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(54) Method for estimating tissue velocity vectors and tissue deformation from ultrasonic diagnostic imaging data

(57) A method for estimating tissue velocity vectors and oriented strain from ultrasonic diagnostic imaging data, comprises the following steps:

Acquiring ultrasound imaging data from an object by transmitting ultrasound beams against the said object and receiving the corresponding reflected beams by the said object;
Defining at least one or a certain number of reference points in an ultrasonic image field corresponding to the ultrasonic image data obtained from evaluation of the ultrasonic reflected beams;
Determining the direction of motion and the velocity vector of the said reference points from the ultrasonic image data;
According to the present invention the ultrasound imaging data consist in a sequence of at least two image frames, said images being two dimensional images or three dimensional data;
The imaging data are B-mode grey-scale echographic images;
The velocity of motion of each reference point between two successive B-mode image frames are determined by applying a so called particle image velocimetry technique abbreviated as PIV.

Any component of the strain is then obtained from time integration of strain-rate that is evaluated from the gradient of velocity estimated from the velocity data in two or more points.

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Description

[0001] The invention relates to a method for estimating tissue velocity vectors and tissue deformation, oriented strain, shear, from ultrasonic diagnostic imaging data, comprising the following steps:

[0002] Acquiring ultrasound imaging data from an object by transmitting ultrasound beams against the said object and receiving the corresponding reflected beams by the said object;

[0003] Defining a certain number of reference points in an ultrasonic image field corresponding to the ultrasonic image data obtained from evaluation of the ultrasonic reflected beams;

[0004] Determining the direction of motion and the velocity vector of the said reference points from the ultrasonic image data;

[0005] Evaluating the deformation state about the said reference points from the determined velocity data;

[0006] In many diagnostic evaluations of ultrasound images, the quantitative evaluation of the tissue kinematic properties (velocity and deformation) improves the ability to identify dysfunctions.

[0007] A field where this kind of analysis has a particular relevance is the field of echocardiographic diagnostic imaging. In this field, the assessment of the effective ventricular function requires the knowledge of numerous properties about the ventricular dynamics.

[0008] A recent technique for evaluating velocity is the so called Doppler Tissue Imaging, so called DTI. This technique allows to measure tissue velocity over all points in the ventricular wall. The measurement of velocity itself provides a direct information about the wall motion and helps to uncover abnormalities not immediately observable from the visualization in B-mode. The velocity contains information about either rigid body displacement and contraction/distension, the latter being immediately related to the myocardial activity. Post processing of the DTI velocity data allows the evaluation of additional quantities, namely strain-rate and strain, that are strictly related to the regional function. Segmental strain gives a direct evaluation of the degree of contractility of the myocardium during systole, as well as of its relaxation during ventricular filling.

[0009] Nevertheless DTI suffers from a few drawbacks consisting in limitations of the technique. The evaluation of velocity, and to a greater degree when strain rate and strain are evaluated , requires a higher frame rate with respect to be mode imaging because velocity is a more rapidly varying function than B-mode displacement. A Doppler signal requires additional processing with respect to the simple echo. Doppler tissue imaging suffers further of an intrinsic limitation due to the fact that only the component of velocity along a scanline can be measured. This limitation has several drawbacks. When tissue moves in a direction that is not aligned with the scanline, the Doppler velocity does not reflect the effective tissue kinematics. Only the component of strain and strain rate along the scanline can be evaluated, giving a reduced view of the local deformation state. This limits the application of DTI to the anatomic sites that can be imagined aligned along a scanline. In echocardiography this corresponds essentially to the interventricular septum and to the lateral walls in apical view.

[0010] A strain rate analysis method in ultrasonic diagnostic imaging applying the above mentioned DTI technique is disclosed in WO 02/45587. According to this document strain rate analysis is performed for ultrasonic images in which the spatial gradient of velocity is calculated in the direction of tissue motion. Strain rate is calculated for cardiac ultrasound images in the direction of motion which, for myocardial images , may be either in the plane of the myocardium or across the myocardium. Strain rate information is calculated for a sequence of images of a heart cycle and displayed for an automatically drawn border such as the endocardial border over the full heart cycle. Using DTI technique the method of document WO02/45587 suffers of the same drawbacks as the DTI technique. Furthermore WO02/45587 teaches how to carry out the automatic drawing of a border and the successive tracking of the said border during its motion. In any case such a method is affected, as all the other border detection methods that are based on arbitrary definitions of border, by a non complete reliability and thus by a rare practical use in clinic diagnosis, since the imaged structures are often not so easy to be determined.

[0011] From the fluid dynamics perspective, a velocity field estimation method is known called Particle Image Velocimetry. According to this method a sequence of grey scale images are taken on an illuminated slice of a fluid seeded with non buoyant micro particles, for measuring the velocity of the said micro-particles out form the sequence of images. The method is an optical flow method and, as such, it is based on the assumption of conservation of brightness. According to this assumption, an object (a patch of brightness) displaces without local changes from one image frame to the consecutive frame. PIV is actually well suited for fluid motion where relevant deformations are present and it has widely employed in measuring turbulent flow showing a good reliability in such extreme conditions when explicit subject is not clearly identifiable. For better understanding of PIV see Adrian RJ, Particle-Image technique for experimental fluid mechanics Annu. Rev. Fluid Mech. 1991, 23; 261; Melling A, Tracer particles and seeding for particle image velocimetry Meas. Sci. Technol. 1997, 8; 1406. Singh A. Optic Flow Computation: A unified Perspective. Piscataway, NJ; IEEE Comput. Soc. Press, 1992; Barrow JL, Fleet DJ, Beuchermin S. Performance of optical flow techniques, International Journal of Computer Vision 1994, 12;43-77; Hu H. Saga, T. Kobayashi, T.Taniguchi, N.Research on the vertical and turbulent structures in the lobed jet flow by using LIF and PIV. Meas.Sci. Technolo. 2000, 1; 698 and BrowneP, Ramuzat A, Saxena R, Yoganathan AP.

[0012] The invention aims to provide for a method for estimating tissue velocity vectors and deformation state, strain, shear, from ultrasonic diagnostic imaging data, which does not need to acquire ultrasonic image data in Doppler mode and which can obviate to the drawbacks of the velocity and strain evaluation carried out starting from the said Doppler mode ultrasonic data, still furnishing a reliable and precise evaluation of the velocity vector and of the deformation tensor.

[0013] Furthermore the invention aims to provide for an evaluation of velocity vectors and strain data, which allows to determine velocity components which are transversal to the scanline and all of the independent components of a two dimensional strain consisting in the longitudinal strain along two orthogonal axis, particularly along the tissue and across the thickness, and in the shear.

[0014] According to the present invention a method for estimating tissue velocity vectors and deformation from ultrasonic diagnostic imaging data, comprises the following steps:

[0015] Acquiring ultrasound imaging data from an object by transmitting ultrasound beams against the said object and receiving the corresponding reflected beams by the said object;

Defining a certain number of reference points in an ultrasonic image field corresponding to the ultrasonic image data obtained from evaluation of the ultrasonic reflected beams;

Determining the direction of motion and the velocity vector of the said reference points from the ultrasonic image data;

The ultrasound imaging data consist in a sequence of at least two image frames;

The imaging data are B-mode grey-scale echographic images;

The velocity of motion of each reference point between two successive B-mode image frames are determined by applying a so called optical flow method, like, for example, the particle image velocimetry technique abbreviated as PIV.

[0016] More particularly the particle image velocimetry applied in the present invention comprises the following steps:

a) Acquiring at least two consecutive B-mode and grey scale image frames along an ultrasound scanline;

b) Defining at least an identical point in the at least two consecutive image frames;

c) Defining a small region of NxN pixels where N=natural number which region is centered on the said point;

d) Carrying out a first displacement and velocity estimation cycle of the said point between the first and the second frame of the said at least two consecutive frames by calculating the cross-correlation between the two small regions in the two consecutive frames and determining the position where the local correlation of the two consecutive frames is a maximum;

e) Determining the displacement of the said maximum from the first frame to the second frame of the said two consecutive frames and defining the said displacement as the displacement of the point from the position of the point in the first frame to position of the said point in the second frame of the said two consecutive frames;

f) Calculating the velocity as the quotient of the displacement of the point from the position of the said point in the first of the two consecutive frames to the position of the said point in the second of the said two consecutive frames and the time distance between the said two consecutive frames.

g) Evaluating the deformation from time integration of the appropriate component of the velocity gradient, the latter evaluated by estimating the spatial derivatives from velocity in two or more points.

[0017] In a further improvement a sequence of more than two consecutive frames are acquired and the displacement of a certain defined point and the velocity is evaluated as described before for each couple of consecutive frames in the said sequence of consecutive frames.

[0018] According to still another improvement more than one point is defined and the said method steps as described before are applied to each one of the said points.

[0019] Considering a local region of the image frames acquired of NXN pixels for a certain point X centered in the said region in the first of the consecutive frames of a sequence of frames, the above disclosed first estimation cycle would lead to the determination of a sequence of displacements Δx_i for the said point X from a frame i to the following frame i+1.

[0020] The velocity of the point X in the displacement from the frame I to the following consecutive frame i+1 of the sequence of frames is than $\Delta x_i/\Delta t_i$ which is the time interval between the two consecutive frames i and i+1.

[0021] If necessary the above mentioned method steps consisting in a first estimation cycle of the displacements of a certain defined point or of certain defined points and of their velocity along the sequence of consecutive frames can be followed by further cycles for improving the precision.

[0022] The said further cycles for improving the precision of the estimation comprising the following steps:

Repeating at least a second time or more than a second time the above disclosed method steps c) to f) by defining a new small region in each frame

of the said sequence of consecutive frame as the square regions centered at the defined point displaced by the corresponding displacement of the point from one first frame to the consecutive frame in the said sequence of frames as calculated in the first or previous estimation cycle;
Carrying out the cross correlation between the said regions and determining as in the first estimation cycle a second displacement value;
Adding the said second displacement value for each couple of consecutive frames to the first displacement value calculated in the first cycle for the said couple of consecutive frames.

[0023] Considering the further example related on the point X for second frame of the two consecutive frames the local region of NxN pixels, for example of 64x64 pixels, is displaced form the first frame i to the consecutive frame i+1 by Δx_i.

[0024] According to a further improvement, the region in the first frame i is chosen centered at $X-\Delta x_i/2$ and the region in the following frame i+1 is chosen centered at $X+\Delta x_i/2$. This two regions of the two consecutive image frames are now approximately centered on the same moving point, or object and the cross correlation of the two regions gives a correction value to the displacement of point X evaluated according to the first estimation cycle which has to be added to the said displacement value according to the first estimation cycle.

[0025] Further iterations of the said cycle can be carried out till a certain minimum value of the correction of the displacement is reached.

[0026] According to a further improvement, after the last iteration the maximum of the local correlation between the position of the defined point in the two consecutive frames is further individuated by interpolating the computed values of cross-correlations in order to achieve a sub-pixel precision in the determination of the velocity.

[0027] According to still another feature of the method the small region in the image frames is chosen in such a way as the number N of pixels in each of the two spatial directions is great enough to contain any possible displacement of the chosen point in the first frame along the sequence of consecutive frames.

[0028] During the iteration process, according to another feature, the NxN small image region can be reduced in size at each iteration in order to improve resolution. For example employing n consecutive division by 2,the result is an estimation of velocity on a region $2^{-n}N x 2^{-n}N$, N and n may vary in different applications. Typically N=64 and n=2 gives acceptable precisions.

[0029] According to a further feature, a validation of data, for example a nonlinear median filter, is applied to the result to ensure a spatial and time coherence of results and eliminate the possibility of outliers points produced by image noise.

[0030] The method according to the invention has particular relevance for echocardiographic images. The method according to the invention is not limited by the scanline direction as the Doppler Tissue Imaging method and allows therefore to evaluate velocity also in a transversal direction to the scanline direction.

[0031] This is a considerable advantage, since in applying the method according to the present invention the relative position of the probe and of the imaged object is not critical as for evaluation of velocities according to the traditional Doppler Tissue Imaging.

[0032] Comparisons of the results obtained by the method according to the present invention with the results obtained by velocity estimation by means of the DTI technique are in very good agreement.

[0033] The method according to the present invention allows to gain knowledge of all the components of velocity vector along an arbitrary direction. This is very relevant for strain computation from the velocity data and allows evaluation of contraction/relaxation of tissues (longitudinal strain) along a arbitrary oriented line.

[0034] The evaluation of the two components of a two dimensional velocity vector allows observations of tissue motion and of dynamic properties that cannot be analyzed otherwise, like the simultaneous record of transversal and longitudinal velocity components. The analysis of the complete tissue dynamics from an y scan plane projection, including short axis is also made possible. Also the evaluation of strain and of strain rate oriented along an arbitrary direction and, if required, of the tissue shear is made possible.

[0035] The method can be applied without conceptual change to sequence of three dimensional imaging data, or volumetric data set. In this case the image area NxN is substituted by a volume NxNxN. The correlation between two consecutive three-dimensional fields are identically defined mathematically, the result of the said procedure is a displacement three-dimensional vector.

[0036] Application to three dimensional imaging allows the evaluation of the three dimensional velocity vector in one or more points, and the six components of deformation including elongation along any direction in space, and shear about any axis.

Claims

1. A method for estimating tissue velocity vectors and oriented strain from ultrasonic diagnostic imaging data, comprises the following steps:

   Acquiring ultrasound imaging data from an object by transmitting ultrasound beams against the said object and receiving the corresponding reflected beams by the said object;
   Defining at least one or a certain number of reference points in an ultrasonic image field corresponding to the ultrasonic image data obtained from evaluation of the ultrasonic reflect-

ed beams;
Determining the direction of motion and the velocity vector of the said reference points from the ultrasonic image data;

Characterised in that
The ultrasound imaging data consist in a sequence of at least two image frames, said images being two dimensional images or three dimensional data;
The imaging data are B-mode grey-scale echographic images;
The velocity of motion of each reference point between two successive B-mode image frames are determined by applying a so called particle image velocimetry technique abbreviated as PIV.
Any component of the strain is then obtained from time integration of strainrate that is evaluated from the gradient of velocity estimated from the velocity data in two or more points.

2. A method according to claim 1 in which the following steps are provided:

a) Acquiring at least two consecutive B-mode and grey scale image frames along an ultrasound scanline;
b) Defining at least an identical point in the at least two consecutive image frames;
c) Defining a small region of NxN pixels where N=natural number which region is centered on the said point;
d) Carrying out a first displacement and velocity estimation cycle of the said point between the first and the second frame of the said at least two consecutive frames by calculating the cross-correlation between the two small regions in the two consecutive frames and determining the position where the local correlation of the two consecutive frames is a maximum;
e) Determining the displacement of the said maximum from the first frame to the second frame of the said two consecutive frames and defining the said displacement as the displacement of the point from the position of the point in the first frame to position of the said point in the second frame of the said two consecutive frames;
f) Calculating the velocity as the quotient of the displacement of the point from the position of the said point in the first of the two consecutive frames to the position of the said point in the second of the said two consecutive frames and the time distance between the said two consecutive frames.

3. A method according to claim 2 **characterised in that** a sequence of more than two consecutive frames are acquired and the displacement of a certain defined point and the velocity is evaluated as described before for each couple of consecutive frames in the said sequence of consecutive frames.

4. A method according to claims 2 or 3 **characterised in that** more than one point is defined and the said method steps as described before are applied to each one of the said points.

5. A method according to claims 4 with the following step (g) integrating those described in claim 2:

g) Evaluating the deformation, strain, shear, from time integration of the appropriate component of the velocity gradient, the latter evaluated by estimating the spatial derivatives from velocity in two or more points.

6. A method according to one or more of the preceding claims **characterised in that** the steps c) to f) consisting in a first estimation cycle of the displacements of a certain defined point or of certain defined points and of their velocity along the sequence of consecutive frames can be followed by further cycles for improving the precision, the said further cycles for improving the precision of the estimation comprising the following steps:

Repeating at least a second time or more than a second time the above disclosed method steps c) to f) by defining a new small region in each frame of the said sequence of consecutive frame as the square regions centered at the defined point displaced by the corresponding displacement of the point from one first frame to the consecutive frame in the said sequence of frames as calculated in the first or previous estimation cycle;
Carrying out the cross correlation between the said regions and determining as in the first estimation cycle a second displacement value;
Adding the said second displacement value for each couple of consecutive frames to the first displacement value calculated in the first cycle for the said couple of consecutive frames.

7. A Method according to claim 6, **characterised in that** further iterations of the said cycle are carried out till a certain minimum value of the correction of the displacement is reached.

8. A method according to claim 6 or 7 **characterised in that** after the last iteration the maximum of the local correlation between the position of the defined point in the two consecutive frames is further individuated by interpolating the computed values of cross-correlations in order to achieve a sub-pixel precision in the determination of the velocity.

9. A method according to one or more of the preceding claims 6 to 8, **characterised in that** the small region in the image frames is chosen in such a way as the number N of pixels in each of the spatial directions is great enough to contain any possible displacement of the chosen point in the first frame along the sequence of consecutive frames.

10. A method according to one or more of the preceding claims 6 to 9, **characterised in that** during the iteration process of the estimation cycle, the small image region can be reduced in size at each iteration in order to improve resolution.

11. A method according to one or more of the preceding claims **characterised in that** a validation method is applied to the result to eliminate the possibility of outliers points.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 42 5638

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A,D	WO 02 45587 A (KONINKL PHILIPS ELECTRONICS NV) 13 June 2002 (2002-06-13) * the whole document * -----	1-11	A61B8/08 G01S7/52
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			A61B G01S

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 February 2004	Manschot, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 03 42 5638

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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16-02-2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0245587 A	13-06-2002	US 2002072674 A1	13-06-2002
		WO 0245587 A1	13-06-2002
		EP 1255489 A1	13-11-2002

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

专利名称(译)	从超声诊断成像数据估计组织速度矢量和组织变形的方法		
公开(公告)号	EP1520517A1	公开(公告)日	2005-04-06
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[标]申请(专利权)人(译)	百胜集团		
申请(专利权)人(译)	ESAOTE S.P.A. AMID SRL		
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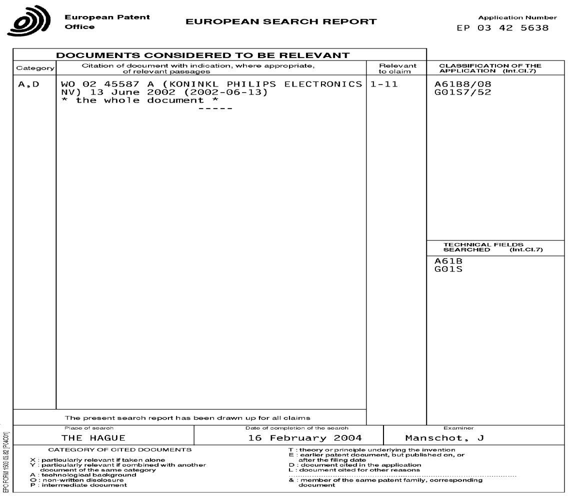
CPC分类号	A61B8/485 A61B8/08 A61B8/0883 A61B8/5223 G01S7/52042 G01S15/8984 G06T7/20 G06T7/269 G06T2207/30048		
其他公开文献	EP1520517B1		
外部链接	Espacenet		

摘要(译)

一种用于从超声诊断成像数据估计组织速度矢量和方向应变的方法，包括以下步骤：通过相对于所述对象发射超声波束并通过所述对象接收相应的反射光束，从对象获取超声成像数据;在与从超声反射束的评估获得的超声图像数据相对应的超声图像场中定义至少一个或一定数量的参考点;从超声图像数据确定所述参考点的运动方向和速度矢量;根据本发明，超声成像数据包括至少两个图像帧的序列，所述图像是二维图像或三维数据;成像数据是B模式灰度回波描记图像;在两个连续的B模式图像帧之间的每个参考点的运动速度通过应用称为PIV的所谓的粒子图像速度测定技术来确定。然后从应变率的时间积分获得应变的任何分量，该应变率从根据两个或更多个点中的速度数据估计的速度的梯度评估。



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EUROPEAN SEARCH REPORT

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