(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 198 200 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
19.03.2008 Bulletin 2008/12

(21) Application number: **00941653.8**

(22) Date of filing: **22.06.2000**

(51) Int Cl.:
A61B 8/00 *(2006.01)* ***A61K 35/00*** *(2006.01)*
G06K 9/00 *(2006.01)* ***G06T 5/00*** *(2006.01)*
A61B 8/08 *(2006.01)*

(86) International application number:
PCT/US2000/017241

(87) International publication number:
WO 2001/001864 (11.01.2001 Gazette 2001/02)

(54) **INTRAVASCULAR ULTRASONIC IMAGE ANALYSIS USING ACTIVE CONTOUR METHOD**

INTRAVASKULÄRE ULTRASCHALLBILDANALYSE UNTER VERWENDUNG EINER AKTIVEN KONTURMETHODE

ANALYSE D'IMAGES ECOGRAPHIQUE INTRAVASCULAIRE UTILISANT UN PROCEDE DE CONTOUR ACTIF

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: **02.07.1999 US 347209**

(43) Date of publication of application:
24.04.2002 Bulletin 2002/17

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Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to medical imaging arts. It finds particular application to an intravascular ultrasonic image analysis system which determines luminal and medial-adventitial boundaries of a vascular object.

[0002] Ultrasonic imaging of portions of a patient's body provides a useful tool in various areas of medical practice for determining the best type and course of treatment. Imaging of the coronary vessels of a patient by ultrasonic techniques can provide physicians with valuable information. For example, the image data may show the extent of a stenosis in a patient, reveal progression of disease, help determine whether procedures such as angioplasty or atherectomy are indicated or whether more invasive procedures may be warranted.

[0003] In a typical ultrasound imaging system, an ultrasonic transducer is attached to the end of a catheter that is carefully maneuvered through a patient's body to a point of interest such as within a blood vessel. The transducer is a single-element crystal or probe which is mechanically scanned or rotated back and forth to cover a sector over a selected angular range. Acoustic signals are transmitted during the scanning and echoes from these acoustic signals are received to provide data representative of the density of tissue over the sector. As the probe is swept through the sector, many acoustic lines are processed building up a sector-shaped image of the patient.

[0004] After the data is collected, images of the blood vessel are reconstructed using well-known techniques. Since the data is acquired along a section of the vessel, hundreds of intravascular images may be generated. A typical analysis includes determining the size of the lumen and amount of plaque in the vessel. This is performed by having a user visually analyze each image and manually draw a boundary contour on the image at a location where the user believes is the luminal boundary and medial-adventitial boundary of the vessel. This is a very time consuming process which can take days to evaluate a set of images from one patient. Furthermore, the boundary determination is made more difficult when the images are of poor quality and the boundaries are difficult to see on the image.

[0005] US 5,495,852 discloses an apparatus for measuring the diameter of an artery using ultrasonic images. The preamble of claim 1 is based on this disclosure.

[0006] The present invention provides an intravascular ultrasonic image analysis system with cures the above problems and others.

SUMMARY OF THE INVENTION

[0007] In accordance with the present invention, a system for determining a boundary contour of a blood vessel is provided according to claim 1.

[0008] In accordance with a more limited aspect of the present invention, the distinguished boundary is determined by radially analyzing pixel values of the ultrasound image.

[0009] In accordance with a more limited aspect of the present invention, the gradient image is formed by converting the ultrasound image to a polar image where the polar image has a plurality of radial scan lines which include a plurality of pixels. An edge of the boundary is radially determined along each of the radial scan lines by applying a gradient filter to each of the plurality of pixels. The gradient filter distinguishes pixels which likely form the edge of the boundary. The distinguished pixels define the distinguished boundary.

[0010] One advantage of the present invention includes determining luminal and medial-adventitial boundaries from an ultrasound image using image data having the same format as the IVUS data which was collected. In particular, IVUS data is collected radially by a rotating transducer or array of transducers. Thus, to obtain a more accurate boundary determination, the boundary determination is influenced by radial edge detection from a polar format of an image.

[0011] Another advantage of the present invention is that the determination of luminal and medial-adventitial boundaries is accurately performed. Additionally, the present system reduces the time necessary for a user to determine these boundaries which may involve manually processing hundreds of images.

[0012] Another advantage of the present invention is that boundary determination can be performed in real-time, for example, in an operating room. In this manner, a surgeon can receive immediate data relating to a patient's blood vessels.

[0013] Still further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The following is a brief description of each drawing used to describe the present invention, and thus, are being presented for illustrative purposes only and should not be imitative of the scope of the present invention, wherein:

Figure 1 is a block diagram of an overall ultrasonic imaging system;

Figure 2 is a process diagram of acquiring and analyzing ultrasound data in accordance with the present invention;

Figure 3 is a block diagram of optimizing a boundary contour based on a radially determined boundary in accordance with the present invention;

Figure 4 is an intravascular ultrasound image showing selected boundary points in the vicinity of the luminal boundary;

Figure 5 shows an initial boundary contour generated from the boundary points of **Figure 4;**

Figure 6A is the intravascular image in Cartesian format;

Figure 6B is the image in **Figure 6A** in polar format;

Figure 7A illustrates the image of **Figure 6B** as a gradient image after filtering;

Figure 7B is the gradient image of **Figure 7A** scan converted into Cartesian format;

Figure 8 is an illustration of moving contour vertices in a neighborhood of pixels in accordance with the present invention;

Figure 9 shows the intravascular image of **Figure 5** with a final boundary contour in accordance with the present invention;

Figure 10 is a representation of a blood vessel showing its luminal size and plaque thickness;

Figure 11 shows a sequence of image frames where control points are selected on a starting and ending frame;

Figure 12 shows the sequence of images frames including an initial luminal boundary contour for each frame;

Figure 13 shows the sequence of images frames including an optimized luminal boundary contour for each frame;

Figure 14 shows a three-dimensional surface contour of a lumen as determined from optimized luminal boundary contour data in accordance with the present invention; and

Figure 15 shows a luminal and medial-advential contours for an image frame.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0015] With reference to **Figure 1,** an overall intravascular ultrasound (IVUS) system is shown. An IVUS system console **10** collects ultrasonic data from a transducer (not shown). The transducer is attached to the end of a catheter that is carefully maneuvered through a patient's body to a point of interest. In the present system, the catheter is maneuvered through the interior of vascular organs in order to obtain intravascular ultrasound data of the surrounding vascular tissue. The IVUS system console 10 is, for example, a C-VIS Clearview Imaging System and the transducer is a single element mechanically rotated ultrasonic device having at least a frequency of 20 MHz. The ultrasonic device may also be an array of transducers circumferentially positioned to cover 360° where each transducer radially acquires data from a fixed position.

[0016] An exemplary process for collecting ultrasound data is as follows. Once the transducer reaches a desired point within the vascular object, the transducer is pulsed and then acquires echoes for about 7 micro seconds. It is rotated 1.5 degrees and pulsed again. This is repeated for 240 scan lines around 360 degrees. The number of samples acquired in each scan line controls the depth of the echoes recorded by the transducer and ultimately the resolution of the image. An image reconstruction processor 15 reconstructs an image from the raw ultrasound data. The reconstruction is performed using any image reconstruction routine known to those of ordinary skill in the art. The present application is not directed to image reconstruction and, thus, will not be discussed in detail. An exemplary reconstructed ultrasound image is shown in Figure 6A which shows a cross-sectional view of a blood vessel.

[0017] The ultrasound data is collected radially by the rotating transducer. The rotational position of the transducer at each point in time a scan line is acquired is used to create the image. Thus, the data is in polar format where each data has an angle θ and a radius R associated with it. Polar images are, however, difficult for a user to visually interpret so the polar data is converted to x and y Cartesian image coordinates. This process is called scan conversion. Equations

(1) and (2) show the common polar to Cartesian coordinate transformation.

$$X = R \cdot \cos(\theta) \qquad (1)$$

$$Y = R \cdot \sin(\theta) \qquad (2)$$

[0018] Scan conversion is well known in the art and is performed by looping through the polar image, calculating the corresponding Cartesian location from R and θ using bi-linear interpolation of neighboring pixels, and assigning the pixel value at the polar location to the Cartesian location. Once the image data is generated, an image analysis routine **20** analyzes the image data which is described in detail below.

[0019] With reference to **Figure 2,** a block diagram of the IVUS image analysis process is shown. As explained above, ultrasound data is acquired **30** by the IVUS system console **10** where the data is acquired radially within a vascular object by an ultrasonic device. An intravascular image is generated **40** from the ultrasound data using any known image reconstruction process. A typical scan may generate hundreds of images along a section of the vascular object. The image data is originally in polar coordinates since the data is acquired radially and is then converted to a Cartesian format. A cross-sectional view of an intravascular image in Cartesian format is shown in **Figure 6A.**

[0020] Once the images are generated, a user may select one or more images for analysis and evaluation. In the preferred embodiment, an intravascular image is analyzed to determine a luminal boundary and a medial adventitial boundary of the vascular object which is imaged. With further reference to **Figure 2** and **Figure 4,** an intravascular image **100** is selected and displayed 50 to the user. It is presumed that the user/operator is experienced in reading ultrasonic images and visually determining an approximate location of the luminal boundary and medial-adventitial boundary. The user selects **60** a set of boundary control points 105 at locations on the image where the user believes are the edges of a boundary, in this case, a luminal boundary.

[0021] With reference to **Figure 5,** an initial boundary contour **110** is generated 70 based on the selected control points **105.** The initial contour **110** connects the control points resulting in an approximate location of the boundary edge. Additional control points may be automatically generated by the system between the user selected control points 105 to generated a better approximation of a boundary edge. The initial boundary **110** can be obtained by interpolating between the control points **105.**

[0022] With further reference to Figure **2**, after the initial boundary contour **110** is generated, an active contour adjustment **80** is performed to obtain an optimized boundary contour which is close to or on the actual boundary edge of interest. In general, the active contour adjustment **80** takes the initial contour **110,** which is a roughly defined contour close to the edge of interest, and moves it around within the image data under an influence of several forces, external and/or internal, until it finds the edge of interest. The external forces are derived from image data properties such that the initial contour **110** is adjusted towards the nearest edge in the image data. The internal forces are defined such that they are proportional to the curvature of the initial contour **110,** and restricts contour adjustment such that the contour maintains first and second order continuity. In the preferred embodiment, the active contour adjustment **80** is based on minimizing an energy functional of Equation (3):

$$E = \int \left(\alpha(s) \cdot E_{cont} + \beta(s) \cdot E_{curv} + \gamma(s) \cdot E_{image} \right) ds \qquad (3)$$

[0023] The first term E_{cont} controls the first order of continuity and the second term E_{curv} controls second order continuity. The last term E_{image} is based on an image quantity determined from the image data. In the preferred embodiment, the image quantity is edge strength based on pixel values in the image. Of course, other terms which control external constraints can be included in the functional to obtain a desired result. The parameters α, β, and γ are weighting factors which control the relative input between the terms. The value of a weighing factor can be increased to increase its influence on the functional. For example, by increasing the value of γ, and decreasing the values of α, and β, the contour adjustment can be made to be entirely influenced by the E_{image} term.

[0024] Each control point **105** corresponds to a vertex on the initial contour **110** which resides at a pixel location on the intravascular image **100.** To improve the contour, neighborhood locations of each vertex (control point) are searched and a location in the neighborhood giving the smallest value for the functional is chosen as the new location for the vertex (control point). This process is repeated through all control points until the number of points moved is less than a specified threshhold or a user defined maximum number of iterations is reached.

[0025] Looking to the functional, the first term E_{cont} is formed by taking an average distance between all contour vertices and subtracting the distance between the current vertex and the previous vertex location as shown by the following Equation:

$$E_{cont} = d - |v_i - v_{i-1}| \qquad (4)$$

[0026] In the above Equation, the v_i denotes the i^{th} vertex and d is the average distance between all the control points **105.** This expression eliminates the possibility of the contour's curve shrinking while satisfying a first order continuity by encouraging even spacing between control points. Points having a distance between them which is near the average distance produce a small value for E_{cont}. A goal of the functional is finding minimum values. The average distance d between the points is then recalculated on every interation.

[0027] The second term E_{curv} encourages second order of continuity and is a curvature term. An estimate of the curvature is shown in the following Equation:

$$E_{curv} = |v_{i-1} - 2v_i + v_{i+1}|^2 \qquad (5)$$

[0028] Small values of E_{curv} in this expression encourage the reduction of curvature which helps the contour **110** maintain its shape and prevents formation of corners. If corners, or other shape features are desired in the final result, the weighing factor β can be adjusted accordingly to raise or lower the influence of curvature in the functional minimization.

[0029] External forces acting on the contour **110** are represented in the third term E_{image} of the functional. The definition of the third term controls what image features or properties the contour **110** is attracted to. In the preferred embodiment, E_{image} is based on gradient values in the image. As explained previously, the ultrasound data is acquired radially by a transducer and, thus, the data is polar in nature. Therefore, to obtain more accurate gradient values of the image to influence the adjustment of the boundary contour **110,** the gradient values are determined from a polar image of the intravascular image **100.**

[0030] With reference to **Figures 6A-B** and **7A-B,** formation of a gradient image which is used to optimize the boundary contour is shown. The original intravascular image 100 selected by the user is shown in **Figure 6A.** The initial boundary contour 110 is generated from this image shown in **Figures 4 and 5.**

[0031] With reference to **Figure 3,** a process for generating the gradient image and optimizing the boundary contour **110** is illustrated. The intravascular image **100** is shown in Cartesian format in **Figure 6A** and is converted **300** to a polar image **600** as shown in **Figure 6B.** As explained above, the image features which will influence the adjustment of the boundary contour **110** are the gradient values of the polar image **600.** The polar image **600** includes a plurality of radial scan lines (not shown) which are defined horizontally across **Figure 6B** as is known in the art. Each scan line contains a plurality of pixel values where each pixel value represents a number, for example between 0 and 255 for an 8-bit system, where 0 represents black and 255 represents white. Once the polar image is generated, the boundaries of the vascular object are determined **305** radially along each scan line. In the preferred embodiment, the boundary determination is performed by applying a one-dimensional gradient filter across each scan line where the filter is: **[-6, -4, -2, 0, 2, 4, 6]**. The filter is applied to the pixels of each scan line in a radial direction and filtered gradient pixel values are found by:

$$\text{Pixel Value D} = (-6A) + (-4B) + (-2C) + (0D) + (2E) + (4F) + (6G) \qquad (6)$$

[0032] Where the alphabetical letters A-G represent a gray value for a pixel. The current pixel is D and its new gradient value is determined based on the values of three previous pixels A, B and C and three subsequent values E, F and G in the radial direction along the current scan line. Of course, there are many gradient filters known in the art which can be used to radially determine edges in an image. By applying the gradient filter, the pixel values of the image near an edge become a distinguished gradient value from other values in the image.

[0033] With reference to **Figure 7A,** a gradient image is shown which is a result of applying the gradient filter to the polar image **600** of **Figure 6B.** Area **700** represents the catheter which was inserted into the blood vessel and **705** is the edge of the catheter **700.** Area **710** represents the lumen of the blood vessel and boundary **715** is the luminal boundary. The medial-adventital boundary of the blood vessel is represented by **725.** Area **720,** which lies between the luminal boundary **715** and the medial-adventitial boundary **725,** may represent the build up of plaque in the blood vessel. The polar gradient image is then converted **310** to a Cartesian format gradient image **730** shown in Figure **7B**. The conversion puts the gradient image **730** into the same format as the intravascular image **100** containing the initial boundary contour **110.** an optimized boundary contour **315.**

[0034] Gradient values of the gradient image **730** are used to calculate the E_{image} term for the minimization and contour adjustment. The boundary contour **110** is optimized **315** based on the edge boundaries found in the gradient image **730.** The E_{image} term is found by:

$$E_{image} = \frac{(\min - g)}{(\max - \min)} \qquad (7)$$

Optimizing the initial boundary contour **110** includes evaluating pixels neighboring each control point **105** to determine if the current control point is to be moved to a neighboring pixel.

[0035] With reference to **Figure 8**, an illustration of a neighborhood approach of moving boundary contour vertices is shown. A current boundary control point **105** is represented by vertex V_i and its two adjacent control points are represented by V_{i-1} and V_{i+1}. A pixel neighborhood **800** is illustrated with the pixel locations adjacent the V_i. The x,y location of the current control point in the intravascular image **100** is used as the location of V_i in the gradient image **730** and identifies the neighborhood pixels **800.** For each vertex V and its neighborhood **800,** the E_{image} term is calculated by determining the minimum and maximum gradient values in the neighborhood **800** which are the min and max terms of the equation. The gradient value at the vertex V_i location is represented by g. The location in the neighborhood **800** which produces the minimum E_{image} value, such as a negative value, means that it is a large gradient value. Large gradient values are typically those which are on or near the boundary edge. Thus, the contour will be attracted to edges with strong energy. For example, after the calculation, vertex V_i might be moved to pixel location **805.** With equation (1), the energy **E** is calculated for each position in the neighborhood 800 and the current vertex V_i is moved to the position giving the minimum value. In this manner, the vertices of the boundary contour **110** move within the image data. The influential factor for adjusting the boundary contour **110** (shown in **Figure 5)** is the boundary contour **715** shown in **Figure 7B** which is a radially determined edge of the luminal boundary. A final optimized contour is obtained when the iteration process is complete.

[0036] With reference to **Figure 9,** a final luminal boundary contour 900 is overlaid on the original image **100** for the user to visualize. The final contour 900 is the result of optimizing the initial boundary contour **110.** The process is then repeated to determine the medial-adventitial boundary of the blood vessel. In this process, the user selects a set of boundary points in the vicinity of the medial-adventitial boundary. A contour is generated and optimized as described. However, the distinguished boundary contour **725** shown in **Figure 7B** (the outer circular boundary) is used to influence the active contour adjustment **80** rather than luminal boundary **715.** As explained above, boundary **725** is a distinguished contour that is radially determined from the polar image **600** using a gradient filter.

[0037] With reference to **Figure 10,** a cross-sectional view representing a blood vessel illustrates an exemplary final luminal boundary **900** and a final medial-adventitial boundary **910.** After these boundaries are determined with the present system, an analysis **90** of the blood vessel is performed. Such analysis includes determining the size of the lumen **920** and determining the thickness of plaque **925** shown between the luminal boundary **900** and the medial-adventitial boundary **910.** Additionally, lumen/medial-adventitial boundary metrics are determined including cross-sectional area, centroid, maximum diameter, minimum diameter, and eccentricity. Furthermore, plaque metrics of the vessel are determined including cross-sectional area, maximum thickness, minimum thickness, eccentricity, and percent occlusion.

[0038] The present invention provides the ability to diagnose a blood vessel in real-time. For example, IVUS image data can be collected from a patient and images reconstructed. A user, who is in the operating room, can perform the present boundary determination for a selected section of images. A physician can receive, in real-time, an analysis of the vessel which returns the size of the lumen, percent occlusion, and other information about the vessel. Based on the analysis, the physician can immediately determine the size of a necessary stent or balloon, evaluate the progression of disease, or identify changes in vessel size which may require medical attention.

[0039] With reference to **Figure 11,** the present invention generates a three-dimensional surface contour from a set of intravascular ultrasound images. Six sequential image slices or frames **0-5** are shown. It is to be understood that these six exemplary frames are part of a large set of frames which may include hundreds of images obtained during an ultrasonic scan. To determine a three-dimensional surface contour of the lumen of the vessel, the user selects a starting frame and an ending frame from a series of sequential image frames in order to generate an initial contour model. In this case, frame **0** is selected as the starting frame and frame **5** as the ending frame. Starting and ending frames are selected based on the visual similarity of the luminal boundary in the sequence of frames. In other words, the starting frame, ending frame and intermediate frames **1-4** therebetween each have a similar luminal contour. A frame which shows a substantially different luminal contour would not be included within a selected starting and ending frame group.

[0040] With further reference to **Figure 11,** the user selects a set of starting control points 1000 in the vicinity of the luminal boundary in the starting frame **0.** The points are selected at locations where the user believes is the boundary. A set of end control points **1005** are similarly selected on the ending frame **5.** The control points are then interpolated to generate a starting initial contour **1010** and an ending initial contour **1015** as shown in **Figure 12.** Based on the starting and ending initial contours, a contour is automatically generated for each intermediate frame **1-4** designated as contours **1011-1014,** respectively. For example, the intermediate contours can be generated by interpolating between the initial contours of the starting frame **0** and ending frame **5.** Once initial luminal boundary contours are determined, they define three-dimensional surface data for the lumen within the segment of the vessel corresponding to the frames **0-5.**

[0041] With reference to **Figure 13,** the initial contours **1010-1015** shown in **Figure 12** are optimized according to the active contour method described above. The energy equation **E,** however, includes an additional E_{curv} term as follows:

$$E = \int \left(\alpha(s) \cdot E_{cont} + \beta_T(s) \cdot E_{curv,T} + \beta_L(s) \cdot E_{curv,L} + \gamma(s) \cdot E_{image} \right) ds \qquad (8)$$

[0042] Since the boundary contours are in three-dimensions, the curvature term now includes $E_{curv,T}$ which is a transverse curvature constraint and $E_{curv,L}$ which is a longitudinal curvature constraint. These terms limit the movement of points such that longitudinal continuity is maintained and kinks in the contour are prevented. The calculation of the term is similar, as explained above, except that the control vertices V are different. In the three-dimensional model, V_i is a vertex from the current image frame, V_{i-1} is the vertex from the previous frame and V_{i+1} is the vertex from the next frame. Thus, bi-directional image data from adjacent frames is used to optimize the boundary contours.

[0043] The contour adjustment is performed iteratively, as described above, where the energy equation is calculated for each boundary control point on the initial contour **1010** of frame **0** one time through. The processing then moves to the next frame **1.** After the ending frame **5** is optimized with the one iteration through all its control points, the process repeats with the starting frame **0** and continues to cycle through the frames until a user selected threshold condition is satisfied for the energy equation or, a user selected number of iterations are performed. As explained previously, the object of the energy equation is to minimize its values by adjusting each point on the contour towards the edge of the luminal boundary. The final contours in each frame become an optimized representation of the actual boundary contour of the lumen. Final optimized boundary contours **1020-1025** are shown in **Figure 13** as contours **1020-1025** in frames **0-5,** respectively.

[0044] With reference to **Figure 14,** a three-dimensional surface contour of a lumen of a blood vessel is shown as determined from a set of final optimized contours obtained from the present invention. The surface data is correlated by using the boundary contour data from one frame to the next. The present invention simplifies boundary determination for the user since input from the user is only required on a starting and ending image frame. Boundaries on intermediate image frames are automatically determined. Thus, hundreds of image frames can be quickly processed by the user by selective grouping of frames between starting and ending frames. Exemplary test results show that with the present invention, contours were determined for about 180 image frames in about 20 minutes. In contrast, a user typically needs about one hour to manually trace contours on ten images.

[0045] With reference to **Figure 15,** image frame **0** is shown including a luminal contour **1030** and a medial-adventitial contour **1035.** To determine the medial-adventitial contour, the process is repeated by selecting control points on the image at locations believed to be in the vicinity of the medial-adventitial boundary of the vessel. Of course, the processing may be performed simultaneously where the user selects boundary control points for both the luminal boundary and medial-adventitial boundary on the selected starting frame and ending frame. Once the medial-adventitial boundary data is found for all frames, plaque analysis can be performed by comparing the luminal boundary contour data and the medial adventitial boundary contour data. By knowing the distance between each frame, as determined by tracking the location of the transducer during image acquisition, volumetric information such as the plaque volume can be calculated.

[0046] The invention has been described with reference to the preferred embodiment. Obviously, modifications and alterations to others upon a reading and understanding of this specification. It is intended to include all such modifications and alterations insofar as they come within the scope of the appended claims are the equivalence thereof.

Claims

1. A system for determining a boundary contour (110) of a blood vessel from an intravascular ultrasound image (100)

where the ultrasound image (100) is generated from data acquired radially within the blood vessel by an ultrasonic device (10), comprising:

a display component configured to display the ultrasound image (100), the ultrasound image (100) being a cross-sectional view of a blood vessel and being a Cartesian image, the ultrasound image (100) including a representation of a boundary of the blood vessel; and
an analytical component configured for receiving selected control points (105) along the boundary, interpolating between the control points (105) to generate a boundary contour (110), and optimizing the boundary contour (110) by adjusting each of the control points (105) based on a gradient image (730) which includes a distinguished boundary, the gradient image (730) being determined from the ultrasound image (100);

characterized in that
the display component is further configured for displaying a plurality of ultrasound images (100) being a sequential sequence of images of the blood vessel, the ultrasound image (100) being a starting image; and
the analytical component is further configured for receiving selected control points (105) along the boundary on an ending image from the plurality of ultrasound images (100) such that at least one intermediate image is between the starting and ending images, and for interpolating between the control points (105) of the starting and ending images to automatically generate a boundary contour (110) on the at least one intermediate image.

2. The system for determining a boundary contour (110) as set forth in claim 1 wherein:

the analytical component is configured for optimizing the boundary contour (110) on the starting image, the at least one intermediate image and the ending image by adjusting each of the control points (105) based on a gradient image (730) which includes a distinguished boundary determined from the ultrasound image (100) of the starting image, the at least one intermediate image and the ending image.

3. The system for determining a boundary contour (110) as set forth in claim 1 wherein the analytical component is further configured for determining the distinguished boundary by radially analyzing pixel values of the ultrasound image (100).

4. The system for determining a boundary contour (110) as set forth in claim 1 wherein the analytical component is configured to form the gradient image (730) by:

converting the ultrasound image (100) to a polar image (600), the polar image (600) having a plurality of radial scan lines which include a plurality of pixels;
radially determining an edge of the boundary along each of the radial scan lines by applying a gradient filter to each of the plurality of pixels, the gradient filter distinguishing pixels which likely form the edge of the boundary, the distinguished pixels defining the distinguished boundary; and
converting the polar image (600) of the ultrasound image (100) to a Cartesian format to obtain the gradient image (730) in Cartesian format including the distinguished boundary.

5. The system for determining a boundary contour (110) as set forth in claim 1 wherein the analytical component is configured to optimize the boundary contour (110) by adjusting each of the control points (105) based on a point spacing constraint and a curvature constraint maintained continuity in the boundary contour (110).

6. The system for determining a boundary contour (110) as set forth in claim 5 wherein the analytical component is configured to iteratively perform the optimization for each of the control points (105).

Patentansprüche

1. System zur Bestimmung einer Begrenzungskontur (110) von einem Blutgefäß aus einem intravaskulären Ultraschallbild (100), wobei das Ultraschallbild (100) aus Daten erzeugt ist, die innerhalb des Blutgefäßes in radialer Richtung durch eine Ultraschallvorrichtung (10) gewonnen sind, mit:

einer Anzeigekomponente, die konfiguriert ist, um das Ultraschallbild (100) anzuzeigen, wobei das Ultraschallbild (100) eine Querschnittsansicht von einem Blutgefäß ist und ein kartesisches Bild ist, wobei das Ultraschallbild (100) eine Darstellung von einer Begrenzung des Blutgefäßes beinhaltet; und einer analytischen Komponente, die ausgestaltet, um ausgewählte Steuerpunkte (105) entlang der Begrenzung zu empfangen, um zwischen den Steuerpunkten (105) zu interpolieren, um eine Begrenzungskontur (110) zu erzeugen und um die Begrenzungskontur (110) zu optimieren, indem jeder der Steuerpunkte (105) basierend auf einem Gradientenbild (730) eingestellt wird, das eine differenzierte Begrenzung beinhaltet, wobei das Gradientenbild (730) aus dem Ultraschallbild (100) bestimmt ist;

dadurch gekennzeichnet, dass
die Anzeigekomponente ferner ausgestaltet ist, um eine Mehrzahl von Ultraschallbildern (100) anzuzeigen, die eine sequentielle Sequenz von Bildern des Blutgefäßes sind, wobei das Ultraschallbild (100) ein Anfangsbild ist; und die analytische Komponente ferner ausgestaltet ist, um ausgewählte Steuerpunkte (105) entlang der Begrenzung auf einem Endbild aus der Mehrzahl von Ultraschallbildern (100) zu empfangen, so dass sich mindestens ein Zwischenbild zwischen dem Anfangsbild und dem Endbild befindet, und um zwischen den Steuerpunkten (105) des Anfangsbildes und des Endbildes zu interpolieren, um automatisch eine Begrenzungskontur (110) auf dem mindestens einen Zwischenbild zu erzeugen.

2. System zur Bestimmung einer Begrenzungskontur (110) nach Anspruch 1, bei dem:

die analytische Komponente konfiguriert ist, um die Begrenzungskontur (110) auf dem Anfangsbild, dem mindestens einen Zwischenbild und dem Endbild zu optimieren, indem jeder der Steuerpunkte (105) basierend auf einem Gradientenbild (730) eingestellt wird, das eine differenzierte Begrenzung enthält, die aus dem Ultraschallbild (100) des Anfangsbildes, des zumindest einen Zwischenbildes und des Endbildes bestimmt ist.

3. System zur Bestimmung einer Begrenzungskontur (110) nach Anspruch 1, bei dem die analytische Komponente ferner ausgestaltet ist, um die differenzierte Begrenzung durch Analysieren von Pixelwerten des Ultraschallbildes (100) in radialer Richtung zu bestimmen.

4. System zur Bestimmung einer Begrenzungskontur (110) nach Anspruch 1, bei dem die analytische Komponente ausgestaltet ist, um ein Gradientenbild (730) zu bilden, durch:

Konvertieren des Ultraschallbildes (100) in ein polares Bild (600), wobei das polare Bild (600) eine Mehrzahl von radialen Abtastlinien aufweist, die eine Mehrzahl von Pixel beinhalten;
Bestimmen einer Kante der Begrenzung in radialer Richtung entlang jeder der radialen Abtastlinien durch Anwenden eines Gradientenfilters auf jedes der Mehrzahl von Pixeln, wobei der Gradientenfilter Pixel differenziert, die mit einer Wahrscheinlichkeit die Kante der Begrenzung bilden, wobei die differenzierten Pixel die differenzierte Begrenzung definieren; und
Konvertieren des polaren Bildes (600) des Ultraschallbildes (100) in ein kartesisches Format, um das Gradientenbild (730) in einem kartesischen Format zu erhalten, einschließlich der differenzierten Begrenzung.

5. System zur Bestimmung einer Begrenzungskontur (110) nach Anspruch 1, bei dem die analytische Komponente konfiguriert ist, um die Begrenzungskontur (110) durch Einstellen von jedem der Steuerpunkte (105) basierend auf einer Punktabstandsbeschränkung und einer Krümmungsbeschränkung zu optimieren, wodurch in der Begrenzungskontur (110) eine Kontinuität beibehalten wird.

6. System zur Bestimmung einer Begrenzungskontur (110) nach Anspruch 5, bei dem die analytische Komponente ausgestaltet ist, um die Optimierung für jeden der Steuerpunkte (105) iterativ durchzuführen.

Revendications

1. Système pour déterminer un contour de frontière (110) d’un vaisseau sanguin à partir d’une image ultrasonore intravasculaire (100) où l’image ultrasonore (100) est générée à partir de données acquises radialement dans le vaisseau sanguin par un dispositif à ultrasons (10), comportant :

un composant d’affichage configuré pour afficher l’image ultrasonore (100), l’image ultrasonore (100) étant une vue en coupe transversale d’un vaisseau sanguin et étant une image cartésienne, l’image ultrasonore (100) incluant une représentation d’une frontière du vaisseau sanguin, et
un composant analytique configuré pour recevoir des points de contrôle sélectionnés (105) le long de la frontière, interpoler entre les points de contrôle (105) pour générer un contour de frontière (110), et optimiser le contour

de frontière (110) en ajustant chacun des points de contrôle (105) sur la base d'une image de gradient (730) qui inclut une frontière distinguée, l'image de gradient (730) étant déterminée à partir de l'image ultrasonore (100),

caractérisé en ce que
le composant d'affichage est également configuré pour afficher une pluralité d'images ultrasonores (100) étant une séquence séquentielle d'images du vaisseau sanguin, l'image ultrasonore (100) étant une image initiale, et
le composant analytique est également configuré pour recevoir des points de contrôle sélectionnés (105) le long de la frontière sur une image finale à partir de la pluralité d'images ultrasonores (100) de telle sorte qu'au moins une image intermédiaire est entre les images initiale et finale, et pour interpoler entre les points de contrôle (105) des images initiale et finale pour générer automatiquement un contour de frontière (110) sur la au moins une image intermédiaire.

2. Système pour déterminer un contour de frontière (110) comme exposé dans la revendication 1 dans lequel :

le composant analytique est configuré pour optimiser le contour de frontière (110) sur l'image initiale, la au moins une image intermédiaire et l'image finale en ajustant chacun des points de contrôle (105) sur la base d'une image de gradient (730) qui inclut une frontière distinguée déterminée à partir de l'image ultrasonore (100) de l'image initiale, de la au moins une image intermédiaire et de l'image finale.

3. Système pour déterminer un contour de frontière (110) comme exposé dans la revendication 1 dans lequel le composant analytique est également configuré pour déterminer la frontière distinguée en analysant radialement des valeurs de pixel de l'image ultrasonore (100).

4. Système pour déterminer un contour de frontière (110) comme exposé dans la revendication 1 dans lequel le composant analytique est configuré pour former une image de gradient (730) en :

convertissant une image ultrasonore (100) en une image polaire (600), l'image polaire (600) ayant une pluralité de lignes de balayage radiales qui incluent une pluralité de pixels,
déterminant radialement un bord de la frontière le long de chacune des lignes de balayage radiales en appliquant un filtre de gradient à chaque pixel de la pluralité de pixels, le filtre de gradient distinguant des pixels qui sont susceptibles de former le bord de la frontière, les pixels distingués définissant la frontière distinguée, et
convertissant l'image polaire (600) de l'image ultrasonore (100) en un format cartésien pour obtenir l'image de gradient (730) au format cartésien incluant la frontière distinguée.

5. Système pour déterminer un contour de frontière (110) comme exposé dans la revendication 1 dans lequel le composant analytique est configuré pour optimiser le contour de frontière (110) en ajustant chacun des points de contrôle (105) sur la base d'une contrainte d'espacement de points et d'une continuité maintenue de contrainte d'incurvation dans le contour de frontière (110).

6. Système pour déterminer un contour de frontière (110) comme exposé dans la revendication 5 dans lequel le composant analytique est configuré pour réaliser itérativement l'optimisation pour chacun des points de contrôle (105).

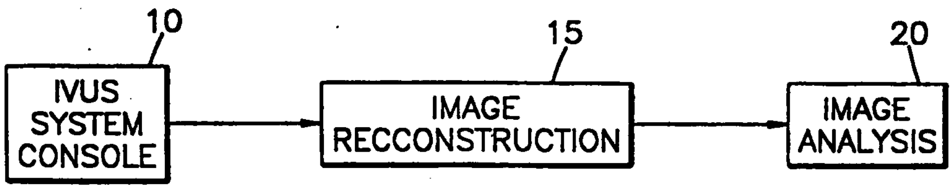


Fig.1

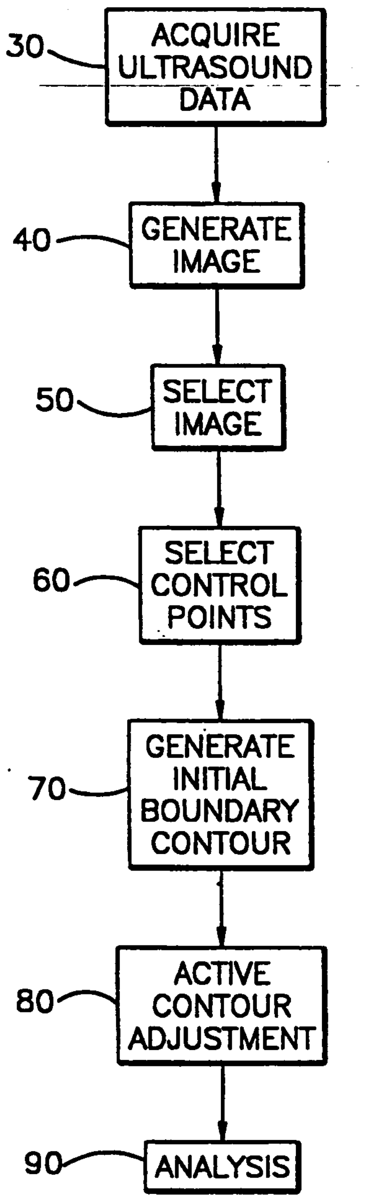


Fig.2

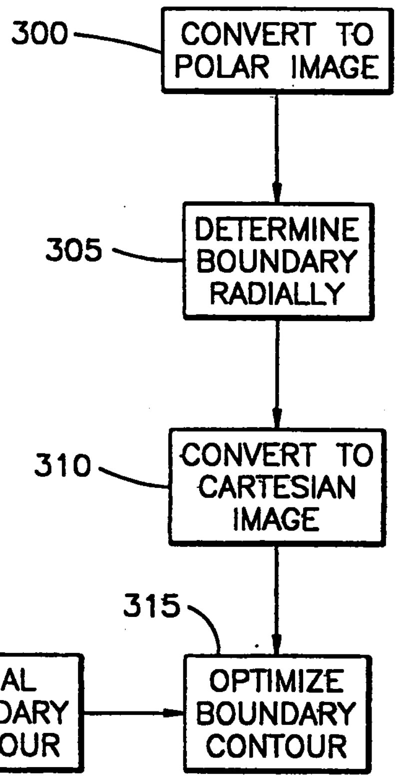


Fig.3

Fig.4

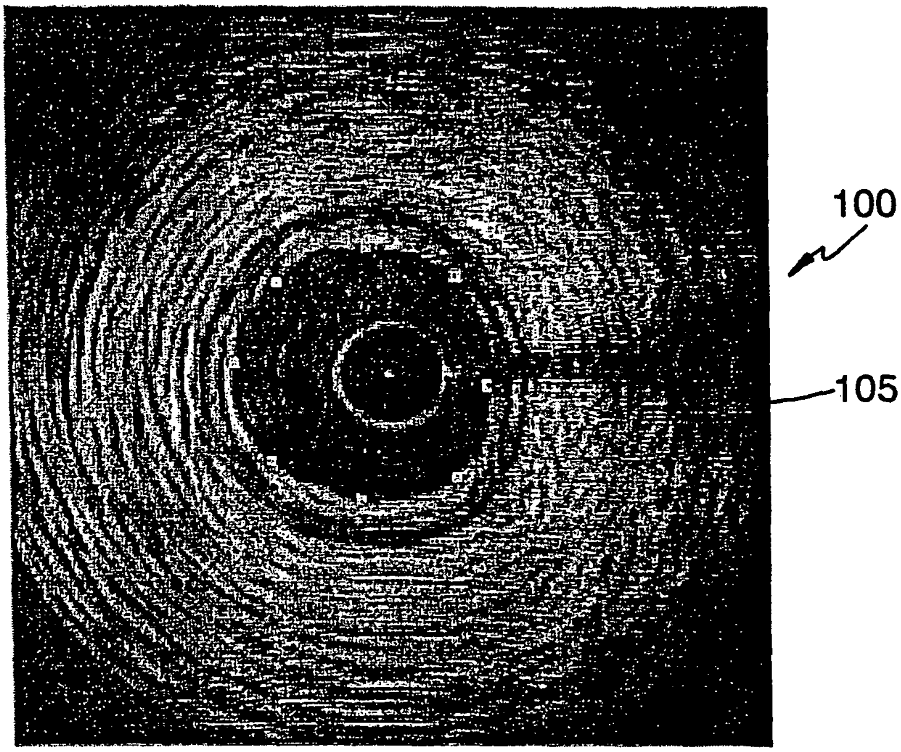
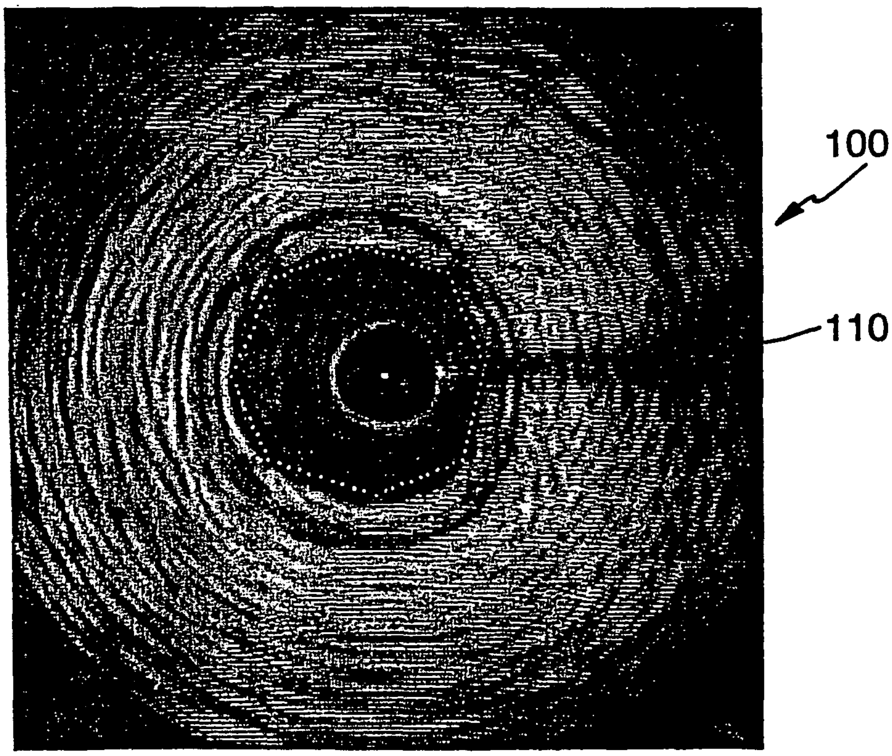


Fig.5



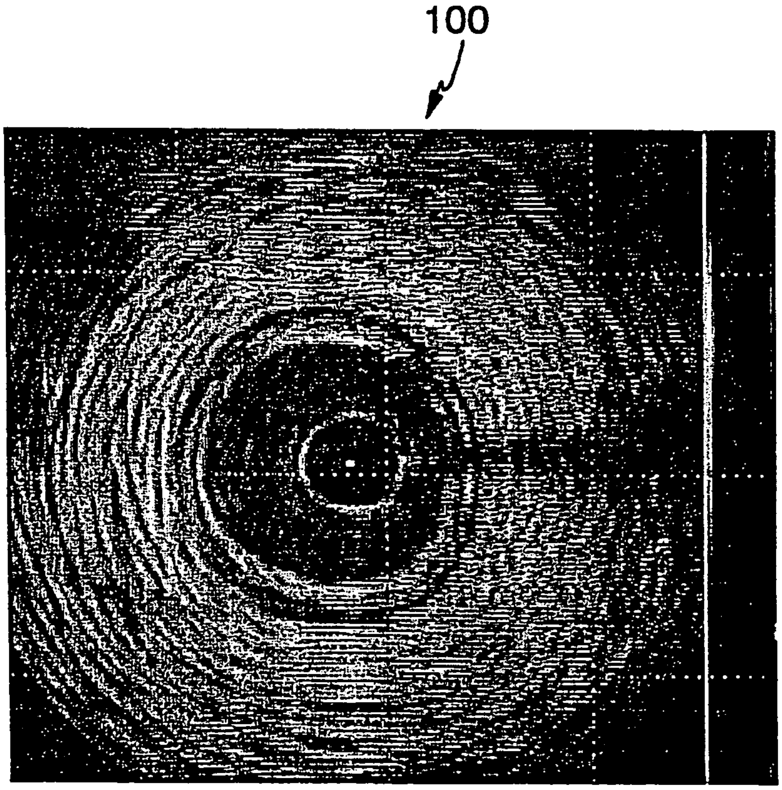


Fig.6A

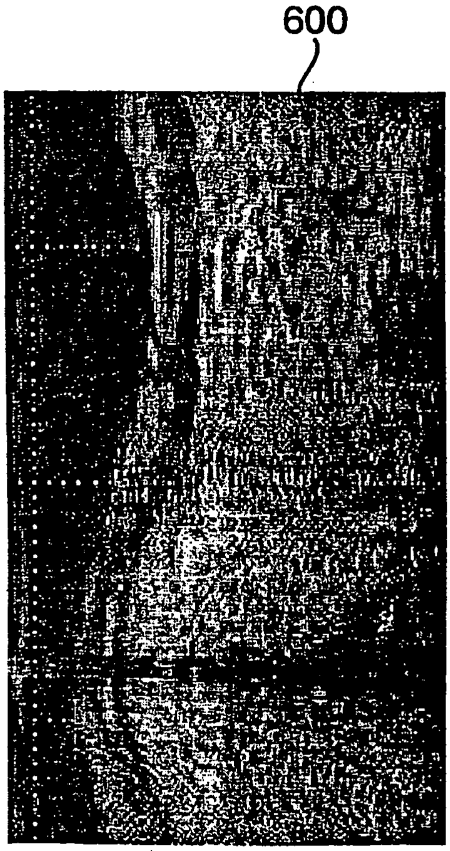


Fig.6B

Fig.7A

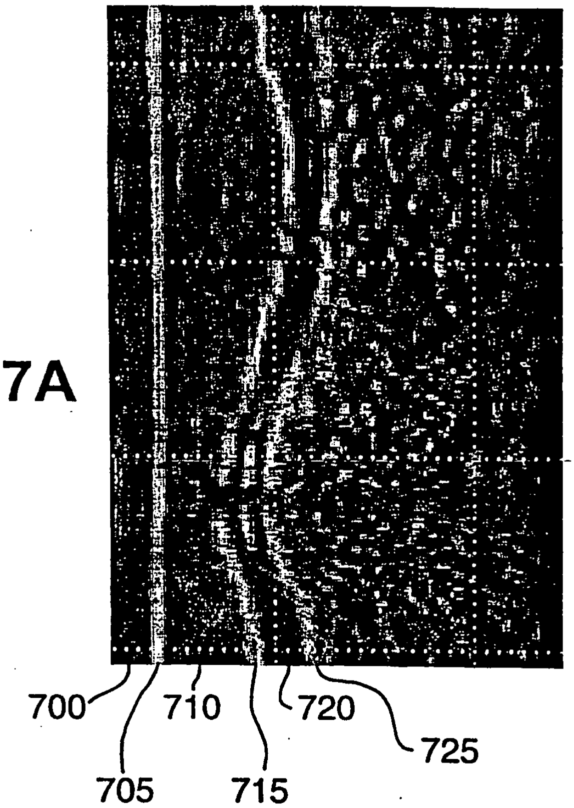
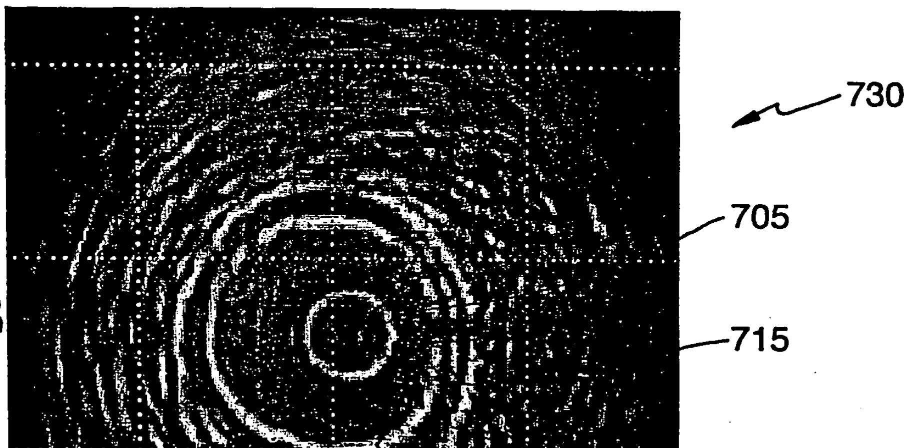


Fig.7B



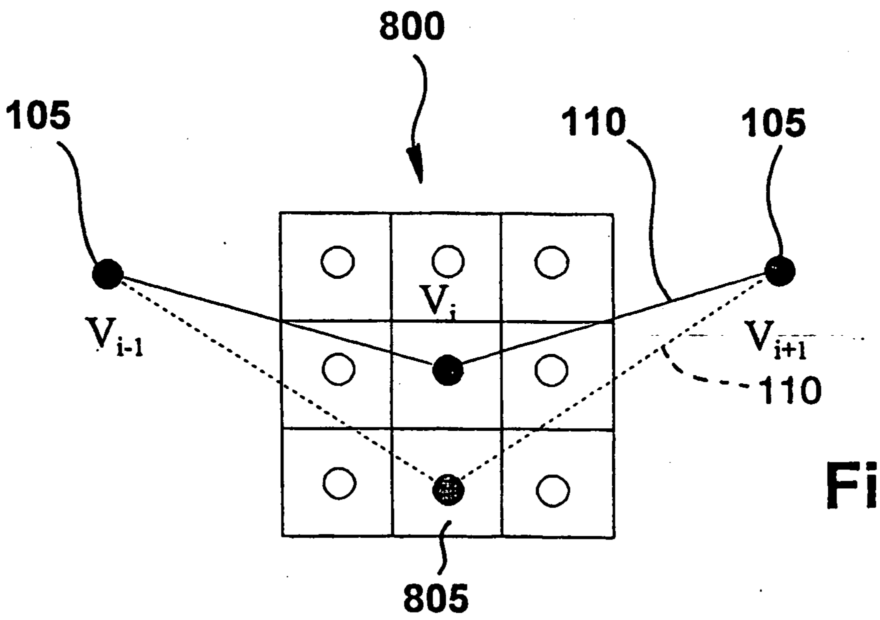
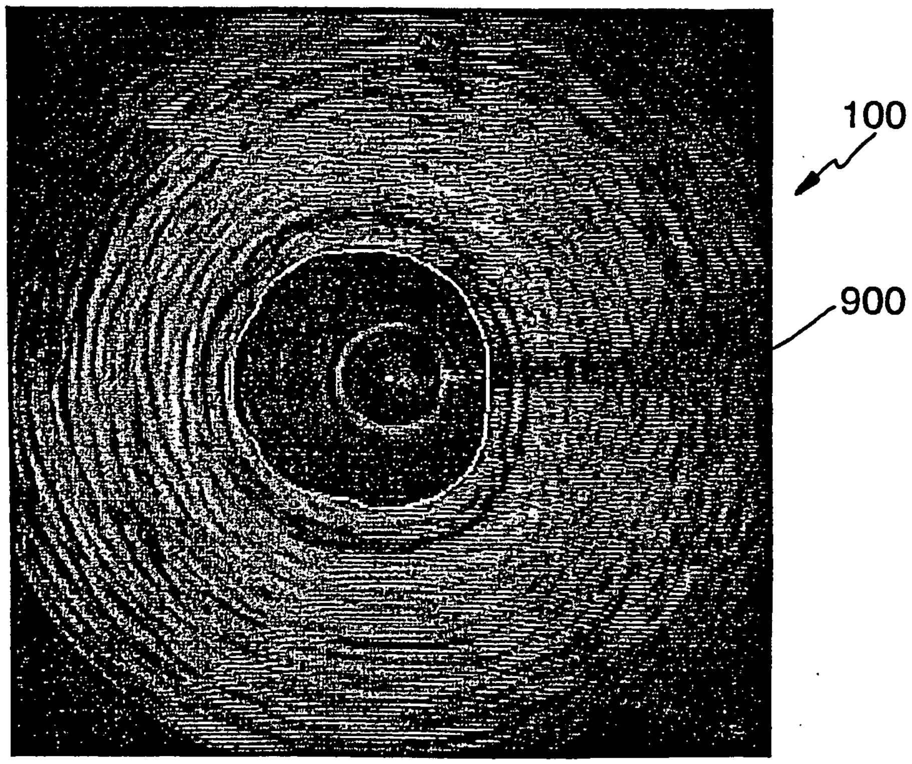


Fig.8

Fig.9



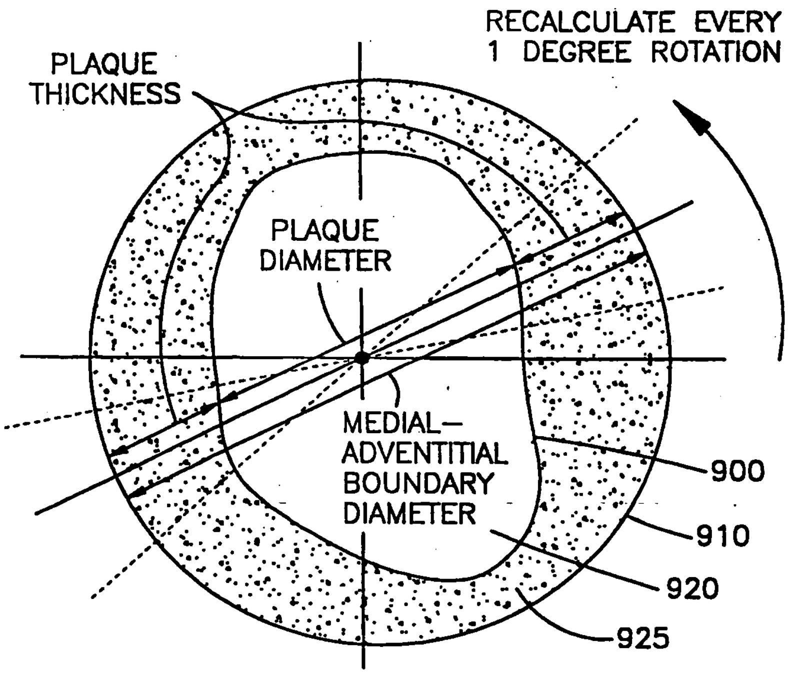

RECALCULATE EVERY
1 DEGREE ROTATION
PLAQUE
THICKNESS
PLAQUE
DIAMETER
MEDIAL-
ADVENTITIAL
BOUNDARY
DIAMETER
900
910
920
925

Fig.10

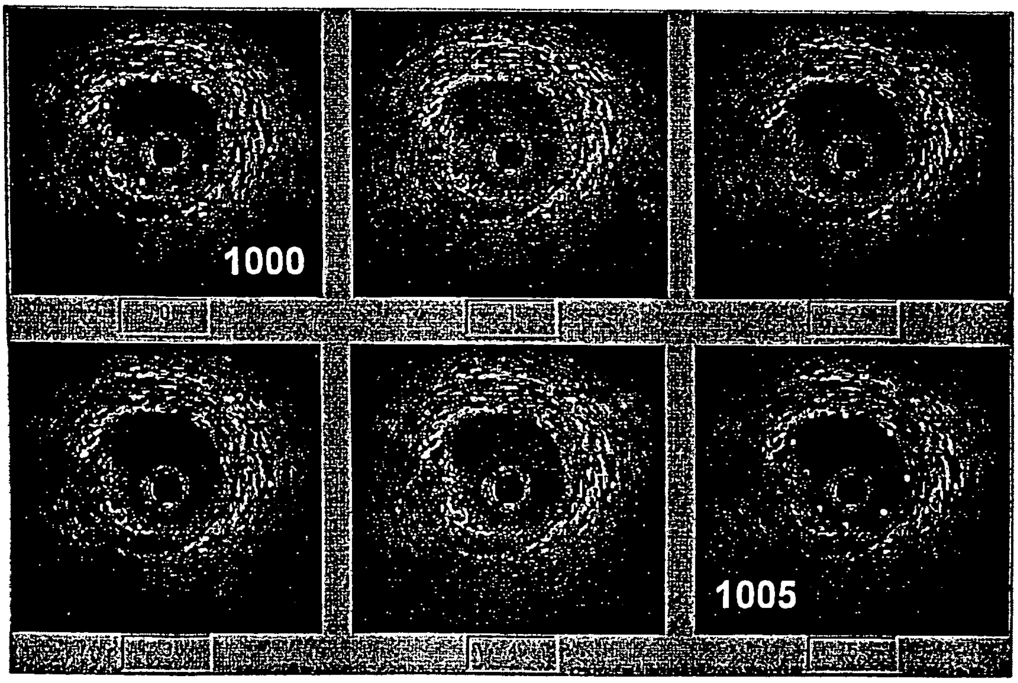

1000
1005

Fig.11

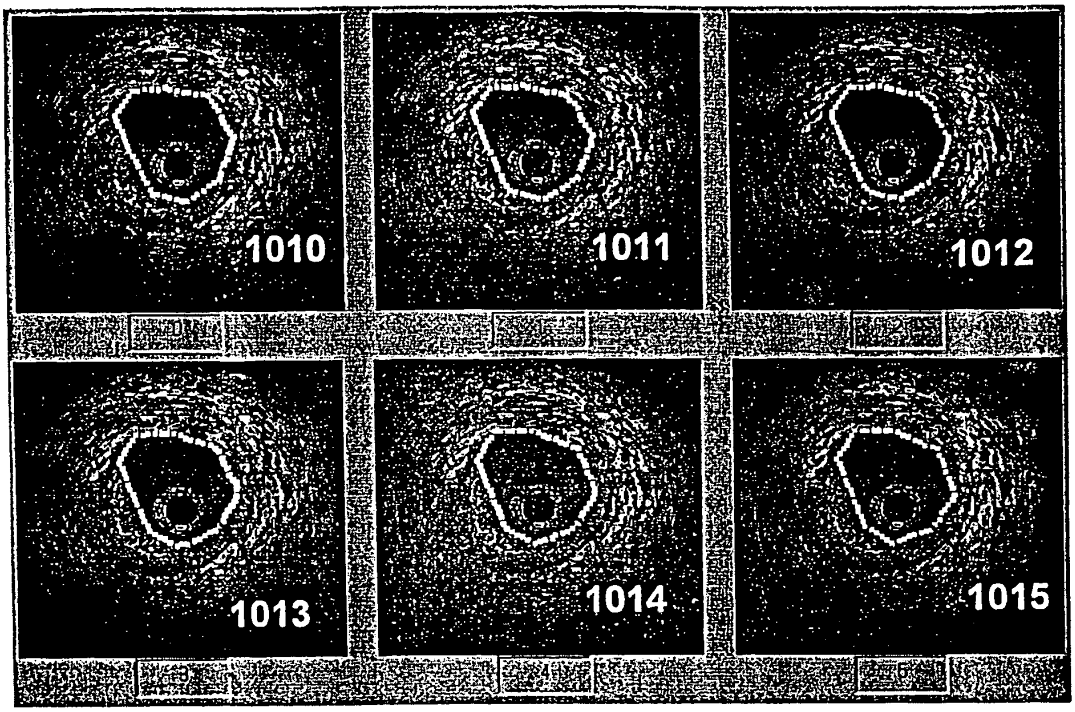


Fig.12

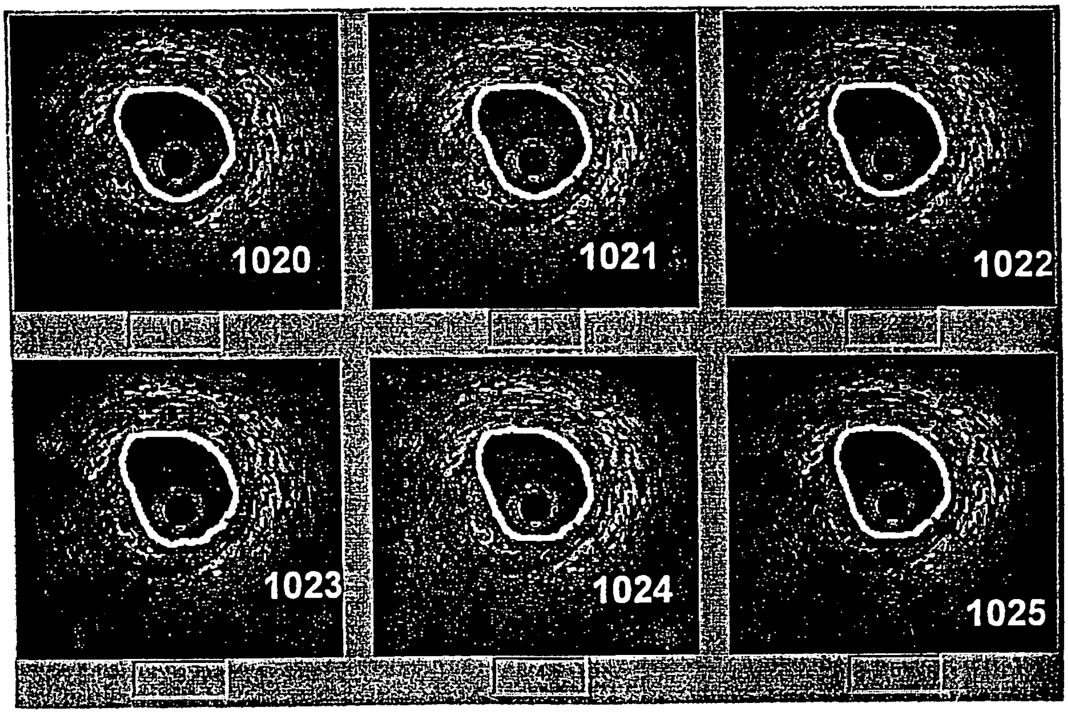


Fig.13

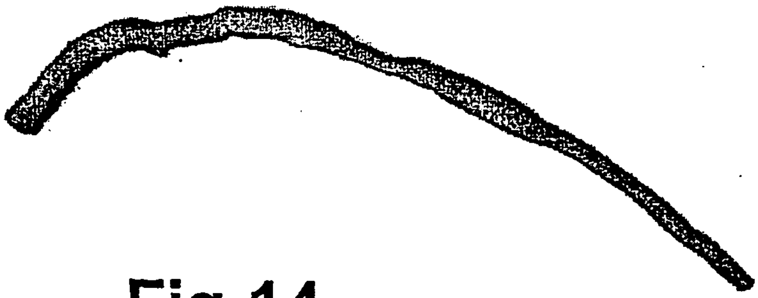


Fig.14

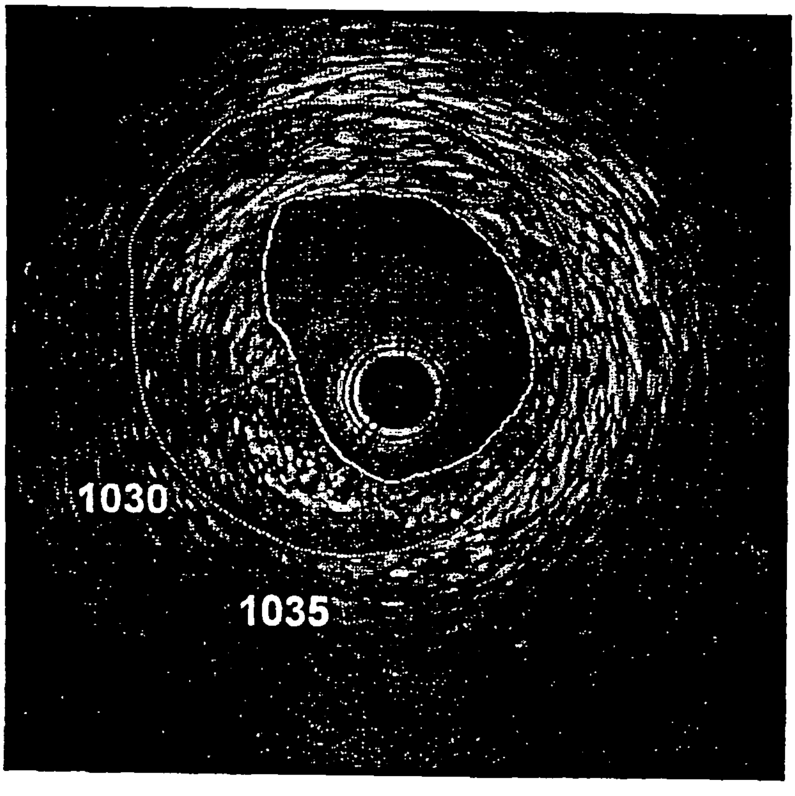


Fig.15

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 5495852 A **[0005]**

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专利名称(译)	使用主动轮廓法和系统进行血管内超声分析		
公开(公告)号	EP1198200A4	公开(公告)日	2004-06-23
申请号	EP2000941653	申请日	2000-06-22
[标]申请(专利权)人(译)	克里夫兰诊所基金会		
申请(专利权)人(译)	克利夫兰诊所基金会		
当前申请(专利权)人(译)	克利夫兰诊所基金会		
[标]发明人	KLINGENSMITH JON D VINCE DAVID GEOFFREY SHEKHAR RAJ		
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IPC分类号	A61B8/12 A61B5/107 A61B8/08 G06K9/64 G06T1/00 G06T5/00 G06T7/60 A61B8/00 A61K35/00 G06K9/00		
CPC分类号	A61B8/4461 A61B5/02007 A61B5/1076 A61B8/0833 A61B8/0858 A61B8/12 A61B8/463 G06K9/6207 G06T7/12 G06T7/149 G06T2207/10132 G06T2207/20101 G06T2207/30101		
优先权	09/347209 1999-07-02 US		
其他公开文献	EP1198200B1 EP1198200A1		
外部链接	Espacenet		

摘要(译)

提供了一种血管内超声（IVUS）分析系统和方法，该系统和方法确定血管的腔和内外膜边界。 超声波数据是通过安装在插入血管的导管尖端的旋转换能器获取的。 从超声数据重建血管内图像。 为了确定血管的腔边界，用户在图像上选择被认为是腔边界位置的边界点。 基于边界点生成边界轮廓。 然后通过基于在极坐标格式的图像上执行的腔边界的径向确定的边缘来调整边界点来优化边界轮廓。 一旦产生了最终的腔边界轮廓，就重复该过程以确定内侧-外膜边界轮廓。 利用轮廓数据，分析血管的特性，包括确定管腔面积和由斑块引起的阻塞百分比。