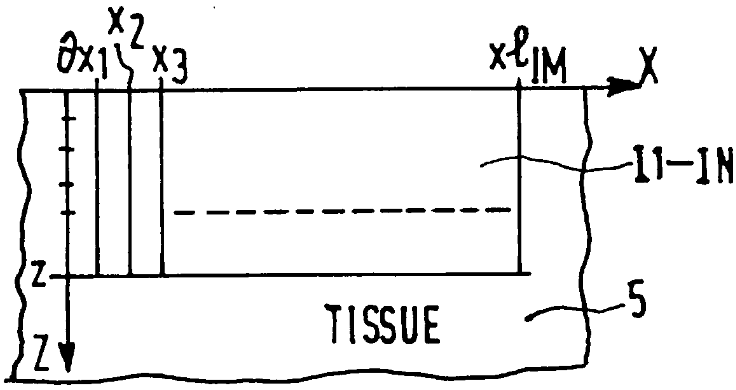

FIG. 1B

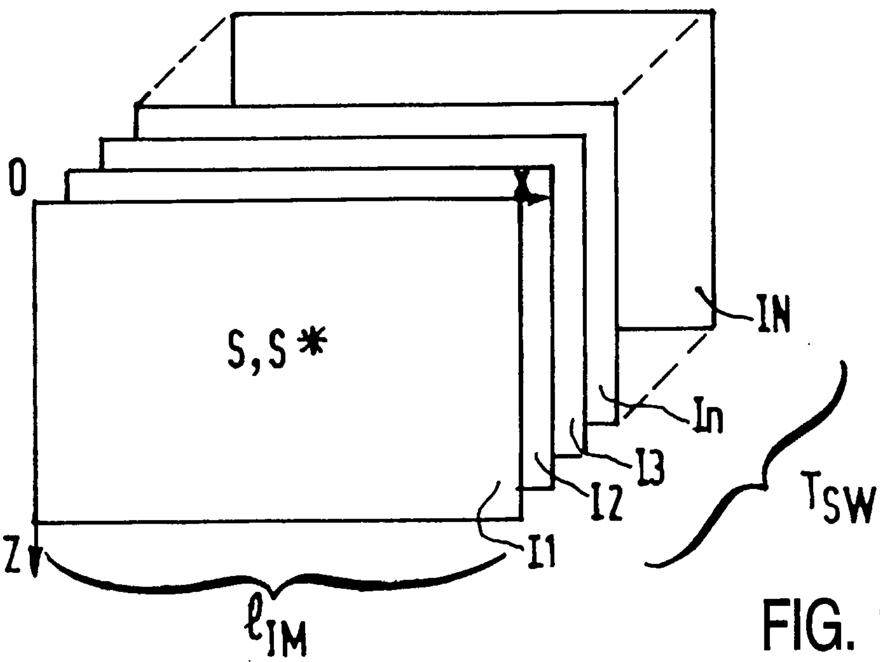

FIG. 1C

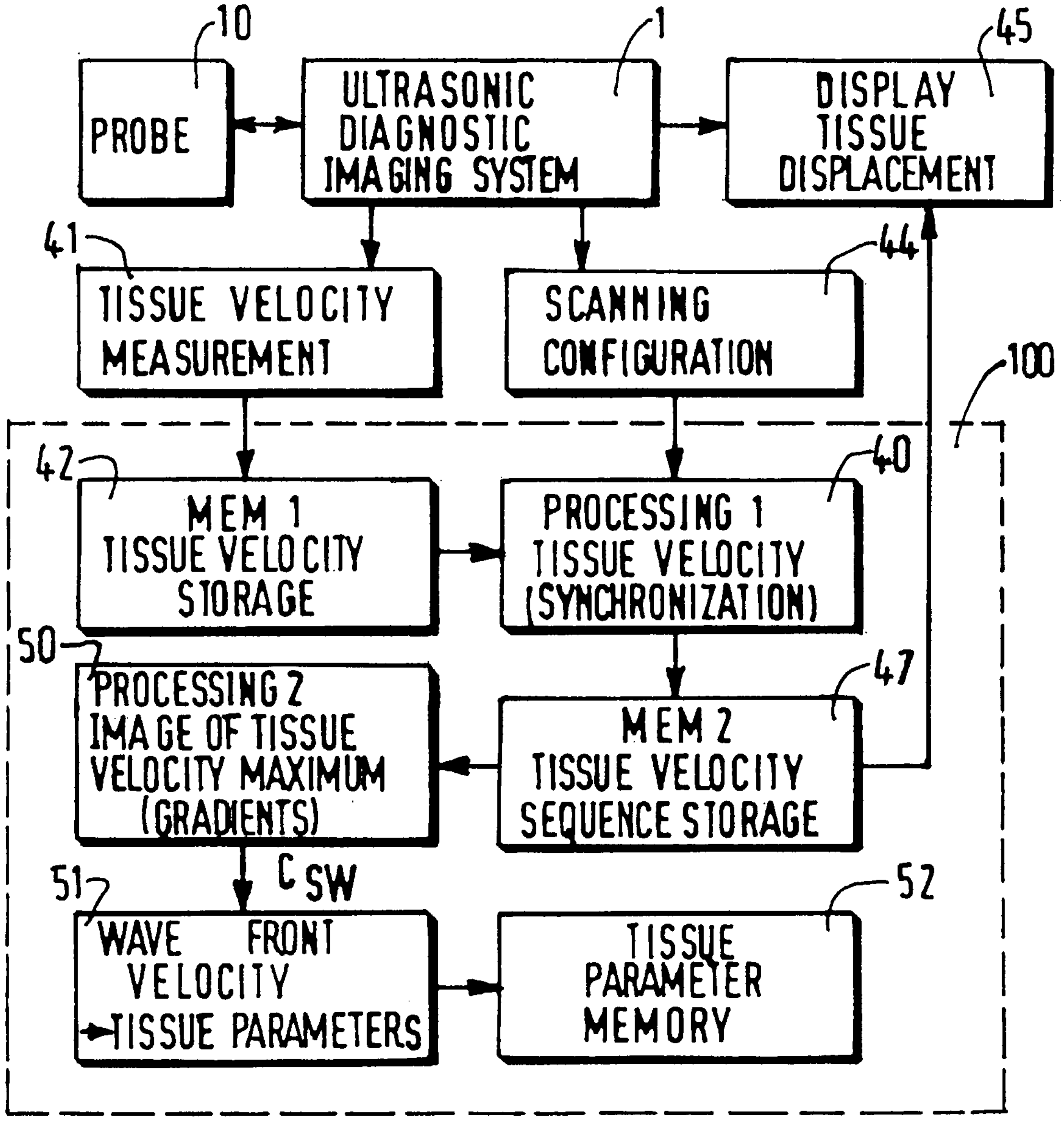
PROBE
10
ULTRASONIC DIAGNOSTIC IMAGING SYSTEM
1
DISPLAY TISSUE DISPLACEMENT
45
TISSUE VELOCITY MEASUREMENT
41
SCANNING CONFIGURATION
44
100
MEM 1 TISSUE VELOCITY STORAGE
42
PROCESSING 1 TISSUE VELOCITY (SYNCHRONIZATION)
40
PROCESSING 2 IMAGE OF TISSUE VELOCITY MAXIMUM (GRADIENTS)
50
MEM 2 TISSUE VELOCITY SEQUENCE STORAGE
47
C SW
WAVE FRONT VELOCITY →TISSUE PARAMETERS
51
TISSUE PARAMETER MEMORY
52

FIG. 2

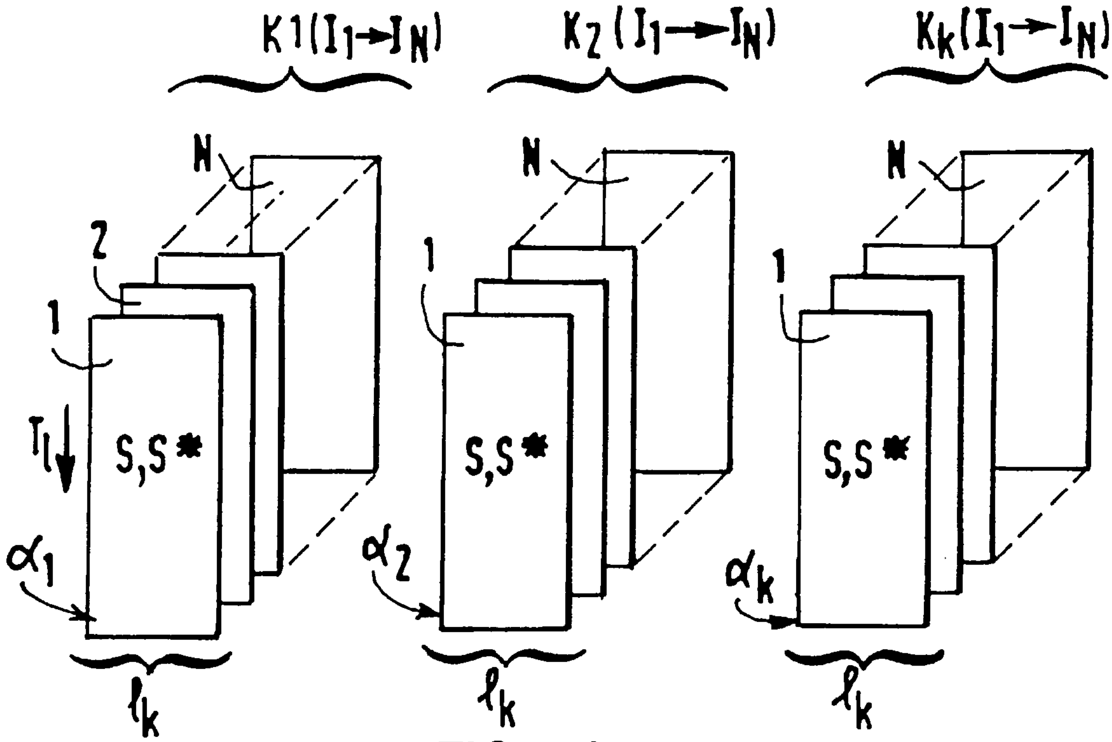
K1(I1→IN)
K2(I1→IN)
Kk(I1→IN)
N
2
1
Tl
S,S*
α1
α2
αk
lk

FIG. 3A

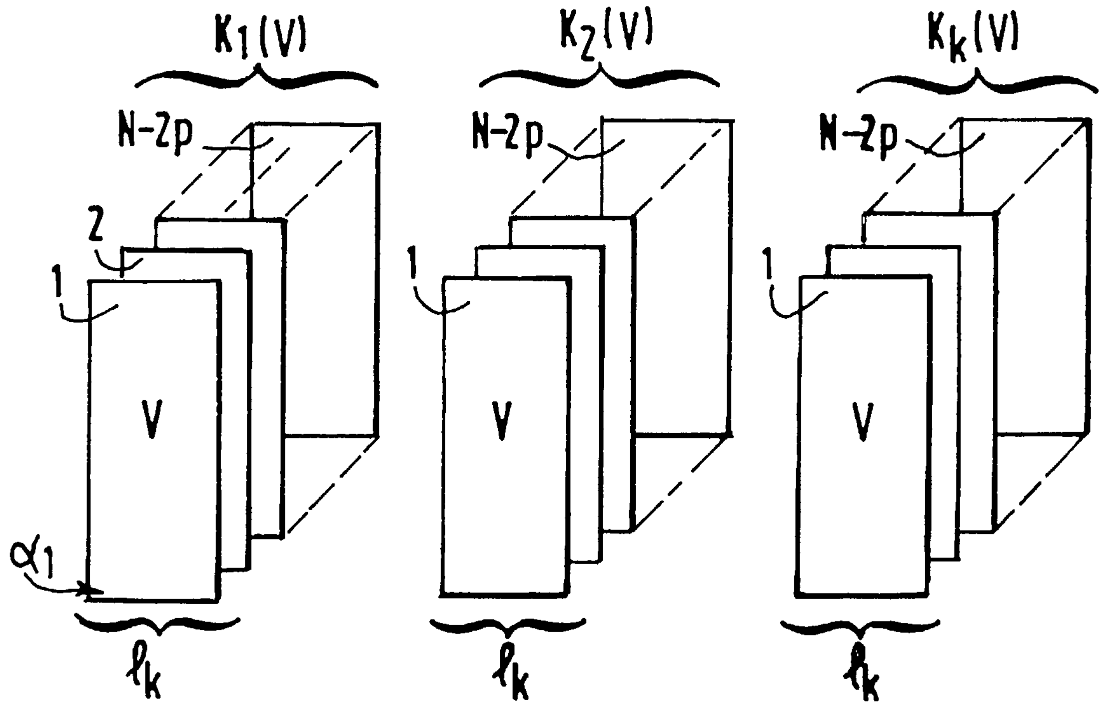
K1(V)
K2(V)
Kk(V)
N-2p
2
1
V
α1
lk

FIG. 3B

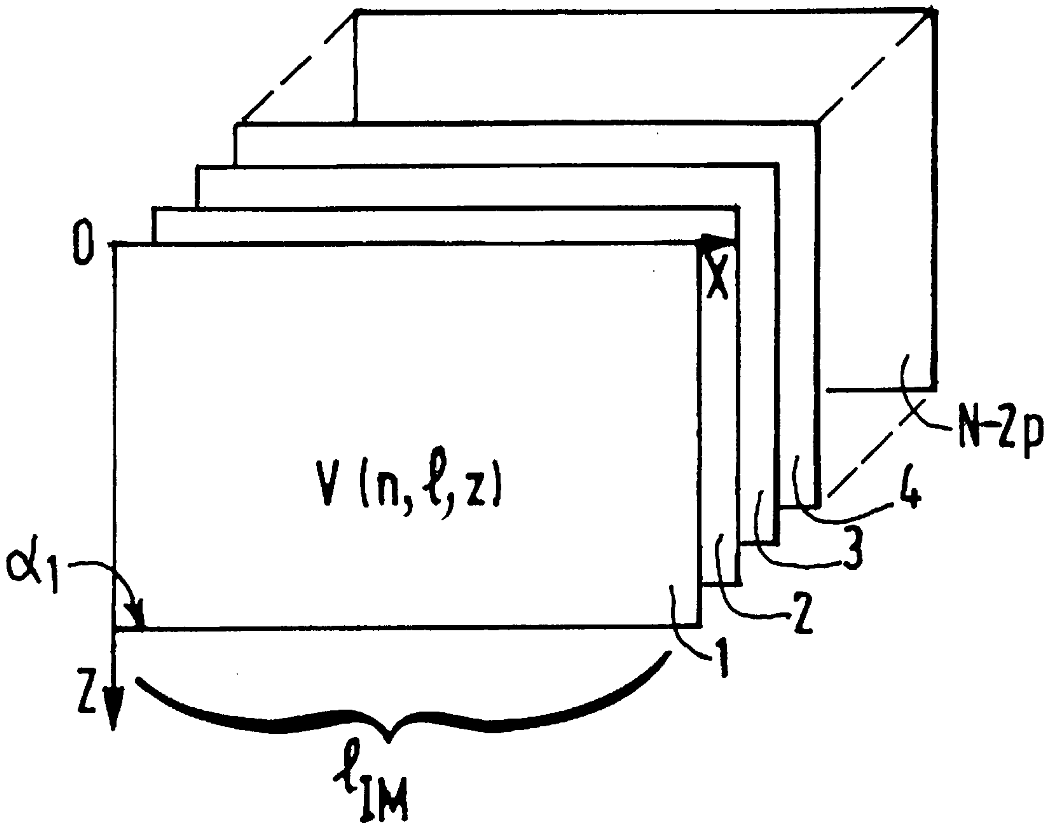

FIG. 4

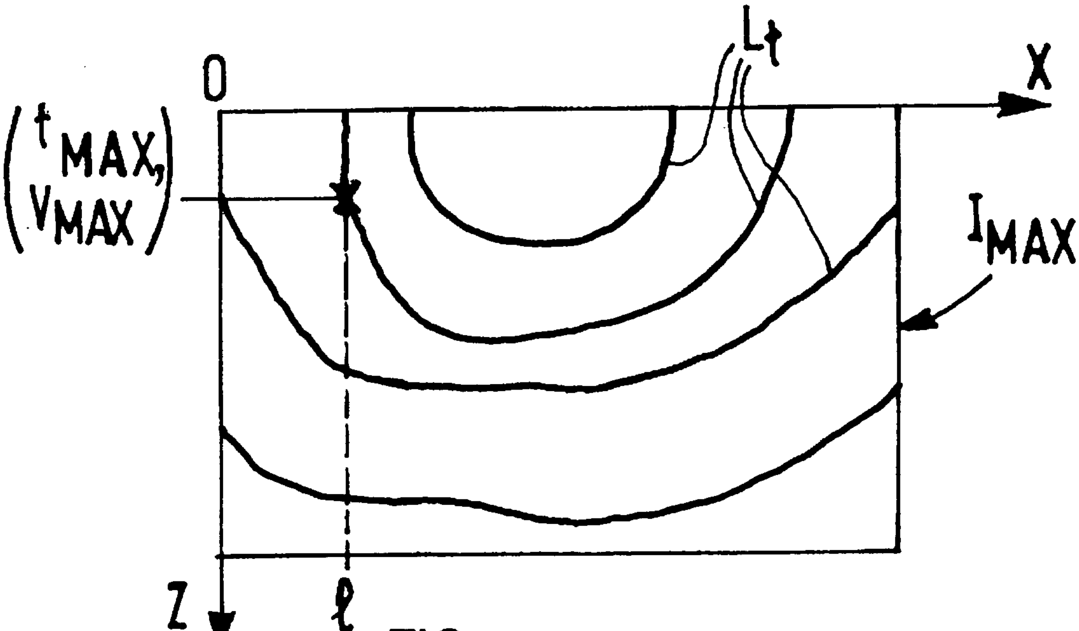

FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 01/04182

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B8/08

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 7 A61B G01S

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	YOSHIKI YAMAKOSHI ET AL: "ULTRASONIC IMAGING OF INTERNAL VIBRATION OF SOFT TISSUE UNDER FORCED VIBRATION" IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS AND FREQUENCY CONTROL, IEEE INC. NEW.YORK, US, vol. 37, no. 2, 1 March 1990 (1990-03-01), pages 45-53, XP000125773 ISSN: 0885-3010 page 45, right-hand column, line 11 -page 48, left-hand column, line 21; tables 1-3 ---	1,7
A	US 5 810 731 A (RUDENKO OLEG V ET AL) 22 September 1998 (1998-09-22) column 3, line 30 -column 4, line 20; table 1 ---	1,7

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° 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 document 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	Date of mailing of the international search report
6 August 2001	10/08/2001
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Authorized officer Weihs, J

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 01/04182

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WALKER W F ET AL: "REAL-TIME IMAGING OF TISSUE VIBRATION USING A TWO-DIMENSIONAL SPECKLE TRACKING SYSTEM" PROCEEDINGS OF THE ULTRASONICS SYMPOSIUM. BALTIMORE, OCT. 31 - NOV. 3, 1993, NEW YORK, IEEE, US, vol. 2, 31 October 1993 (1993-10-31), pages 873-877, XP000475223 page 873, column 1, line 1 -page 874, right-hand column, line 32; tables 1,2 -----	1,7

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 01/04182

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5810731 A	22-09-1998	US 5606971 A	04-03-1997

专利名称(译)	剪切波参数估计的超声波方法和系统		
公开(公告)号	EP1278459A1	公开(公告)日	2003-01-29
申请号	EP2001936226	申请日	2001-04-12
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V.		
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[标]发明人	BONNEFOUS ODILE		
发明人	BONNEFOUS, ODILE		
IPC分类号	A61B8/08 B06B1/06		
CPC分类号	A61B8/08 A61B8/0858 A61B8/485		
代理机构(译)	LOTTIN，CLAUDINE		
优先权	2000401153 2000-04-26 EP		
外部链接	Espacenet		

摘要(译)

本发明涉及一种用于确定瞬时剪切波前的传播参数的超声诊断成像方法，包括以下步骤：在组织中形成瞬时剪切波（5）;沿着图像线采集组织的超声图像数据（S，S *）在瞬时剪切波前沿在所述组织中的深度（z）上传播的时间延迟（TSW）期间估计组织速度（T），估计每条线的组织速度（V），构建组织速度来自超声数据（S，S *）和线上的组织速度（V）的图像序列[I（V）]，并且在序列的时刻导出剪切波阵面的速度（CSW）。然后从所述前速度计算诸如弹性的组织参数。本发明还涉及一种具有用于执行该方法的处理装置（100，PROCESSING1，PROCESSING2）的超声诊断成像系统。处理装置可以是具有用于此目的的指令的计算机程序产品。