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(54) **IMAGE PROCESSING DEVICE, METHOD, AND PROGRAM**

BILDVERARBEITUNGSVORRICHTUNG, VERFAHREN UND PROGRAMM

DISPOSITIF DE TRAITEMENT D'IMAGES, PROCÉDÉ, ET PROGRAMME

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Description

Technical Field

[0001] The present invention relates to an image processing apparatus and method for discriminating structure of a structure in an image, and a program for causing a computer to perform the image processing method.

Background Art

[0002] Recently, high quality three-dimensional images have been used in image diagnosis with the advancement of medical equipment (e.g., multidetector CT and the like). As a three-dimensional image is formed of a multiple of two-dimensional images and has a large amount of information, the doctor may sometimes require a prolonged time to find out a desired observation region and give a diagnosis. Consequently, it is practiced to extract an organ of interest and perform MIP, VR, or CPR display, or the like, in order to enhance the visibility of an entire organ or a lesion and improve efficiency of diagnosis.

[0003] In the meantime, as a method of extracting a blood vessel or a bone in a medical image, Hessian analysis using a Hessian matrix is proposed (refer to Non-Patent Document 1). The Hessian analysis discriminates whether a local structure in an image is a point, a line, or a plane by analyzing eigenvalues of a Hessian matrix whose elements are second order partial differential coefficients calculated by the use of the second differential kernel of a given fil ter, such as Gaussian kernel or the like. The use of the Hessian analysis allows a blood vessel and a bone to be discriminated as a line-like structure and a plate-like structure respectively.

[0004] There are cases, however, in which, if another structure is present in the vicinity of a line-like structure (vicinity structure), the method of Non-Patent Document 1 erroneously discriminates the vicinity structure as the line-like structure. The method of Non-Patent Document 2 improves the filter proposed in Non-Patent Document 1 by convoluting a function representing a solid sphere (solid sphere model function) with the inside of the spherical shape as 1 and the outside as 0 and limiting the calculation range of the second order partial differential coefficients to the surface of the sphere in Hessian analysis, whereby the influence of the vicinity structure on the filtering result may be reduced.

[Prior Art Documents]

[Patent Documents]

[Non-Patent Documents]

[0005]

Non-Patent Document 1: A. F. Frangi et al., "Multiscale vessel enhancement filtering", Proceedings of MICCAI, pp. 130-137, 1998

Non-Patent Document 2: M. Law et al., "Three Dimensional Curvilinear Structure Detection Using Optimally Oriented Flux", Proceedings of ECCV, pp. 368-382, 2008

Disclosure of the Invention

[0006] If a blood vessel, which is a line-like structure, is discriminated from a medical image that includes blood vessels of various thicknesses using the method of Non-Patent Document 2, however, there may be a case in which a blood vessel narrower that an actual blood vessel is erroneously recognized inside a blood vessel. In other words, if a line-like structure is discriminated by the method of Non-Patent Document 2, there may be a problem that an erroneous discrimination is made at a portion of the contour of a structure having a radius of curvature greater than radius of curvature of a solid sphere of a solid sphere model function that a line-like structure having a diameter substantially the same as the diameter of the solid sphere represented by the solid sphere model function is present.

[0007] The aforementioned problem may possibly occur at any contour portion of a structure having a radius of curvature greater than the radius of curvature of the solid sphere of the solid sphere model function. In view of the problem described above, therefore, it is an object of the present invention to prevent, in image processing method that performs filtering using a solid sphere model function in Hessian analysis, erroneous discrimination of structure that occurs at a contour portion of a structure having a radius of curvature greater than the radius of curvature of the solid sphere represented by the solid sphere model function.

[0008] An image processing apparatus according to the first invention includes a filtering unit that performs filtering on each pixel position in an image using a second order partial differential of a function representing a solid sphere and calculates a Hessian matrix, and an evaluation unit that discriminates a structure included in the image using eigenvalues and eigenvectors obtained by performing eigenvalue analysis on the calculated Hessian matrix, wherein the filtering unit includes a correction unit that performs filtering on each pixel position in the image using a first order partial differential of a function representing a hollow sphere having the same radius as the radius of the solid sphere and obtains first order partial differential vectors, and carries out correction to cancel out one of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using values obtained by projecting the obtained first order partial differential vectors onto directions of the eigenvectors. An image processing method according to the first invention includes a filtering step that performs filtering on each pixel position in an image using a second order partial differential of a function representing a solid sphere and calculates a Hessian matrix, and an evaluation step that discriminates a structure included in the image using eigenvalues and eigenvectors obtained by performing eigenvalue analysis on the calculated Hessian matrix, wherein the filtering step performs filtering on each pixel position in the image using a first order partial differential of a function representing a hollow sphere having the same radius as the radius of the solid sphere and obtains first order partial differential vectors, and carries out correction to cancel out one of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using values obtained by projecting the obtained first order partial differential vectors onto directions of the eigenvectors.

[0009] Note that the image processing method according to the first invention may be provided as a program for causing a computer to perform the image processing method.

[0010] The "hollow sphere having the same radius as the radius of the solid sphere" as used herein includes not only the case where the radii of the solid sphere and the hollow sphere strictly corresponds to each other but also the case where the radius of the hollow structure is greater or smaller than the radius of the solid sphere if it is within the range having an effect of cancelling out the response waveform at one position of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using the first order partial differential vectors. In order to satisfactorily obtain the "effect of cancelling out the response waveform at one position", it is preferable that the radii of the hollow sphere and the solid sphere be equal as much as possible and, for example, the difference in radius between the hollow sphere and the solid sphere is preferably 20% or less and the difference in radius between the hollow sphere and the solid sphere is preferably 10% or less.

[0011] In the image processing apparatus according to the first invention, if eigenvalues of the evaluation matrix are taken as λ_1, λ_2, λ_3, eigenvectors are taken as $e_1 = (x_1, y_1, z_1)$, $e_2 = (x_2, y_2, z_2)$, $e_3 = (x_3, y_3, z_3)$, and the first order partial differential vectors of the function representing the hollow sphere are taken as (ρ_1, ρ_2, ρ_3), the correction unit carries out the correction to cancel out the one of the response waveforms by correcting the eigenvalues as shown in Formula (13) given below using ρ_1', ρ_2', ρ_3' calculated by Formula (12) given below and a predetermined coefficient:

$$\left.\begin{array}{l} \rho_1' = \rho_1 \times x_1 + \rho_2 \times y_1 + \rho_3 \times z_1 \\ \rho_2' = \rho_1 \times x_2 + \rho_2 \times y_2 + \rho_3 \times z_2 \\ \rho_3' = \rho_1 \times x_3 + \rho_2 \times y_3 + \rho_3 \times z_3 \end{array}\right\} \quad (12)$$

$$\left.\begin{array}{l} \lambda_1' = \begin{cases} 0 & \text{if } |\lambda_1| < |\alpha\rho_1'| \\ \min(|\lambda_1 + \alpha\rho_1'|, |\lambda_1 - \alpha\rho_1'|) & \text{otherwise} \end{cases} \\ \lambda_2' = \begin{cases} 0 & \text{if } |\lambda_2| < |\alpha\rho_2'| \\ \min(|\lambda_1 + \alpha\rho_2'|, |\lambda_1 - \alpha\rho_2'|) & \text{otherwise} \end{cases} \\ \lambda_3' = \begin{cases} 0 & \text{if } |\lambda_3| < |\alpha\rho_3'| \\ \min(|\lambda_3 + \alpha\rho_3'|, |\lambda_3 - \alpha\rho_3'|) & \text{otherwise} \end{cases} \end{array}\right\} \quad (13)$$

[0012] In the image processing apparatus according to the first invention, the function representing the hollow sphere is preferably represented by Formula (10) given below:

$$\left.\begin{array}{l} f(r)=\delta(r-R_4) \\ r=\sqrt{x^2+y^2+z^2} \end{array}\right\} \quad (10)$$

where, x, y, z are the coordinates of three-dimensional space, r is the polar coordinate representation thereof, and R_4 is the radius of the hollow sphere.

[0013] An image processing apparatus according to the second invention includes a filtering unit that performs filtering on each pixel position in an image using a second order partial differential of a function representing a solid sphere and calculates a Hessian matrix, and an evaluation unit that discriminates a structure included in the image using eigenvalues and eigenvectors obtained by performing eigenvalue analysis on the calculated Hessian matrix, wherein the filtering unit includes a correction unit that performs filtering on each pixel position in the image using a first order partial differential of a function representing a second solid sphere having a second radius greater than a first radius which is the radius of the first solid sphere and calculates first order partial differential vectors, further performs filtering on each pixel position in the image using a first order partial differential of a function representing a third solid sphere having a third radius which is smaller than the first radius and calculates first order partial differential vectors, and carries out correction to cancel out a response waveform at one position of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using values obtained by projecting the first order partial differential vectors of the function representing the second solid sphere onto directions of the eigenvectors and values obtained by projecting the first order partial differential vectors of the function representing the third solid sphere onto directions of the eigenvectors.

[0014] Preferably, in the image processing apparatus according to the second invention, the response waveform at the one position is a waveform in which one positive peak and one negative peak are adjoining to each other, the second radius corresponds to the length from the center of the solid sphere to the positive peak or the length from the center of the solid sphere to the negative peak, whichever is longer, and the third radius corresponds to the length from the center of the solid sphere to the positive peak or the length from the center of the solid sphere to the negative peak, whichever is shorter.

[0015] The "the second radius corresponds to the length from the center of the first solid sphere to the positive peak or the length from the center of the first solid sphere to the negative peak, whichever is longer" includes not only the case where the second radius corresponds strictly to the length from the center of the solid sphere to the positive peak or the length from the center of the solid sphere to the negative peak, whichever is longer (first length), but also the case where the second radius is greater or smaller than the first length if it is within the range having an effect of cancelling out the response waveform at one position of response waveforms of the second order partial differential of the function representing the first solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using the vectors obtained by weighting the first order partial differential vectors of the function representing the second solid sphere and the vectors obtained by weighting the first order partial differential vectors of the function representing the third solid sphere. In order to satisfactorily obtain the "effect of cancelling out the response waveform at one position", it is preferable that the second radius and the first length be equal as much as possible and, for example, the difference between the second radius and the first length is preferably 20% or less and more preferably 10% or less.

[0016] Likewise, the "the third radius corresponds to the length from the center of the first solid sphere to the positive peak or the length from the center of the first solid sphere to the negative peak, whichever is longer" includes not only the case where the third radius corresponds strictly to the length from the center of the solid sphere to the positive peak or the length from the center of the solid sphere to the negative peak, whichever is longer (second length), but also the case where the third radius is greater or smaller than the second length if it is within the range having an effect of cancelling out the response waveform at one position of response waveforms of the second order partial differential of the function representing the first solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using the vectors obtained by weighting the first order partial differential vectors of the function representing the third solid sphere and the vectors obtained by weighting the first order partial differential vectors of the function representing the third solid sphere. In order to satisfactorily obtain the "effect of cancelling out the response waveform at one position", it is preferable that the third radius and the second length be equal as much as possible and, for example, the difference between the third radius and the second length is preferably 20% or less and more preferably 10% or less.

[0017] In the image processing apparatus according to the first invention, the filtering unit preferably calculates, with respect to functions representing the solid sphere in a plurality of sizes, an evaluation matrix by performing filtering with a second order partial differential matrix of a function representing each solid sphere.

[0018] In the image processing apparatus according to the second invention, the filtering unit calculates, with respect to functions representing the first solid sphere in a plurality of sizes, an evaluation matrix by performing filtering with a second order partial differential matrix of a function representing each of the first solid spheres.

[0019] Preferably, in the image processing apparatuses according to the first and the second inventions, the image is a medical image and the structure is a blood vessel.

[0020] Preferably, in the image processing apparatuses according to the first and the second inventions, the filtering unit performs the filtering using the second order partial differential matrix of the function representing the solid sphere in Fourier space.

[0021] Preferably, in the image processing apparatuses according to the first and the second inventions, the evaluation unit discriminate at least one of local point-like, line-like, and plane-like structures of the structural object.

[0022] According to the first invention, a filtering unit that performs filtering on each pixel position in an image using a second order partial differential of a function representing a solid sphere and calculates a Hessian matrix, and an evaluation unit that discriminates a structure included in the image using eigenvalues and eigenvectors obtained by performing eigenvalue analysis on the calculated Hessian matrix are provided, and the filtering unit includes a correction unit that performs filtering on each pixel position in the image using a first order partial differential of a function representing a hollow sphere having the same radius as the radius of the solid sphere and obtains first order partial differential vectors, and carries out correction to cancel out one of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using values obtained by projecting the obtained first order partial differential vectors onto directions of the eigenvectors. This may inhibit erroneous discrimination that occurs when a contour portion of a structure having a radius of curvature greater than the radius of curvature of a solid sphere of a function representing the solid sphere corresponds to only one position of response waveform of the second partial differential of the function representing the solid sphere in each direction and the accuracy of the evaluation values may be improved. Consequently, a structure included in an image may be discriminated more accurately based on the evaluation values.

[0023] According to the second invention, a filtering unit that performs filtering on each pixel position in an image using a second order partial differential of a function representing a solid sphere and calculates a Hessian matrix, and an evaluation unit that discriminates a structure included in the image using eigenvalues and eigenvectors obtained by performing eigenvalue analysis on the calculated Hessian matrix are provided, and the filtering unit includes a correction unit that performs filtering on each pixel position in the image using a first order partial differential of a function representing a second solid sphere having a second radius which is greater than a first radius, the first radius being the radius of the first solid sphere, and calculates first order partial differential vectors, further performs filtering on each pixel position in the image using a first order partial differential of a function representing a third solid sphere having a third radius which is smaller than the first radius and calculates first order partial differential vectors, and carries out correction to cancel out a response waveform at one position of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere, using values obtained by projecting the first order partial differential vectors of the function representing the second solid sphere onto directions of the eigenvectors and values obtained by projecting the first order partial differential vectors of the function representing the third solid sphere onto directions of the eigenvectors. This may inhibit erroneous discrimination that occurs when a contour portion of a structure having a radius of curvature greater than the radius of curvature of a solid sphere of a function representing the solid sphere corresponds to only one position of response waveform of the second partial differential of the function representing the solid sphere in each direction and the accuracy of the evaluation values may be improved. Consequently, a structure included in an image may be discriminated more accurately based on the evaluation values.

Brief Description of Drawings

[0024]

Figure 1 is a schematic block diagram of an image processing apparatus according to a first embodiment of the present invention, illustrating a configuration thereof.

Figure 2 is a drawing for explaining a multiple resolution transformation.

Figure 3 is a drawing for explaining eigenvalues of a line-like structure.

Figure 4 is a drawing for explaining eigenvalues of a plane-like structure.

Figure 5A is a drawing for explaining the principle of correction processing according to the first embodiment of the present invention.

Figure 5B is a drawing for explaining response of second order partial differential of a solid sphere model function in x direction used for filtering of the first embodiment of the present invention.

Figure 5C is a drawing for explaining response of first order partial differential of a hollow sphere model function in x direction used for correction processing of the first embodiment of the present invention.

Figure 5D is a drawing for explaining the response of the second order partial differential of the solid sphere in x direction corrected by the first order partial differential of the hollow sphere model function of the first embodiment of the present invention.

Figure 6A is a drawing for explaining response after performing the correction processing according to the first embodiment of the present invention (case where the size of the structure corresponds to the size of the solid sphere represented by the solid sphere model function).

Figure 6B is a drawing for explaining response after performing the correction processing according to the first embodiment of the present invention (case where the size of the solid sphere represented by the solid sphere model function is greater than the size of the structure).

Figure 7 is a flowchart of processing performed in the first embodiment of the present invention.

Figure 8A is an example in which the image processing according to the first embodiment of the present invention is applied to blood vessel extraction (pseudo three-dimensional image).

Figure 8B is an example in which the image processing according to the first embodiment of the present invention is applied to blood vessel extraction (tomographic image).

Figure 9A is a drawing for explaining the principle of correction processing according to a second embodiment of the present invention.

Figure 9B is a drawing for explaining the principle of correction by first order partial differential vectors of second and third solid sphere model function of the second embodiment of the present invention.

Best Mode for Carrying Out the Invention

[0025] Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings. Figure 1 is a schematic block diagram of an image processing apparatus according to an embodiment of the present invention, illustrating a configuration thereof. The configuration of the image processing apparatus 1 shown in Figure 1 is realized by executing a program read into an auxiliary storage (not shown) on a computer (e.g., personal computer). The program is provided being recorded on an information storage medium, such as CD-ROM and the like, or distributed via a network, such as the Internet, and installed on a computer.

[0026] The image processing apparatus 1 generates a three-dimensional image M0 using a plurality of two-dimensional images captured, for example, by an X-ray CT system 2 and automatically segments a line-like structure and a plate-like structure included in the three-dimensional image M0. The image processing apparatus 1 includes an image obtaining unit 10, a detection region setting unit 20, a discrimination unit 30, a segmentation unit 40, a display unit 50, and an input unit 60.

[0027] The image obtaining unit 10 obtains a plurality of CT images (two-dimensional images) captured, for example, by the X-ray CT system 2, and generates a three-dimensional image M0 from the plurality of two-dimensional images. The image obtaining unit 10 may be a unit that obtains two-dimensional images, such as so-called MRI images, RI images, PET images, X-ray images, and the like, as well as CT images.

[0028] The detection region setting unit 20 first makes the voxel dimensions of the three-dimensional image M0 isotropic. For example, if the voxel dimensions of the three-dimensional image M0 are 0.3mm, 0.3mm, and 0.6mm in the X, Y, and Z directions of the three-dimensional image M0 respectively, they are made isotropic to (X, Y, Z) = (0.5, 0.5, 0.5) (mm).

[0029] The detection region setting unit 20 performs a multiple resolution transformation on the three-dimensional image M0 after making the image isotropic and generates a plurality of three-dimensional multiple resolution images Msi (i=0 to n) (Gaussian pyramid) as shown in Figure 2. Note that i=0 represents the same resolution as the resolution of the three-dimensional image M0 and i=n represents the lowest resolution. The image is reduced by the increments of $\sqrt{2}$ and the voxel dimensions of the three-dimensional multiple resolution images Msi are (X, Y, Z) = (0.5, 0.5, 0.5), (0.7, 0.7, 0.7), (1.0, 1.0, 1.0), and so on in descending order of resolution.

[0030] The discrimination unit 30 includes a filtering unit 32, a correction unit 33, and an evaluation unit 34. The filtering unit 32 performs filtering, which is identical to the filtering of the method of Non-Patent Document 2, on each of the three-dimensional multiple resolution images Msi using a function representing a solid sphere to be described later (solid sphere model function) and a Gaussian kernel in order to perform Hessian analysis using a Hessian matrix (evaluation matrix). That is, a filter kernel of the same size is convoluted with each of the multiple resolution images Msi having different resolutions. The solid sphere model function is defined by the radius R of the solid sphere and "σ" of the Gaussian kernel. For these, appropriate values are set based on the knowledge acquired by preliminary analysis and the like. For the radius R of the solid sphere, a value which is at least greater than "σ" of the Gaussian kernel is set.

[0031] By convoluting the filter kernel of the same size (e.g., R=2.0 (voxels), σ=0.5(voxels)) with each of the three-dimensional multiple resolution images Msi, filter kernels of different sizes are applied, in effect, to the three-dimensional image M0, so that a point-like structure, a line-like structure (e.g., blood vessel), and a plate-like structure (e.g., cortical bone) having different sizes may be detected. In other words, functions representing solid sphere with radius R in a plurality of sizes are used, and an evaluation matrix is calculated by performing filtering using a second order partial differential matrix of a function representing each solid sphere.

[0032] The Hessian analysis using a second order partial differential of the solid sphere model function of Non-Patent Document 2 will be described. The Hessian matrix used for the Hessian analysis is a 3x3 matrix for the three-dimensional image, as indicated in Formula (1) given below.

$$\nabla^2 I = \begin{bmatrix} Ixx & Ixy & Ixz \\ Iyx & Iyy & Iyz \\ Izx & Izy & Izz \end{bmatrix} \qquad (1) \qquad Ixx = \frac{\partial^2 I}{\partial x^2}, \quad Ixy = \frac{\partial^2 I}{\partial x \partial y}, \ldots$$

[0033] Each of the elements of the aforementioned Hessian matrix Ixx, Ixy, Iyy, Iyz, Izz, Izx is calculated by performing filtering (convolution operation) on the image data of a target image on second order partial differential of a hollow sphere model function f(r) and a Gaussian kernel function g(r).

[0034] In Non-Patent Document 2, the filtering processing is performed in Fourier space. First, the image data of a target image are Fourier transformed. Then, the Fourier transformed solid sphere model function, the Gaussian kernel function, and the second order partial differential are added up to the Fourier transformed target image (FT (image)). Then, by performing a reverse Fourier transform on the added-up result, the filtering result is obtained. Note that the obtained filtering result is the same as the filtering result obtained by performing a convolution operation in real space. If the Fourier transform of the solid sphere model function is taken as F(v) and the Fourier transform of the Gaussian kernel function is taken as G(ν)), the above relationship may be represented by Formula (2) given below.

$$FT^{-1}\left(FT(image) \times F(v) \times G(v) \times (2\pi v_x)^l \times (2\pi v_y)^m \times (2\pi v_z)^n\right) \qquad (2)$$

$$G(v) = \exp(-\frac{v^2\sigma^2}{2}) \qquad (3)$$

$$\left.\begin{aligned} v &= \sqrt{v_x^{\,2} + v_y^{\,2} + v_z^{\,2}} \\ F(v) &= \frac{4\pi \sin(av) - 4\pi av \cos(av)}{v^3} \end{aligned}\right\} \qquad (4)$$

$$\left.\begin{aligned} r &= \sqrt{x^2 + y^2 + z^2} \\ f(r) &= \begin{cases} 1, & \text{if } r \le R \\ 0, & \text{otherwise} \end{cases} \end{aligned}\right\} \qquad (5)$$

where, x, y, z are the three-dimensional axes in real space, and R is the radius of the solid sphere. The polar coordinate representation of the variable (frequency) of the three-dimensional Fourier space is expressed as v= $(\nu_x^2+\nu_y^2+\nu_z^2)^{1/2}$ as indicated in Formula (4) .

[0035] With respect to each function used in Formula (2), the Fourier transformed Gaussian kernel G(v) is shown in

Formula (3) above and the solid sphere model function F(v) is shown in Formula (4) above. The solid sphere model function F(v) shown in Formula (4) may be obtained by Fourier transforming the function F(r)representing a solid sphere shown in Formula (5). The Gaussian kernel function G(v) shown in Formula (3) is used to define the differential range of pixel values of the target image, as in Non-Patent Documents 1 and 2.

[0036] In Formula (2), the part $(2\pi v_x)^l \times (2\pi vy)^m \times (2\pi v_z)^n$ corresponds to the differential processing in Fourier space and a value corresponding to each of the elements Ixx, Ixy, Iyy, Iyz, Izz, and Izx may be calculated by assigning coefficients 1, m, and n corresponding to the respective differential directions in Formula (4) such that l+m+n = 2 (0<1, 0<m, 0<n). For example, the element Ixx which is a second order partial differential value in x direction in the Hessian matrix at a processing target pixel of the three-dimensional multiple resolution images Msi may be calculated by assigning l=2 in x direction and m=n=0 in Y and Z directions in Formula (2). Further, the element Ixy in the Hessian matrix at a processing target pixel of the three-dimensional multiple resolution images Msi may be calculated by assigning l=m=1 in X and Y directions and n=0 in Z direction in Formula (2).

[0037] When eigenvalues are obtained by applying eigenvalue decomposition to the Hessian matrix calculated in the manner described above, it is known that a line-like structure has characteristics that two of the three eigenvalues are relatively large while the remaining one is close to 0, as shown in Figure 3. For example, eigenvalues of Formula (1) have the relationship of Formula (6) with a target tissue of a line-like structure. It is assumed that the eigenvalues are $|\lambda_1|<|\lambda_2|<|\lambda_3|$.

Eigenvalues of $\nabla^2 I$: $\lambda_1, \lambda_2, \lambda_3$

$$\left.\begin{array}{l}\lambda 1 \approx 0 \\ \lambda 2 >> 0 \\ \lambda 3 >> 0\end{array}\right\} \quad (6)$$

[0038] Further, it is known that a plate-like structure has characteristics that one of the three eigenvalues is large while the remaining two are close to 0, as shown in Figure 4. For example, eigenvalues of Formula (1) have the relationship of Formula (7) with a target tissue of a plate-like structure.

$$\left.\begin{array}{l}\lambda 1 \approx 0 \\ \lambda 2 \approx 0 \\ \lambda 3 >> 0\end{array}\right\} \quad (7)$$

Still further, it is known that a point-like structure has characteristics that all three eigenvalues are large. For example, eigenvalues of Formula (1) have the relationship of Formula (8) with a target tissue of a point-like structure.

$$\left.\begin{array}{l}\lambda 1 >> 0 \\ \lambda 2 >> 0 \\ \lambda 3 >> 0\end{array}\right\} \quad (8)$$

[0039] Therefore, line-like structureness, plane-like structureness, and point-like structureness may be discriminated from the eigenvalues, and a blood vessel region which is a line-like structure and a bone region which is a plate-like structure may be segmented in the three-dimensional image M0 using the discrimination results.

[0040] The correction section 33 in the present embodiment applies eigenvalue decomposition to the Hessian matrix calculated by the filtering unit 32 and calculates three eigenvalues $\lambda_1, \lambda_2, \lambda_3$ ($|\lambda_1|\leq|\lambda_2|\leq|\lambda_3|$).

[0041] Here, the principle of inhibiting erroneous discrimination according to the present embodiment will be described using Figures 5A, 5B, 5C, 5D and specific correction processing by the correction section 33 based on the principle will be described thereafter.

[0042] Figure 5A shows a solid sphere model function (dash-dot line) and a response of the second order partial differential (solid line) of the solid sphere model function at each x position in x direction in (A), a hollow sphere model function (dash-dot line) and a response of the first order partial differential (broken line) of the hollow sphere model function at each x position in x direction in (B), and a solid sphere model function and a response of the second order partial differential of the solid sphere model function at each x position in x direction corrected using the first order partial differential of the solid sphere model function in (C).

[0043] As illustrated in Figure 5A(A), the second order partial differential of the solid sphere model function in each direction shows response waveforms at two separate positions corresponding to the surface of the solid sphere. If a line segment traversing a structure, such as the diameter of a blood vessel or the like, corresponds to the diameter of the solid sphere represented by the solid sphere model function, two opposite portions of the contour of a structure (both ends of a line segment traversing the structure) in an image correspond respectively to the two positions where the aforementioned response waveforms of the second order partial differential of the solid sphere model function are indicated in each differential direction and large responses (expected responses) may be obtained. Thus, according to the Hessian analysis of the method of Non-Patent Document 2, a structure, such as a blood vessel and the like, may be discriminated.

[0044] In the meantime, if only one position of the response waveform of the second order partial differential of the solid sphere model function in each differential direction corresponds to a contour portion of a structure larger in radius of curvature than the solid sphere in an image, a response of a given magnitude corresponding to the response of the one position can be obtained. The present inventors have presumed that it is a cause of the erroneous discrimination of a structure having substantially the same diameter as the diameter of the solid sphere that no distinction cannot be made between the response having a given magnitude and the expected response. Then, the present inventors have found out that the erroneous discrimination can be eliminated by cancelling out the response waveform at one position of the second order partial differential of the solid sphere model function in each direction. Then, as illustrated in Figure 5A(A), the second order partial differential of the solid sphere model function in each direction has characteristics that it shows response waveforms at two positions symmetrical with respect to the center. Thus, the present inventors have paid attention to cancel out the response waveform at one position of the second order partial differential matrix of the solid sphere model function by the use of a function having a response waveform substantially identical in shape to the one response waveform with a reversed positive/negative sign at the same position as the position of the one response waveform of the second order partial differential of the solid sphere model function.

[0045] The present embodiment utilizes the fact that the response of first order partial differential of a hollow sphere model function $f_1(r)$ of the same size as the size of the solid sphere in x direction has characteristics that it has a response waveform having a substantially identical shape to the shape of one response waveform of the solid sphere model function with the same positive/negative sign at the same position as the position of the one of the response waveforms of the second order partial differential of the solid sphere model function in x direction and a response waveform having a substantially identical shape to the shape of the other response waveform of the solid sphere model function with a reversed positive/negative sign at the same position as the position of the other waveform of the second order partial differential of the solid sphere model function in x direction, as illustrated in Figure 5A (B), and a first order partial differential value of the hollow sphere model function $f_1(r)$ of the same size as the size of the solid sphere in x direction is used to cancel out the response waveform at one position of the second order partial differential of the solid sphere model in x direction.

[0046] That is, addition of the response of the filtering using the second order partial differential of the solid sphere model function in x direction and the response of the filtering using the first order partial differential of the hollow sphere model function representing the hollow sphere having substantially the same radius as the radius of the solid sphere represented by the solid sphere model function will result in that the response waveforms on the negative side in x direction are cancelled out as they have reverse signs at the same position and the response waveforms on the positive side in x direction are reinforced as they have the same sign at the same position, and a response waveform appears only one position on the positive side in x direction, as shown in Figure 5A(C).

[0047] Figure 5B(A) shows a solid sphere model function f(r) and (B) shows a response of the second order partial differential of the solid sphere model function f(r) in x direction. Figure 5C(A) shows a hollow sphere model function $f_1(r)$ and (B) shows a response of the first order partial differential of the hollow sphere model function $f_1(r)$ in x direction. Figure 5D shows a result of the addition of the response of the second order partial differential of the solid sphere model function shown in Figure 5B(B) and the response of the first order partial differential of the hollow sphere model function $f_1(r)$ shown in Figure 5C. In Figures 5B to D, each response described above is shown by a plurality of x-y plan views having different z coordinate values of equal intervals, and the plurality of x-y plan views is arranged in descending order of z coordinate values from the top in the vertical direction.

[0048] In the x-y plan views representing each response, the higher (whiter) the brightness, the greater the response in the positive direction and the darker (blacker) the brightness, the greater the response in the negative direction. The response waveform of the adjoining positive peak and negative peak located on the negative side of the center of the solid sphere shown in Figure 5B(B) and the response waveform of the adjoining negative peak and positive peak located on the negative side of the center of the solid sphere shown in Figure 5C(B) mutually cancel out, and it is known that no response waveform appears on the negative side of the center of the solid sphere in Figure 5D. Likewise, the response waveform on the negative side of the center of the solid sphere may be cancelled out in each direction.

[0049] In the present invention, the correction unit 33 corrects eigenvalues of the Hessian matrix using a first order partial differential vectors of the hollow sphere model function such that the response waveform at one position of the solid sphere model function f(r) in each direction is cancelled out based on the aforementioned principle. A specific correction method will be described hereinafter.

[0050] The second order partial differential matrix and the first order partial differential vector of the solid sphere model function on the aforementioned image, in the present embodiment, the correction section 33 first calculates first order partial differential vectors to be used for correction using Formula (9). More specifically, as shown in Formula (9), a Fourier transformed Gaussian kernel function G (v) and a first order partial differential filter of a Fourier transformed hollow sphere model function $F_1(v)$ shown in Formula (11) are convoluted with a processing target pixel of a Fourier transformed three-dimensional multiple resolution images Msi, and the first order partial differential vectors to be used for the eigenvalue correction of the Hessian matrix are calculated by performing reverse Fourier transform of the filtering result. Here, the hollow sphere model function f_1 (v) used in Formula (11) may be obtained by performing Fourier transform on the hollow sphere model function f(r) defined by the delta function $\delta(r-R_4)$ represented by Formula (10).

$$FT^{-1}\left(FT(\text{image}) \times F_1(v) \times G(v) \times (2\pi v_x)^l \times (2\pi v_y)^m \times (2\pi v_z)^n\right) \qquad (9)$$

$$\left.\begin{aligned} f_1(r) &= \delta(r - R_4) \\ r &= \sqrt{x^2 + y^2 + z^2} \end{aligned}\right\} \qquad (10)$$

$$\left.\begin{aligned} F_1(v) &= \frac{\sin(R_4 v)}{R_4 v} \\ v &= \sqrt{v_x^2 + v_y^2 + v_z^2} \end{aligned}\right\} \qquad (11)$$

[0051] In Formula (9), the part $(2\pi v_x)^l \times (2\pi v_y)^m \times (2\pi v_z)^n$ corresponds to the differential processing in Fourier space and a value corresponding to each of the elements ρ_1, ρ_2, ρ_3 of the first order partial differential vectors may be calculated by assigning coefficients 1, m, n corresponding to the respective differential directions in Formula (9) such that $l+m+n = 1$ ($0<1$, $0<m$, $0<n$).

[0052] In Formula (9), the filtering is performed in Fourier space, but the filtering may be performed in real space. In Formula (10), x, y, z are coordinates of three-dimensional space, r is the polar coordinate representation thereof, and R_4 is the radius of the hollow sphere. In the present embodiment, the radius R_4 of the hollow sphere represented by the hollow sphere model function is the same as the radius R of the solid sphere represented by the solid sphere model function. Note that the radius R_4 of the hollow sphere may be larger or smaller than the radius R of the solid sphere within the range having an effect of cancelling out the response waveform at one position of the second order partial differential of the solid sphere model function, but it is preferable that the radius R_4 corresponds strictly to the radius R of the solid sphere in order to make the response waveform of the first order differential of the hollow sphere model function correspond more to the response waveform at one position of the second order partial differential of the solid sphere model function.

[0053] As the first order partial differential vectors (ρ_1, ρ_2, ρ_3) of X direction, Y direction, and Z direction calculated in the manner described above are deviated from the directions of the eigenvectors e_1, e_2, e_3 of the eigenvalues λ_1, λ_2, λ_3, the correction unit 33 calculates first order partial differential vectors ρ_1', ρ_2', ρ_3' corresponding to the directions of the eigenvectors e_1, e_2, e_3 by Formula (12) given below. Note that, eigenvectors of the evaluation matrix is taken as $e_1 = (x_1, y_1, z_1)$, $e_2 = (x_2, y_2, z_2)$, $e_3 = (x_3, y_3, z_3)$, and the first order partial differential vectors of the function representing the hollow sphere are taken as (ρ_1, ρ_2, ρ_3).

$$\left.\begin{aligned} \rho_1' &= \rho_1 \times x_1 + \rho_2 \times y_1 + \rho_3 \times z_1 \\ \rho_2' &= \rho_1 \times x_2 + \rho_2 \times y_2 + \rho_3 \times z_2 \\ \rho_3' &= \rho_1 \times x_3 + \rho_2 \times y_3 + \rho_3 \times z_3 \end{aligned}\right\} \quad (12)$$

[0054] Then, the eigenvalues of the Hessian matrix are corrected as shown in Formula (13). Note that the eigenvalues of the evaluation matrix are taken as λ_1, λ_2, λ_3 and α is taken as a predetermined coefficient. Here, α is a predetermined weight designed so as to cancel out one of the response waveforms most that appear at two positions equidistance from the origin of the second order partial differential of solid sphere model function (center of the solid sphere). The weight is designed according to the radius R of the solid sphere and the kernel size s.

$$\left.\begin{aligned} \lambda_1' &= \begin{cases} 0 & \text{if } |\lambda_1| < |\alpha\rho_1'| \\ \min\left(|\lambda_1 + \alpha\rho_1'|, |\lambda_1 - \alpha\rho_1'|\right) & \text{otherwise} \end{cases} \\ \lambda_2' &= \begin{cases} 0 & \text{if } |\lambda_2| < |\alpha\rho_2'| \\ \min\left(|\lambda_1 + \alpha\rho_2'|, |\lambda_1 - \alpha\rho_2'|\right) & \text{otherwise} \end{cases} \\ \lambda_3' &= \begin{cases} 0 & \text{if } |\lambda_3| < |\alpha\rho_3'| \\ \min\left(|\lambda_3 + \alpha\rho_3'|, |\lambda_3 - \alpha\rho_3'|\right) & \text{otherwise} \end{cases} \end{aligned}\right\} \quad (13)$$

[0055] In Formula (13), λ_1+$\alpha\rho$' represents a response when a correction for cancelling out one (e.g., the response waveform on the left side of Figure 5A(A)) of the two response waveforms symmetrical with respect to the center of the solid sphere model function is performed in each differential direction. λ_1-$\alpha\rho$' represents a response when a correction for cancelling out the other one (e.g., the response waveform on the right side of Figure 5A(A)) of the two response waveforms. As shown in Formula (13), the eigenvalue λ_1' is corrected to a value smaller of the two responses |λ_1+$\alpha\rho$'| and |λ_1-$\alpha\rho$'|. As a result, if either one of the |λ_1-$\alpha\rho$'| and |λ_1-$\alpha\rho$'| is small, the value of each eigenvalue λ_1' becomes small while the value of each eigenvalue λ_1' becomes large only when each of the |λ_1-$\alpha\rho$'| and |λ_1-$\alpha\rho$'| is large. The same is true for λ_2' and λ_3'.

[0056] In the case where a structure is erroneously detected by the conventional method, that is, in the case where a response is obtained only one of the two response waveforms symmetrical with respect to the center of the solid sphere model function, if either one of the responses of the solid sphere model function is cancelled out, at least one of the values of the |λ_1-$\alpha\rho$'| and |λ_1-$\alpha\rho$'| becomes small and the value min (|λ_1-$\alpha\rho$'|, |λ_1-$\alpha\rho$'|) becomes small. On the other hand, in the case where a structure is correctly detected, that is, in the case where two opposite portions of the contour of a structure (both ends of a line segment traversing the structure) in an image correspond respectively to the two positions where the response waveforms of the second order partial differential of the solid sphere model function are indicated with respect to each differential direction, even when either one of the two response waveforms symmetrical with respect to the center of the solid sphere model function, a large response may be obtained based on the other response waveform, so that the minimum value of the two responses |λ_1-$\alpha\rho$'| and |λ_1-$\alpha\rho$'| becomes large. Therefore, the case where a structure is erroneously detected, that is, the case where the response is obtained only for either one of the two response waveforms may be discriminated and structures may be discriminated accurately. Formula (13) illustrates an example case where the correction is performed using the absolute values of the responses, but the correction may performed without using the absolute values. Further, the discrimination of a target structure may be made by using the |λ_1-$\alpha\rho$'| and |λ_1-$\alpha\rho$'| separately without using the min (|λ_1-$\alpha\rho$'|, |λ_1-$\alpha\rho$'|).

[0057] Then, the evaluation unit 34 uses corrected eigenvalues λ_1', λ_2', λ_3' instead of the eigenvalues λ_1, λ_2, λ_3 in Formulae (14) and (15) given below and, using the values R_A, R_B, R_C calculated by this, calculates an evaluation value L0 (lineness) of line-like structureness and the evaluation value P0 (planeness) of plane-like structureness at each pixel of the three-dimensional multiple resolution image Msi. As described above, the evaluation unit 34 may discriminate a point-like structure, a line-like structure, and a plane-like structure based on the corrected eigenvalues λ_1' , λ_2', λ_3' of the Hessian matrix and eigenvectors e_1, e_2, e_3, but it is not necessarily to evaluate all of the point-like structure, line-like structure, and plane-like structure, and may perform discrimination for only some of the point-like structure, line-like structure, and plane-like structure according to the requirements of the specifications. As the present embodiment intends to extract a line-like structure and a plane-like structure from a medical image, evaluation values are calculated only for the line-like structure and the plane-like structure.

$$\mathrm{L0(Lineness)} = \left(1-\exp\left(-\frac{R_A{}^2}{2a^2}\right)\right)\exp\left(-\frac{R_B{}^2}{2b^2}\right)\left(1-\exp\left(-\frac{S_{2nd}{}^2}{2c^2}\right)\right) \quad (14)$$

$$\mathrm{P0(Planeness)} = \exp\left(-\frac{R_A{}^2}{2e^2}\right)\exp\left(-\frac{R_C{}^2}{2f^2}\right)\left(1-\exp\left(-\frac{S_{2nd}{}^2}{2g^2}\right)\right) \quad (15)$$

[0058] Note that a to h in Formulae (14) and (15) are constants. Further, R_A, R_B, R_C are calculated by Formulae (16) to (19) given below. Still further, S_{2nd} is the power of the second order partial differential value and calculated by Formula (19) given below.

$$R_A = \frac{|\lambda_2|}{|\lambda_3|} \quad (16)$$

$$R_B = \frac{|\lambda_1|}{\sqrt{\lambda_2\lambda_3}} \quad (17)$$

$$R_C = \frac{\sqrt{\lambda_1\lambda_2}}{|\lambda_3|} \quad (18)$$

$$S_{2nd} = \sqrt{\lambda_1{}^2 + \lambda_2{}^2 + \lambda_3{}^2} \quad (19)$$

[0059] An example response obtained by performing correction processing on a sample image representing a line-like structure by the correction unit 33 after filtering processing by the filtering unit 32 will be illustrated using Figures 6A and 6B. Figure 6A is a drawing for explaining a response in the case where the size of the structure (length of a line segment traversing the structure) substantially corresponds to the size of the solid sphere model function (diameter of the solid sphere) . Figure 6A(A) shows an X-y plan view of luminance values of the line-like structure. Figure 6A(B) shows an x-y plan view of a response obtained by performing filtering processing on the image data of Figure 6A(A) using the second order partial differential of the solid sphere model function in x direction. Figure 6A(C) shows an x-y plan view of a response obtained by performing filtering processing on the image data of Figure 6A(A) using the first order partial differential of the hollow sphere model function in x direction. Figure 6A(D) shows an x-y plan view of a response obtained by performing filtering processing on the image data of Figure 6A(A) using the second order partial differential of the solid sphere model function in x direction corrected using the response obtained by the first order partial differential filtering of the hollow sphere in x direction.

[0060] As shown in Figure 6A(D), a peak of line-like structureness appears near the center of the line-like structure, and it is known that a favorable response for discriminating a line-like structure is obtained by the image processing according to the present embodiment.

[0061] Figure 6B is a drawing for explaining a response in the case where the size of a structure in x direction (length of a line segment traversing the structure) is greater than the diameter of the solid sphere of the solid sphere model function. Figure 6B(A) shows an X-y plan view of luminance values of the line-like structure. Figure 6B(B) shows an x-y plan view of a response obtained by performing filtering processing on the image data of Figure 6B(A) using the second order partial differential of the solid sphere model function in x direction. Figure 6B(C) shows an x-y plan view of a response obtained by performing filtering processing on the image data of Figure 6B(A) using the first order partial differential of the hollow sphere model function in x direction. Figure 6B(D) shows an x-y plan view of a response obtained by performing filtering processing on the image data of Figure 6B(A) using the second order partial differential of the solid sphere model function in x direction corrected using the response obtained by the first order partial differential filtering of the hollow sphere in x direction.

[0062] Whereas, Figure 6B(B) that shows an evaluation value corresponding to the method of Non-Patent Document 2, certain responses appear at two positions (two negative peaks) which causes erroneous discrimination, Figure 6B(D) that shows a response obtained by the method of the present embodiment, the response is very weak and it is known that the response that causes erroneous discrimination is suppressed.

[0063] Figure 6A(D) and Figure 6B(D) show responses when an element (Ixx) of the Hessian matrix shown in Formula (1) is applied instead of λ_1 of Formula (13). The processing for calculating the eigenvalues performs only linear transform of the space in Hessian matrix and does not influence on the value of the response. Therefore, instead of the eigenvalue λ_1 obtained by performing eigenvalue analysis on the Hessian matrix in Formula (13) described above, correction of the element of the Hessian matrix before being subjected to eigenvalue analysis allows the effect of cancelling out the response that causes erroneous detection to be observed by the corrected element.

[0064] In the present embodiment, an evaluation value L0 of line-like structureness and an evaluation value P0 of plane-like structureness are calculated in multiple resolution three-dimensional images Msi having different resolutions. The calculated evaluation values L0, P0 serve as evaluation values at a corresponding pixel position of the original three-dimensional image M0, but the evaluation values are calculated at corresponding pixel positions of all of the multiple resolution three-dimensional images Msi.

[0065] The segmentation unit 40 segments a blood vessel region and the region other than the blood vessel region of the three-dimensional image M0 based on the evaluation value L0 of line-like structureness and the evaluation value P0 of plane-like structureness calculated by the discrimination unit 30. More specifically, the blood vessel region is set as a target region while the region other than the blood vessel region is set as a background region, then a discrimination region of a predetermined pixel size is set at all pixel positions within the three-dimensional image M0, and the discrimination regions are divided into target regions and background regions using a graph cut segmentation method. The graph cut segmentation method is described in Yuri Y. Boykov, Marie-Pierre Jolly, "Interactive Graph Cuts for Optimal Boundary and Region Segmentation of Objects in N-D images", Proceedings of "International Conference on Computer Vision", Vancouver, Canada, July 2001 vol.I, pp.105-112. In the present embodiment, the segmentation unit 40 segments the blood vessel region and the region other than the blood vessel region of the three-dimensional image M0 by the method which is the same as the method described in Japanese Unexamined Patent Publication No. 2011-206531, which is a past application by the present inventor, based on the evaluation value L0 of line-like structureness and evaluation value P0 of plane-like structureness calculated by the discrimination unit 30.

[0066] The display unit 50 is a monitor, a CRT screen, or the like that displays a two-dimensional image, a three-dimensional image, and the like. In the present embodiment, a line-like structure or a plane-like structure may be overviewed and the continuity thereof may be visualized by performing a volume rendering display of the line-like structure segmented as the target region on the display unit 50.

[0067] The input unit 60 includes a key board, a mouse, and the like.

[0068] Next, processing performed in the present embodiment will be described. Figure 7 is a flowchart of processing performed in the present embodiment. First, the image obtaining unit 10 generates a three-dimensional image M0 from two dimensional images captured by the X-ray CT system 2 (step ST1) . Then, the detection region setting unit 20 makes the three-dimensional image M0 isotropic and generates a plurality of three-dimensional multiple resolution images Msi having different resolutions by performing a multiple resolution transformation on the three-dimensional image M0 (step ST2).

[0069] Next, the filtering unit 32 of the discrimination unit 30 performs filtering on each of the three-dimensional multiple resolution images Msi using second order partial differential of a solid sphere model function and a Gaussian kernel function and calculates a Hessian matrix at each pixel position (step ST3) . Then, the correction unit 33 corrects an eigenvalue of the aforementioned Hessian matrix using a first order partial differential vector of the solid sphere model function (step ST4). Next, the evaluation unit 34 calculates an evaluation value L0 of line-like structureness and an evaluation value P0 of plane-like structureness based on the corrected eigenvalue and the eigenvector (step ST5).

[0070] Next, the segmentation unit 40 divides the three-dimensional image M0 into a target region (blood vessel region) and a background region using the aforementioned graph cut segmentation method (step ST6) . Then, the display unit 50 performs a volume rendering display of the divided target region and the background region (step ST7) and the processing is completed.

Examples in which the image processing of the present embodiment is applied to blood vessel discrimination in a chest CT image of an actual patient and the conventional method is applied to blood vessel discrimination in the same CT image are shown in Figures 8A and 8B. In Figures 8A and 8B, application examples of the conventional image processing (comparative examples) are shown on the left and application examples of the present embodiment are shown on the right. Figure 8A shows pseudo three-dimensional images in which discriminated blood vessel regions are rendered by a volume rendering method while Figure 8B represents a portion of Figure 8A in an enlarged axial tomographic image.

[0071] As shown in Figure 8A, the conventional method displays many blood vessels due to erroneous discrimination while in the application example of the present embodiment, it is known that erroneous discrimination is largely suppressed and blood vessels are extracted accurately. Further, in the comparative example (left) in Figure 8B, a portion which is erroneously discriminated as being likely a line-like structure is shown in light gray inside of the blood vessel, but in the application example of the present embodiment (right), it is known that the portion erroneously discriminated as being likely a line-like structure inside of the blood vessel (light gray portion) is not observed.

[0072] As described above, according to the present embodiment, first order partial differential vectors of a function having a response waveform at the same position as the position of one response waveform of the second order partial differential of a solid sphere model function which is substantially identical in shape to the one response waveform with a reversed positive/negative sign is calculated, and a correction is made such that, of the response waveforms of the second order partial differential of the solid sphere model function in each direction which appear at two positions symmetrically separated with respect to the center of the solid sphere, a response waveform appearing at one position is cancelled out using values obtained by projecting the first order partial differential vectors onto the directions of the Hessian matrix. This may inhibit erroneous discrimination that occurs when the contour of a structure corresponds to only one position where a response waveform of the second order partial differential of the solid sphere model function in any one of the directions appears and the accuracy of the evaluation values may be improved. Consequently, a structure included in an image may be discriminated more accurately based on the evaluation values. In image filtering processing in Fourier space, it is generally not easy to perform correction to change only a certain undesirable value of the filter coefficients, by focusing attention on the response characteristics of the second order partial differential of the solid sphere model function and using the response characteristics of the first order partial differential of the hollow sphere model function, as in the present embodiment, the problem of erroneous discrimination in the method of Non-Patent Document 1 may be eliminated.

[0073] Further, as the "first order" partial differential vectors of the hollow sphere model function are used for correction in the first embodiment, once the partial differential values in x, y, z directions are calculated, a partial differential value in any direction may be calculated. That is, the use of the "first order" partial differential vectors of the solid sphere model function by projecting onto directions of the eigenvectors of the second order partial differential, the correction of the second order partial differential in any direction is possible. As a result, the increase in the amount of calculation for correction is relatively small and computers with various processing power may be used as the image processing apparatus of the present embodiment.

[0074] Further, as the response waveform of the first partial differential of the hollow model function at one position in each direction has a reversed positive/negative sign to the sign of the response waveform at one position of the second partial differential of the solid sphere model function in each direction with a very similar shape, the response waveform at one position of the second order partial differential of the solid sphere model function may be cancelled out favorably.

[0075] Still further, in the first embodiment described above, with respect to functions representing solid spheres of a plurality of sizes with radius R, Hessian matrices are calculated, then based on the plurality of Hessian matrices, corrections for suppressing responses that cause erroneous discrimination are made, and evaluation values of line-like structureness and plane-like structrureness are calculated at each pixel position. Consequently, a structure of a size corresponding to each solid sphere size may be evaluated properly. In addition, if the target region is segmented based on the evaluation values, as in the first embodiment described above, structures of a plurality of sizes may be segmented properly as the target regions.

[0076] As the method for performing Hessian analysis on structures of different sizes, a method that performs Hessian analysis on the images of a plurality of different resolutions by applying a constant kernel size "σ" and a constant radius R of solid sphere model function may be used, as in the present embodiment, or a method that performs Hessian analysis on an image of a constant resolution by applying different constant kernel sizes "σ" and different radii R of solid sphere model functions may be used. For example, it is conceivable that the length of a line segment traversing a detection target structure, such as the long axis and the short axis of the structure, are obtained in advance from experimentally obtained data and the resolution of the three-dimensional multiple resolution image Msi or the kernel size "σ" and the radius R are set such that the length of a line segment traversing a detection target structure corresponds to the size of the radius R.

[0077] In the first embodiment described above, both the evaluation value L0 of line-like structureness and the evaluation value P0 of plane-like structureness are calculated, but only either one of the evaluation value L0 of line-like structureness and the evaluation value P0 of plane-like structureness may be calculated.

[0078] A second embodiment of the present invention will be described herein below. In the second embodiment, the correction processing differs from the correction processing of the first embodiment but, other than that, the second embodiment is identical to the first embodiment and the function of each functional block is also common. Hereinafter, a description will be made focusing on the difference from the first embodiment and the description for the identical points will be omitted here.

[0079] In order to cancel out the response waveform at one position of response waveforms at two positions by the second order partial differential of the solid sphere model function described above, in the second embodiment, the attention is focused on the characteristics that the response waveform of the second order partial differential of the solid sphere model function located on the negative side of the x direction has one positive peak and one adjoining negative peak from the negative side of the x direction, while the response waveform located on the positive side of the x direction has one negative peak and one adjoining positive peak from the negative side of the x direction, and it is found that a response waveform located at the same position as the position of one of the response waveforms with a reversed positive/negative sign to the sign of the one of the waveforms and substantially the same shape as the shape of the one of the waveforms can be generated by combining first order partial differential of a solid sphere model function f_2 (r) (second solid sphere model function) of a solid sphere slightly smaller than the solid sphere in each direction and first order partial differential of a solid sphere model function f_3 (r) (third solid sphere model function) of a solid sphere slightly larger than the solid sphere in each direction. Note that the solid sphere model function used in filtering processing by the filtering unit 32 is referred to as the first solid sphere model function here for the purpose of distinction.

[0080] Figure 9A(A) shows a response of first order partial differential of the second solid sphere model function f_2(r) having a radius R_2 in x direction, Figure 9A(B) shows a response of first order partial differential of the third solid sphere model function f_3(r) having a radius R_3 in x direction, and Figure 9A(C) shows a response obtained by adding the first order partial differential of the third solid sphere model function f_3 (r) in x direction to a first order partial differential obtained by reversing the positive/negative sign of the second solid sphere model function f_2(r) in x direction.

[0081] As illustrated in Figures 9A(A), (B), the responses of the first order partial differential of the second and the third solid model functions f2(r), f3(r) have characteristics that they have response waveforms having one positive peak on the negative side of the center of the solid sphere and one negative peak on the positive side of the center of the solid sphere, and each response waveform appears symmetrically with respect to the center.

[0082] By combining a first order partial differential obtained by reversing the positive/negative sign of the first order partial differential of the solid sphere model function f_2(r) in x direction shown in Figure 9A(A) with the first order partial differential of the solid sphere model function f_3 (r) in x direction shown in Figure 9A(B), the response in x direction shown in Figure 9A(C) may be obtained. Figure 9A(C) has response waveforms at two positions symmetrical with respect to the center of the solid sphere and the response waveforms have characteristics that the response waveform located on the negative side of x direction has one negative peak and one adjoining positive peak from the negative side of x direction while the response waveform located on the positive side of x direction has one negative peak and one adjoining positive peak from the negative side of x direction.

[0083] That is, if the responses of the first order partial differentials of the second and third solid sphere model functions f_2(r), f_3(r) shown in Figure 9A(C) are combined to the filtering by the second order partial differential matrix of the solid sphere model function in each direction, the response waveforms on the positive side in each direction are cancelled out as they have reverse signs at the same position, while the response waveforms on the negative side in each direction are reinforced as they have the same sign at the same position, thereby resulting in that a response waveform appears only at one position on the positive side of x direction, as shown in Figure 5A(C).

[0084] In the present embodiment, in order to cancel out the response waveform at one position of the second order partial differential of the first solid sphere model function, the second radius R_2 is the same as the distance from the center of the solid sphere to the positive peak of the response waveform located on the positive direction in the second order partial differential of the first solid sphere model function, while the third radius R_3 is the same as the distance from the center of the solid sphere to the negative peak of the response waveform located on the positive direction in the second order partial differential of the first solid sphere model function. With respect to the second radius R_2 (third radius R_3), "the distance from the center to the positive (negative) peak" may be greater or smaller than the second radius R_2 (third radius R_3) within the range having an effect of cancelling out the response waveform at one position of the second order partial differential of the aforementioned solid sphere model function in each direction. Preferably, however, the second radius R_2 (third radius R_3) corresponds strictly to the distance from the center to the positive (negative) peak in order to make the response waveform of combined first order partial differentials of the second and the third solid sphere model functions in each direction correspond more to the response waveform of the second order partial differential of the solid sphere model function, as in the present embodiment.

[0085] The responses of the first order differentials of the second and the third solid sphere model functions in x direction will be described with reference to Figure 9B. Figure 9B(A) shows a response of the first order partial differential of the second solid sphere model function f_2(r) in x direction, Figure 9B(B) shows a response of the first order partial differential of the third solid sphere model function f_3(r) in x direction, and Figure 9B(C) shows a response when the first order partial differential of the solid sphere model function f_3(r) is added to a first order partial differential obtained by reversing the positive/negative sign of the first order partial differential of the second solid sphere model function f_2(r) in x direction. In Figure 9B, each response described above is shown by a plurality of x-y plan views having different z coordinate values of equal intervals, and the plurality of x-y plan views is arranged in descending order of z coordinate values from the top in the vertical direction. In each of the x-y plan views in Figure 9B, the higher (whiter) the brightness, the greater the response in the positive direction and the darker (blacker) the brightness, the greater the response in the negative direction.

[0086] It is known that, in the response waveform on the negative side shown in Figure 9B(C), the negative peak located on the negative side of the center of the first order partial differential of the second solid sphere model function in x direction shown in Figure 9B(A) and the negative peak located on the negative side of the center of the first order partial differential of the third solid sphere model function in x direction shown in Figure 9B(B) are shifted and overlapped, thereby forming a waveform in which a negative peak and a positive peak are adjoining from the negative direction. Further, it is known that, in the response waveform on the positive side shown in Figure 9B(C), the positive peak located on the positive side of the center of the first order partial differential of the second solid sphere model function in x direction shown in Figure 9B(A) and the positive peak located on the positive side of the center of the first order partial differential of the third solid sphere model function in x direction shown in Figure 9B(C) are shifted and overlapped, thereby forming a waveform in which a negative peak and a positive peak are adjoining from the negative direction. If the second order partial differential of the first solid sphere model function in x direction shown in Figure 5C(B) by combining the first order partial differentials of the first and the second solid sphere model functions so as to show the response of Figure 9B(C), the response waveform on the negative side of the center of the solid sphere may be cancelled out, as illustrated in Figure 5D.

[0087] In the second embodiment, the correction unit 33 corrects the Hessian matrix such that only the response at one position of the first solid sphere model function f(r) is cancelled out using each first order partial differential of the second and the third solid sphere model functions based on the aforementioned principle. A specific correction method will be described hereinafter.

[0088] First, with respect to the solid sphere model function of the second radius R_2, the correction unit 33 calculates first order partial differential vectors using the second radius R_2 in Formula (2) instead of radius R. In Formula (2), the part $(2\pi\nu_x)^l \times (2\pi\nu y)^m \times (2\pi\nu_x)^n$ corresponds to the differential processing in Fourier space, and each of first order partial differential vectors (S_x, S_y, S_z) calculated with respect to the second solid sphere model function $f_2(r)$ may be calculated by substituting the coefficients 1, m, n corresponding to the respective differential directions to Formula (9) such that $l+m+n = 1$ $(0<1, 0<m, 0<n)$. Likewise, the correction unit 33 calculates the first order partial differential vectors (t_x, t_y, t_z) with respect to the third solid sphere model function $f_3(r)$ by using the third radius R_3 in Formula (2) instead of radius R. Then, each of the first order partial differential vectors (s_x, s_y, s_z) calculated with respect to the second solid sphere model function $f_2(r)$ and each of the first order partial differential vectors (t_x, t_y, t_z) calculated with respect to the third solid sphere model function $f_3(r)$ are weight added to calculate $(\rho_1, \rho_2, \rho_3) = (s_x-\beta t_x, s_y-\beta t_y, s_z-\beta t_z)$.

[0089] In Formula (2), the filtering is performed in Fourier space, but the filtering may be performed in real space.

[0090] As the first order partial differential vectors (ρ_1, ρ_2, ρ_3) of X direction, Y direction, and Z direction calculated in the manner described above are deviated from the directions of the eigenvectors e_1, e_2, e_3 of the eigenvalues $\lambda_1, \lambda_2, \lambda_3$, the correction unit 33 calculates first order partial differential vectors $\rho_1', \rho_2', \rho_3'$ corresponding to the directions of the eigenvectors e_1, e_2, e_3 by Formula (12) given below.

[0091] Then, the eigenvalues of the Hessian matrix are corrected based on Formula (13), as in the first embodiment. Note that the eigenvalues of the evaluation matrix are taken as $\lambda_1, \lambda_2, \lambda_3$ and α, β are taken as predetermined coefficients. Here, α, β are predetermined weights designed so as to cancel out one of the response waveforms most that appear at two positions equidistance from the origin of the second order partial differential of solid sphere model function (center of the solid sphere). These weights are designed according to the radius R of the solid sphere and the kernel size s.

[0092] Then, as in the first embodiment, the evaluation unit 34 uses eigenvalues $\lambda_1', \lambda_2', \lambda_3'$ instead of the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ in Formulae (14) and (15) given below and, using the values R_A, R_B, R_C calculated by this, calculates an evaluation value L0 (lineness) of line-like structureness and the evaluation value P0 (planeness) of plane-like structureness at each pixel of the three-dimensional multiple resolution images Msi.

[0093] Also in the second embodiment, as in the first embodiment, first order partial differential vectors of a function (function of combined first order partial differentials of solid sphere model functions of two different sizes) having a response waveform at the same position as the position of one response waveform of the second order partial differential of a solid sphere model function which is substantially identical in shape to the one response waveform with a reversed positive/negative sign is calculated, and a correction is made such that, of the response waveforms of the second order partial differential of the solid sphere model function in each direction which appear at two positions symmetrically separated with respect to the center of the solid sphere, a response waveform appearing at one position is cancelled out using values obtained by projecting the first order partial differential vectors onto the directions of the Hessian matrix. Consequently, as in the first embodiment, erroneous discrimination that occurs when the contour of a structure corresponds to only one position where a response waveform of the second order partial differential of the solid sphere model function in any one of the directions appears to be inhibited, whereby the accuracy of the evaluation values may be improved, although the amount of calculation for correction processing by the correction unit 33 is slightly increased as the second embodiment uses the first order differential of each of the solid sphere model functions of two different sizes in correction while the method of the first embodiment uses the first order differential of the solid sphere model function of one size in correction.

[0094] Further, in the second embodiment, the second radius R_2 corresponds to the length from the center of the solid sphere to the positive peak or the length from the center of the solid sphere to the negative peak, whichever is longer, while the third radius R_3 corresponds to the length from the center of the solid sphere to the positive peak or the length from the center of the solid sphere to the negative peak, whichever is shorter. Therefore, the effect of cancelling out the response waveform more corresponds to one of the response waveforms of the first solid sphere in which the positive peak and the negative peak are adjoining, and this may preferably realize suppression of the response waveform that causes erroneous discrimination.

[0095] Also in the second embodiment, it is preferable that, with respect to functions representing the solid sphere with radius R in a plurality of sizes, Hessian matrices are calculated, then based on the plurality of Hessian matrices, corrections to suppress responses that cause erroneous discrimination are made, and evaluation values of line-like structureness and plane-like structrureness are calculated at each pixel position. In this case, a structure of a size corresponding to each kernel size may be evaluated properly. For that purpose, the image processing of the second embodiment may be performed on images of a plurality resolutions using the first solid sphere model function with the constant radius R or the image processing of the second embodiment may be performed on an image of one resolution by changing the first radius R and using the first solid sphere model functions of a plurality of sizes of first radius R.

[0096] The image processing method according to each embodiment described above is applicable to the following image processing apparatus for direction discrimination. For example, the image processing apparatus for direction discrimination may be configured not to include the segmentation unit 40, the evaluation unit 34, and the display unit 50 in the first embodiment, but to include a direction discrimination unit instead. As an example of such processing apparatus, the direction discrimination unit may be configured in the following manner with the image obtaining processing performed by the image obtaining unit 10, the detection region setting processing performed by the detection region setting unit 20, and the filtering processing performed by the filtering unit 32 being identical to those of the first embodiment and the function of each functional block also being common.

[0097] The direction discrimination unit calculates eigenvalues and eigenvectors e_1, e_2, e_3 by performing eigenvalue analysis on the evaluation matrix calculated by the filtering unit 32, and discriminates a principal axis direction of a line-like structure or a normal direction of a plane-like structure based on the directions of the calculated eigenvectors. More specifically, the direction discrimination unit obtains λ_1, λ_2, λ_3 and eigenvectors e_1, e_2, e_3 of the Hessian matrix obtained by the filtering unit 32 and discriminates the direction pointed by the eigenvector e_1 corresponding to the eigenvalue λ_1 as the axis direction of the line-like structure, if the relationship indicated in Formula (6) is satisfied and, if the relationship indicated in Formula (7) is satisfied, discriminates the direction pointed by the eigenvector e_2 corresponding to the eigenvalue λ_2 as the normal direction of the plate-like structure. Note that the direction discrimination unit may discriminate only either one of the axis direction of a line-like structure according to Formula (6) and the normal direction of a plane-like structure according to Formula (7) based on the eigenvalues and the eigenvectors of the Hessian matrix.

[0098] The axis direction of a line-like structure and the normal direction of a plane-like structure obtained by such an image processing apparatus for direction discrimination as described above may be used, for example, as the axis direction when generating a CPR (Curved Planar Reformation/Reconstruction) image of a tubular structure, such as a blood vessel, a large intestine, or the like, reconstructed from a three-dimensional image by the CPR method, and are favorably used in various types of known processing that requires the axis direction of a line-like structure and the normal direction of a plane-like structure. The axis direction of a line-like structure and the normal direction of a plane-like structure obtained by the present invention may be used for various types of known CPR image generation methods, including, for example, Armin Kanitsar, Dominik Fleischmann, Rainer Wegenkittl, Petr Felkel, Eduard Groller "CPR - Curved Planar Reformation", IEEE Visualization, 2002.

[0099] As the image is a medical image and the structure is a blood vessel in each embodiment described above, the accuracy of discrimination of structures in medical images, in which erroneous discrimination has occurred many times due to the inclusion of blood vessels of various diameters, may be improved significantly.

[0100] Further, in each embodiment described above, the filtering unit performs filtering using a second order partial differential matrix of a function representing a solid sphere and filtering using a first order partial differential matrix of a function representing a solid sphere in Fourier space, which is preferable as the processing cost and processing speed may be reduced in comparison with the case where the filtering is performed in real space. But, the filtering unit may perform filtering using a second order partial differential matrix of a function representing a solid sphere, filtering using a first order partial differential matrix of a function representing a solid sphere, and filtering using a first order partial differential matrix of a function representing a hollow sphere in real space.

[0101] As described in each aforementioned embodiment, the evaluation unit may discriminate at least one of the point-like local structure, line-like local structure, and plane-like local structure of a structure based on eigenvectors and corrected eigenvalues. Note that the eigenvectors and the eigenvalues, however, may be used to discriminate a structure of any shape, as well as the point-like structure, line-like structure, and plane-like structure.

[0102] In each embodiment described above, discrimination of blood vessel is described as an example of line-like structure, but the discrimination method may also be applied to the other like-like structures, such as bronchus and the like. Further, the discrimination method may also be applied not only to bone but also to the other plane-like structures, such as skin, interlobar membrane, and the like.

[0103] In each embodiment described above, each evaluation processing or direction discrimination processing is performed with a line-like structure and a plane-like structure included in a three-dimensional image M0 as targets, but each evaluation processing or direction discrimination processing may be performed with a line-like structure and a plane-like structure included in a two-dimensional image as targets.

[0104] Further, in each embodiment described above, a line-like structure and a plane-like structure are segmented using a graph cut segmentation method but, of course, other segmentation methods, such as the watershed algorithm and the like, may also be used. The watershed algorithm is a method of segmenting an image like, when water is filled in a terrain in which pixel value information of the image is regarded as height, a boundary is formed between water accumulated in different depressions. Therefore, the line-like structure and the plane-like structure may be segmented by performing appropriate smoothing processing on the evaluation values L0 and P0 of the three-dimensional image M0 and implementing the watershed algorithm.

[0105] It should be appreciated that each embodiment described above is for illustration purposes only, and any of the above descriptions should not be used to interpret the technical scope of the present invention in a limited way.

[0106] In addition, various modifications made to the system configurations, hardware configurations, processing flows, module organizations, user interfaces, specific processing contents, and the like of the embodiments described above without departing from the scope of the present invention as defined by the appended claims are included in the technical scope of the present invention.

Claims

1. An image processing apparatus, comprising:

   a filtering unit (32) that performs filtering on each voxel position in a three-dimensional image by convoluting a filter kernel, which represents a second order partial differential of a function representing a solid sphere, to calculate a Hessian matrix; and
   an evaluation unit (34) that discriminates a structure, which is included in the image and is at least one of a local point-like, a line-like, and a plane-like structure, using eigenvalues and eigenvectors of the Hessian matrix obtained by performing eigenvalue analysis on the calculated Hessian matrix,
   wherein the filtering unit (32) includes a correction unit (33) that performs filtering on each voxel position in the image by convoluting a filter kernel, which represents a first order partial differential of a function representing a hollow sphere having the same radius as the radius of the solid sphere, to calculate a first order partial differential vector, and corrects the eigenvalues of the Hessian matrix (i) by adding projected values, which are obtained by projecting the first order partial differential vector onto directions of the eigenvectors, or by adding the projected values weighted with a predetermined coefficient to the eigenvalues, or (ii) by subtracting the projected values or the projected values weighted with a predetermined coefficient from the eigenvalues to cancel out one of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere.

2. The image processing apparatus as claimed in claim 1, **characterized in that**, if eigenvalues of the Hessian matrix are taken as λ_1, λ_2, λ_3, eigenvectors are taken as $e_1= (x_1, y_1, z_1)$, $e_2= (x_2, y_2, z_2)$, $e_3= (x_3, y_3, z_3)$, and the first order partial differential vectors of the function representing the hollow sphere are taken as (ρ_1, ρ_2, ρ_3), the correction unit (33) carries out the correction to cancel out the one of the response waveforms by correcting the eigenvalues as shown in Formula (13) given below using ρ_1', ρ_2', ρ_3' calculated by Formula (12) given below and a predetermined coefficient α:

$$\left.\begin{aligned} \rho_1' &= \rho_1 \times x_1 + \rho_2 \times y_1 + \rho_3 \times z_1 \\ \rho_2' &= \rho_1 \times x_2 + \rho_2 \times y_2 + \rho_3 \times z_2 \\ \rho_3' &= \rho_1 \times x_3 + \rho_2 \times y_3 + \rho_3 \times z_3 \end{aligned}\right\} \quad (12)$$

$$\left.\begin{aligned} \lambda_1' &= \begin{cases} 0 & \text{if } |\lambda_1| < |\alpha\rho_1'| \\ \min(|\lambda_1 + \alpha\rho_1'|, |\lambda_1 - \alpha\rho_1'|) & \text{otherwise} \end{cases} \\ \lambda_2' &= \begin{cases} 0 & \text{if } |\lambda_2| < |\alpha\rho_2'| \\ \min(|\lambda_2 + \alpha\rho_2'|, |\lambda_2 - \alpha\rho_2'|) & \text{otherwise} \end{cases} \\ \lambda_3' &= \begin{cases} 0 & \text{if } |\lambda_3| < |\alpha\rho_3'| \\ \min(|\lambda_3 + \alpha\rho_3'|, |\lambda_3 - \alpha\rho_3'|) & \text{otherwise} \end{cases} \end{aligned}\right\} \quad (13)$$

3. The image processing apparatus as claimed in claim 1 or 2, **characterized in that** the function representing the hollow sphere is represented by Formula (10) given below:

$$\left.\begin{aligned} f(r) &= \delta(r - R_4) \\ r &= \sqrt{x^2 + y^2 + z^2} \end{aligned}\right\} \quad (10)$$

where, x, y, z are the coordinates of three-dimensional space, r is the polar coordinate representation thereof, and R_4 is the radius of the hollow sphere.

4. An image processing apparatus, comprising:

a filtering unit (32) that performs filtering on each voxel position in a three dimensional image by convoluting a filter kernel, which represents a second order partial differential of a function representing a solid sphere, to calculate a Hessian matrix; and

an evaluation unit (34) that discriminates a structure, which is included in the image and is at least one of a local point-like, a line-like, and a plane-like structure, using eigenvalues and eigenvectors of the Hessian matrix obtained by performing eigenvalue analysis on the calculated Hessian matrix,

wherein the filtering unit (32) includes a correction unit (33) that performs filtering on each voxel position in the image by convoluting a filter kernel, which represents a first order partial differential of a function representing a second solid sphere having a second radius greater than a first radius which is the radius of the first solid sphere, to calculate a further first order partial differential vector, further performs filtering on each voxel position in the image by convoluting a filter kernel, which represents a first order partial differential of a function representing a third solid sphere having a third radius smaller than the first radius, to calculate a further first order partial differential vector, and corrects the eigenvalues of the Hessian matrix (i) by adding projected values, each of which represents a weighted sum of a value which is obtained by projecting the first order partial differential vector onto directions of the eigenvectors and a value which is obtained by projecting the further first order partial differential vector onto the directions of the eigenvectors to the eigenvalues or (ii) by subtracting the projected values from the eigenvalues to cancel out a response waveform at one position of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere.

5. The image processing apparatus as claimed in claim 4, **characterized in that**:

the response waveform at the one position is a waveform in which one positive peak and one negative peak are adjoining to each other;
the second radius corresponds to the length from the center of the first solid sphere to the positive peak or the length from the center of the first solid sphere to the negative peak, whichever is longer; and
the third radius corresponds to the length from the center of the first solid sphere to the positive peak or the length from the center of the first solid sphere to the negative peak, whichever is shorter.

6. The image processing apparatus as claimed in any of claims 1 to 3, **characterized in that** the filtering unit (32) calculates, with respect to functions representing the solid sphere in a plurality of sizes, Hessian matrix by performing filtering with a second order partial differential matrix of a function representing each solid sphere.

7. The image processing apparatus as claimed in claim 4 or 5, **characterized in that** the filtering unit (32) calculates, with respect to functions representing the first solid sphere in a plurality of sizes, Hessian matrix by performing filtering with a second order partial differential matrix of a function representing each of the first solid spheres.

8. The image processing apparatus as claimed in any of claims 1 to 3 and 6, **characterized in that** the filtering unit (32) performs the filtering using the second order partial differential matrix of the function representing the solid sphere in Fourier space.

9. The image processing apparatus as claimed in any of claims 4, 5 and 7, **characterized in that** the filtering unit (32) performs the filtering using the second order partial differential matrix of the function representing the first solid sphere in Fourier space.

10. The image processing apparatus as claimed in any of claims 1 to 9, **characterized in that** the image is a medical image and the structure is a blood vessel.

11. An image processing method, comprising:

a filtering step that performs filtering on each voxel position in a three dimensional image by convoluting a filter kernel, which represents a second order partial differential of a function representing a solid sphere to calculate a Hessian matrix; and
an evaluation step that discriminates a structure which is included in the image and is at least one of a local point-like, a line-like, and a plane-like structure, using eigenvalues and eigenvectors of the Hessian matrix obtained by performing eigenvalue analysis on the calculated Hessian matrix,
wherein the filtering step performs filtering on each voxel position in the image by convoluting a filter kernel, which represents a first order partial differential of a function representing a hollow sphere having the same radius as the radius of the solid sphere to calculate a first order partial differential vector, and corrects the eigenvalues of the Hessian matrix (i) by adding projected values, which are obtained by projecting the first order partial differential vector onto directions of the eigenvectors, or by adding the projected values weighted with a predetermined coefficient to the eigenvalues, or (ii) by subtracting the projected values or the projected values weighted with a predetermined coefficient from the eigenvalues to cancel out one of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere.

12. A recording medium on which is recorded an image processing program that causes a computer to perform:

a filtering step that performs filtering on each voxel position in a three dimensional image by convoluting a filter kernel, which represents a second order partial differential of a function representing a solid sphere, to calculate a Hessian matrix; and
an evaluation step that discriminates a structure which is included in the image and is at least one of a local point-like, a line-like, and a plane-like structure, using eigenvalues and eigenvectors of the Hessian matrix obtained by performing eigenvalue analysis on the calculated Hessian matrix,
wherein the filtering step performs filtering on each voxel position in the image by convoluting a filter kernel, which represents a first order partial differential of a function representing a hollow sphere having the same radius as the radius of the solid sphere, to calculate a first order partial differential vector and corrects the eigenvalues of the Hessian matrix (i) by adding projected values, which are obtained by projecting the first order

partial differential vector onto directions of the eigenvectors, or by adding the projected values weighted with a predetermined coefficient to the eigenvalues, or (ii) by subtracting the projected values or the projected values weighted with a predetermined coefficient from the eigenvalues to cancel out one of response waveforms of the second order partial differential of the function representing the solid sphere in each direction, the response waveforms appearing at two positions symmetrically separated with respect to the center of the solid sphere.

Patentansprüche

1. Bildverarbeitungsvorrichtung, umfassend:

eine Filtereinheit (32), die eine Filterung an jeder Voxel-Position in einem dreidimensionalen Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial zweiter Ordnung einer Funktion darstellt, die eine massive Kugel darstellt, um eine Hesse-Matrix zu berechnen; und
eine Evaluierungseinheit (34), die eine Struktur, die in dem Bild enthalten ist und mindestens eines von einer lokalen punktartigen, einer linienartigen und einer ebenenartigen Struktur ist, unter Verwendung von Eigenwerten und Eigenvektoren der Hesse-Matrix unterscheidet, die durch Ausführen einer Eigenwert-Analyse an der berechneten Hesse-Matrix erhalten wurde,
wobei die Filtereinheit (32) eine Korrektureinheit (33) umfasst, die eine Filterung an jeder Voxel-Position in dem Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial erster Ordnung einer Funktion darstellt, die eine hohle Kugel darstellt, die den gleichen Radius wie der Radius der massiven Kugel aufweist, um einen partiellen Differenzialvektor erster Ordnung zu berechnen, und die Eigenwerte der Hesse-Matrix korrigiert durch: (i) Addieren projizierter Werte, die durch Projizieren des partiellen Differenzialvektors erster Ordnung auf Richtungen der Eigenvektoren erhalten werden, oder durch Addieren der projizierten Werte, die mit einem zuvor festgelegten Koeffizienten gewichtet wurden, zu den Eigenwerten, oder (ii) durch Subtrahieren der projizierten Werte oder der projizierten Werte, die mit einem zuvor festgelegten Koeffizienten gewichtet wurden, von den Eigenwerten, um eine von Antwortwellenformen des partiellen Differenzials zweiter Ordnung der Funktion, welche die massive Kugel in jeder Richtung darstellt, auszulöschen, wobei die Antwortwellenformen an zwei Positionen erscheinen, die mit Bezug auf die Mitte der massiven Kugel symmetrisch getrennt sind.

2. Bildverarbeitungsvorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass**, wenn Eigenwerte der Hesse-Matrix als $\lambda_1, \lambda_2, \lambda_3$ genommen werden, Eigenvektoren als $e_1 = (x_1, y_1, z_1)$, $e_2 = (x_2, y_2, z_2)$, $e_3 = (x_3, y_3, z_3)$ genommen werden, und die partiellen Differenzialvektoren erster Ordnung der Funktion, welche die hohle Kugel darstellt, als (ρ_1, ρ_2, ρ_3) genommen werden, die Korrektureinheit (33) die Korrektur ausführt, um die eine der Antwortwellenformen durch Korrigieren der Eigenwerte, wie in Formel (13) unten gezeigt, unter Verwendung von ρ_1', ρ_2', ρ_3', die durch die Formel (12) unten berechnet wurden, und eines zuvor festgelegten Koeffizienten α auszulöschen:

$$\left.\begin{aligned} \rho_1' &= \rho_1 \times x_1 + \rho_2 \times y_1 + \rho_3 \times z_1 \\ \rho_2' &= \rho_1 \times x_2 + \rho_2 \times y_2 + \rho_3 \times z_2 \\ \rho_3' &= \rho_1 \times x_3 + \rho_2 \times y_3 + \rho_3 \times z_3 \end{aligned}\right\} \quad (12)$$

$$\left.\begin{aligned} \lambda_1' &= \begin{cases} 0 & \text{falls } |\lambda_1| < |\alpha\rho_1'| \\ \min(|\lambda_1 + \alpha\rho_1'|, |\lambda_1 - \alpha\rho_1'|) & \text{anderenfalls} \end{cases} \\ \lambda_2' &= \begin{cases} 0 & \text{falls } |\lambda_2| < |\alpha\rho_2'| \\ \min(|\lambda_2 + \alpha\rho_2'|, |\lambda_2 - \alpha\rho_2'|) & \text{anderenfalls} \end{cases} \\ \lambda_3' &= \begin{cases} 0 & \text{falls } |\lambda_3| < |\alpha\rho_3'| \\ \min(|\lambda_3 + \alpha\rho_3'|, |\lambda_3 - \alpha\rho_3'|) & \text{anderenfalls} \end{cases} \end{aligned}\right\} \quad (13)$$

3. Bildverarbeitungsvorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** die Funktion, welche die hohle Kugel darstellt, durch die Formel (10) unten darstellt wird:

$$\left.\begin{array}{l} f(r) = \delta(r - R_4) \\ r = \sqrt{x^2 + y^2 + z^2} \end{array}\right\} \quad (10)$$

wobei x, y, z die Koordinaten des dreidimensionalen Raumes sind, r die polare Koordinatendarstellung davon ist und R_4 der Radius der hohlen Kugel ist.

4. Bildverarbeitungsvorrichtung, umfassend:

eine Filtereinheit (32), die eine Filterung an jeder Voxel-Position in einem dreidimensionalen Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial zweiter Ordnung einer Funktion darstellt, die eine massive Kugel darstellt, um eine Hesse-Matrix zu berechnen; und

eine Evaluierungseinheit (34), die eine Struktur, die in dem Bild enthalten ist und mindestens eines von einer lokalen punktartigen, einer linienartigen und einer ebenenartigen Struktur ist, unter Verwendung von Eigenwerten und Eigenvektoren der Hesse-Matrix unterscheidet, die durch Ausführen einer Eigenwert-Analyse an der berechneten Hesse-Matrix erhalten wurde,
wobei die Filtereinheit (32) eine Korrektureinheit (33) umfasst, die eine Filterung an jeder Voxel-Position in dem Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial erster Ordnung einer Funktion darstellt, die eine zweite massive Kugel darstellt, die einen zweiten Radius hat, der größer als ein erster Radius ist, der der Radius der ersten massiven Kugel ist, um einen weiteren partiellen Differenzialvektor erster Ordnung zu berechnen, des Weiteren ein Filtern an jeder Voxel-Position in dem Bild durch Falten eines Filterkernel ausführt, der ein partielles Differenzial erster Ordnung einer Funktion darstellt, die eine dritte massive Kugel darstellt, die einen dritten Radius hat, der kleiner als der erste Radius ist, um einen weiteren partiellen Differenzialvektor erster Ordnung zu berechnen, und die Eigenwerte der Hesse-Matrix korrigiert durch: (i) Addieren projizierter Werte, von denen jeder eine gewichtete Summe eines Wertes darstellt, der durch Projizieren des partiellen Differenzialvektors erster Ordnung auf Richtungen der Eigenvektoren erhalten wird, und eines Wertes, der durch Projizieren des weiteren partiellen Differenzialvektors erster Ordnung auf die Richtungen der Eigenvektoren erhalten wird, zu den Eigenwerten, oder (ii) durch Subtrahieren der projizierten Werte von den Eigenwerten, um eine Antwortwellenform an einer Position von Antwortwellenformen des partiellen Differenzials zweiter Ordnung der Funktion auszulöschen, welche die massive Kugel in jeder Richtung darstellt, wobei die Antwortwellenformen an zwei Positionen erscheinen, die mit Bezug auf die Mitte der massiven Kugel asymmetrisch getrennt sind.

5. Bildverarbeitungsvorrichtung nach Anspruch 4, **dadurch gekennzeichnet, dass**:

die Antwortwellenform an der einen Position eine Wellenform ist, bei der eine positive Spitze und eine negative Spitze aneinander grenzen;
die zweite Radius der Länge von der Mitte der ersten massiven bis zur positiven Spitze oder der Länge von der Mitte der ersten massiven Kugel bis zur negativen Spitze entspricht, je nachdem, was länger ist; und
der dritte Radius der Länge von der Mitte der ersten massiven Kugel bis zur positiven Spitze oder der Länge von der Mitte der ersten massiven Kugel bis zur negativen Spitze entspricht, je nachdem, was kürzer ist.

6. Bildverarbeitungsvorrichtung nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** die Filtereinheit (32) mit Bezug auf Funktionen, welche die massive Kugel in mehreren Größen darstellen, eine Hesse-Matrix durch Ausführen einer Filterung mit einer partiellen Differenzialmatrix zweiter Ordnung einer Funktion, die jede massive Kugel darstellt, berechnet.

7. Bildverarbeitungsvorrichtung nach Anspruch 4 oder 5, **dadurch gekennzeichnet, dass** die Filtereinheit (32) mit Bezug auf Funktionen, welche die erste massive Kugel in mehreren Größen darstellen, eine Hesse-Matrix durch Ausführen einer Filterung mit einer partiellen Differenzialmatrix zweiter Ordnung einer Funktion, die jede der ersten massiven Kugeln darstellt, berechnet.

8. Bildverarbeitungsvorrichtung nach einem der Ansprüche 1 bis 3 und 6, **dadurch gekennzeichnet, dass** die Filtereinheit (32) das Filtern unter Verwendung der partiellen Differenzialmatrix zweiter Ordnung der Funktion, welche die massive Kugel im Fourier-Raum darstellt, ausführt.

9. Bildverarbeitungsvorrichtung nach einem der Ansprüche 4, 5 und 7, **dadurch gekennzeichnet, dass** die Filtereinheit (32) das Filtern unter Verwendung der partiellen Differenzialmatrix zweiter Ordnung der Funktion, welche die erste massive Kugel im Fourier-Raum darstellt, ausführt.

10. Bildverarbeitungsvorrichtung nach einem der Ansprüche 1 bis 9, **dadurch gekennzeichnet, dass** das Bild ein medizinisches Bild ist und die Struktur ein Blutgefäß ist.

11. Bildverarbeitungsverfahren, umfassend:

    einen Filterungsschritt, der eine Filterung an jeder Voxel-Position in einem dreidimensionalen Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial zweiter Ordnung einer Funktion darstellt, die eine massive Kugel darstellt, um eine Hesse-Matrix zu berechnen; und
    einen Evaluierungsschritt, der eine Struktur, die in dem Bild enthalten ist und mindestens eines von einer lokalen punktartigen, einer linienartigen und einer ebenenartigen Struktur ist, unter Verwendung von Eigenwerten und Eigenvektoren der Hesse-Matrix unterscheidet, die durch Ausführen einer Eigenwert-Analyse an der berechneten Hasse-matrix erhalten wurde,
    wobei der Filterungsschritt eine Filterung an jeder Voxel-Position in dem Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial erster Ordnung einer Funktion darstellt, die eine hohle Kugel darstellt, die den gleichen Radius wie der Radius der massiven Kugel aufweist, um einen partiellen Differenzialvektor erster Ordnung zu berechnen, und die Eigenwerte der Hesse-Matrix korrigiert durch: (i) Addieren projizierter Werte, die durch Projizieren des partiellen Differenzialvektors erster Ordnung auf Richtungen der Eigenvektoren erhalten werden, oder durch Addieren der projizierten Werte, die mit einem zuvor festgelegten Koeffizienten gewichtet wurden, zu den Eigenwerten, oder (ii) durch Subtrahieren der projizierten Werte oder der projizierten Werte, die mit einem zuvor festgelegten Koeffizienten gewichtet wurden, von den Eigenwerten, um eine von Antwortwellenformen des partiellen Differenzials zweiter Ordnung der Funktion, welche die massive Kugel in jeder Richtung darstellt, auszulöschen, wobei die Antwortwellenformen an zwei Positionen erscheinen, die mit Bezug auf die Mitte der massiven Kugel symmetrisch getrennt sind.

12. Aufzeichnungsmedium, auf dem ein Bildverarbeitungsprogramn aufgezeichnet ist, das einen Computer veranlasst, Folgendes auszuführen:

    einen Filterungsschritt, der eine Filterung an jeder Voxel-Position in einem dreidimensionalen Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial zweiter Ordnung einer Funktion darstellt, die eine massive Kugel darstellt, um eine Hesse-Matrix zu berechnen; und
    einen Evaluierungsschritt, der eine Struktur, die in dem Bild enthalten ist und mindestens eines von einer lokalen punktartigen, einer linienartigen und einer ebenenartigen Struktur ist, unter Verwendung von Eigenwerten und Eigenvektoren der Hesse-Matrix unterscheidet, die durch Ausführen einer Eigenwert-Analyse an der berechneten Hesse-Matrix erhalten wurde,
    wobei der Filterungsschritt eine Filterung an jeder Voxel-Position in dem Bild durch Falten eines Filterkernels ausführt, der ein partielles Differenzial erster Ordnung einer Funktion darstellt, die eine hohle Kugel darstellt, die den gleichen Radius wie der Radius der massiven Kugel aufweist, um einen partiellen Differenzialvektor erster Ordnung zu berechnen, und die Eigenwerte der Hesse-Matrix korrigiert durch: (i) Addieren projizierter Werte, die durch Projizieren des partiellen Differenzialvektors erster Ordnung auf Richtungen der Eigenvektoren erhalten werden, oder durch Addieren der projizierten Werte, die mit einem zuvor festgelegten Koeffizienten gewichtet wurden, zu den Eigenwerten, oder (ii) durch Subtrahieren der projizierten Werte oder der projizierten Werte, die mit einem zuvor festgelegten Koeffizienten gewichtet wurden, von den Eigenwerten, um eine von Antwortwellenformen des partiellen Differenzials zweiter Ordnung der Funktion, welche die massive Kugel in jeder Richtung darstellt, auszulöschen, wobei die Antwortwellenformen an zwei Positionen erscheinen, die mit Bezug auf die Mitte der massiven Kugel symmetrisch getrennt sind.

Revendications

1. Appareil de traitement d’image, comprenant :

une unité de filtrage (32), laquelle réalise un filtrage sur chaque position de voxel dans une image tridimensionnelle par convolution d'un noyau de filtre, lequel représente une dérivée partielle de second ordre d'une fonction représentant une sphère solide, afin de calculer une matrice hessienne, et
une unité d'évaluation (34), laquelle discrimine une structure, qui est incluse dans l'image et est au moins une structure locale de type point, de type ligne et de type plan, à l'aide de valeurs propres et de vecteurs propres de la matrice hessienne obtenus en réalisant une analyse de valeurs propres sur la matrice hessienne calculée, dans lequel l'unité de filtrage (32) inclut une unité de correction (33), laquelle réalise un filtrage sur chaque position de voxel dans l'image par convolution d'un noyau de filtre, lequel représente une dérivée partielle de premier ordre d'une fonction représentant une sphère creuse présentant le même rayon que la sphère solide, afin de calculer un vecteur de dérivée partielle de premier ordre, et corrige les valeurs propres de la matrice hessienne (i) en additionnant des valeurs projetées, lesquelles sont obtenues en projetant le vecteur de dérivée partielle de premier ordre sur des directions des vecteurs propres, ou en additionnant les valeurs projetées pondérées avec un coefficient prédéterminé aux valeurs propres, ou (ii) en soustrayant les valeurs projetées ou les valeurs projetées pondérées avec un coefficient prédéterminé des valeurs propres afin d'annuler une des formes d'onde de réponse de la dérivée partielle de second ordre de la fonction représentant la sphère solide dans chaque direction, les formes d'onde de réponse apparaissant sur deux positions séparées symétriquement par rapport au centre de la sphère solide.

2. Appareil de traitement d'image selon la revendication 1, **caractérisé en ce que** si des valeurs propres de la matrice hessienne sont prises comme λ_1, λ_2, λ_3, des vecteurs propres sont pris comme $e_1= (x_1, y_1, z_1)$, $e_2=(x_2, y_2, z_2)$, $e_3=(x_3, y_3, z_3)$, et les vecteurs de dérivée partielle de premier ordre de la fonction représentant la sphère creuse sont pris comme (ρ_1, ρ_2, ρ_3), l'unité de correction (33) effectue la correction afin d'annuler la une forme des formes d'onde de réponse en corrigeant les valeurs propres comme montré à la formule (13) donnée ci-après à l'aide de ρ'_1, ρ'_2, ρ'_3 calculées par la formule (12) donnée ci-après et un coefficient prédéterminé α :

$$\left.\begin{aligned} \rho_1' &= \rho_1 \times x_1 + \rho_2 \times y_1 + \rho_3 \times z_1 \\ \rho_2' &= \rho_1 \times x_2 + \rho_2 \times y_2 + \rho_3 \times z_2 \\ \rho_3' &= \rho_1 \times x_3 + \rho_2 \times y_3 + \rho_3 \times z_3 \end{aligned}\right\} \quad (12)$$

$$\left.\begin{aligned} \lambda_1' &= \begin{cases} 0 & \text{if } |\lambda_1| < |\alpha\rho_1'| \\ \min(|\lambda_1 + \alpha\rho_1'|, |\lambda_1 - \alpha\rho_1'|) & \text{otherwise} \end{cases} \\ \lambda_2' &= \begin{cases} 0 & \text{if } |\lambda_2| < |\alpha\rho_2'| \\ \min(|\lambda_2 + \alpha\rho_2'|, |\lambda_2 - \alpha\rho_2'|) & \text{otherwise} \end{cases} \\ \lambda_3' &= \begin{cases} 0 & \text{if } |\lambda_3| < |\alpha\rho_3'| \\ \min(|\lambda_3 + \alpha\rho_3'|, |\lambda_3 - \alpha\rho_3'|) & \text{otherwise} \end{cases} \end{aligned}\right\} \quad (13)$$

3. Appareil de traitement d'image selon la revendication 1 ou 2, **caractérisé en ce que** la fonction représentant la sphère creuse est représentée par la formule (10) donnée ci-après :

$$\left.\begin{aligned} f(r) &= \delta(r - R_4) \\ r &= \sqrt{x^2 + y^2 + z^2} \end{aligned}\right\} \quad (10)$$

où x, y, z sont les coordonnées de l'espace tridimensionnel, r est la représentation de coordonnées polaires de celui-ci, et R_4 est le rayon de la sphère creuse.

4. Appareil de traitement d'image, comprenant :

une unité de filtrage (32), laquelle réalise un filtrage sur chaque position de voxel dans une image tridimensionnelle par convolution d'un noyau de filtre, lequel représente une dérivée partielle de second ordre d'une fonction représentant une sphère solide, afin de calculer une matrice hessienne, et
une unité d'évaluation (34), laquelle discrimine une structure, qui est incluse dans l'image et est au moins une structure locale de type point, de type ligne et de type plan, à l'aide de valeurs propres et de vecteurs propres de la matrice hessienne obtenus en réalisant une analyse de valeurs propres sur la matrice hessienne calculée,
dans lequel l'unité de filtrage (32) inclut une unité de correction (33), laquelle réalise un filtrage sur chaque position de voxel dans l'image par convolution d'un noyau de filtre, lequel représente une dérivée partielle de premier ordre d'une fonction représentant une deuxième sphère solide présentant un deuxième rayon supérieur à un premier rayon, qui est le rayon de la première sphère solide, afin de calculer un autre vecteur de dérivée partielle de premier ordre, réalise en outre un filtrage sur chaque position de voxel dans l'image par convolution d'un noyau de filtre, lequel représente une dérivée partielle de premier ordre d'une fonction représentant une troisième sphère solide présentant un troisième rayon inférieur au premier rayon, afin de calculer un autre vecteur de dérivée partielle de premier ordre, et corrige les valeurs propres de la matrice hessienne (i) en additionnant des valeurs projetées, dont chacune représente une somme pondérée d'une valeur obtenue en projetant le vecteur de dérivée partielle de premier ordre sur des directions des vecteurs propres et une valeur obtenue en projetant l'autre vecteur de dérivée partielle de premier ordre sur les directions des vecteurs propres aux valeurs propres, ou (ii) en soustrayant les valeurs projetées des valeurs propres, afin d'annuler une forme d'onde de réponse sur une position des formes d'onde de réponse de la dérivée partielle de second ordre de la fonction représentant la sphère solide dans chaque direction, les formes d'onde de réponse apparaissant sur deux positions séparées symétriquement par rapport au centre de la sphère solide.

5. Appareil de traitement d'image selon la revendication 4, **caractérisé en ce que** :

la forme d'onde de réponse sur la une position est une forme d'onde dans laquelle une crête positive et une crête négative sont adjacentes l'une à l'autre ;
le deuxième rayon correspond à la longueur du centre de la première sphère solide à la crête positive, ou à la longueur du centre de la première sphère solide à la crête négative, en prenant celle qui est la plus longue, et
le troisième rayon correspond à la longueur du centre de la première sphère solide à la crête positive, ou à la longueur du centre de la première sphère solide à la crête négative, en prenant celle qui est la plus longue.

6. Appareil de traitement d'image selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que** l'unité de filtrage (32) calcule, par rapport aux fonctions représentant la sphère solide dans une pluralité de tailles, une matrice hessienne en réalisant un filtrage avec une matrice de dérivée partielle de second ordre d'une fonction représentant chaque sphère solide.

7. Appareil de traitement d'image selon la revendication 4 ou 5, **caractérisé en ce que** l'unité de filtrage (32) calcule, par rapport aux fonctions représentant la première sphère solide dans une pluralité de tailles, une matrice hessienne en réalisant un filtrage avec une matrice de dérivée partielle de second ordre d'une fonction représentant chacune des premières sphères solides.

8. Appareil de traitement d'image selon l'une quelconque des revendications 1 à 3 et 6, **caractérisé en ce que** l'unité de filtrage (32) réalise le filtrage à l'aide de la matrice de dérivée partielle de second ordre de la fonction représentant la sphère solide dans un espace de Fourier.

9. Appareil de traitement d'image selon l'une quelconque des revendications 4, 5 et 7, **caractérisé en ce que** l'unité de filtrage (32) réalise le filtrage à l'aide de la matrice de dérivée partielle de second ordre de la fonction représentant la première sphère solide dans un espace de Fourier.

10. Appareil de traitement d'image selon l'une quelconque des revendications 1 à 9, **caractérisé en ce que** l'image est une image médicale, et la structure est un vaisseau sanguin.

11. Procédé de traitement d'image, comprenant :

une étape de filtrage, laquelle réalise un filtrage sur chaque position de voxel dans une image tridimensionnelle par convolution d'un noyau de filtre, lequel représente une dérivée partielle de second ordre d'une fonction

représentant une sphère solide, afin de calculer une matrice hessienne, et
une étape d'évaluation, laquelle discrimine une structure, qui est incluse dans l'image et est au moins une structure locale de type point, de type ligne et de type plan, à l'aide de valeurs propres et de vecteurs propres de la matrice hessienne obtenus en réalisant une analyse de valeurs propres sur la matrice hessienne calculée, dans lequel l'étape de filtrage réalise un filtrage sur chaque position de voxel dans l'image par convolution d'un noyau de filtre, lequel représente une dérivée partielle de premier ordre d'une fonction représentant une sphère creuse présentant le même rayon que le rayon de la sphère solide, afin de calculer un vecteur de dérivée partielle de premier ordre, et corrige les valeurs propres de la matrice hessienne (i) en additionnant des valeurs projetées, lesquelles sont obtenues en projetant le vecteur de dérivée partielle de premier ordre sur des directions des vecteurs propres, ou en additionnant les valeurs projetées pondérées avec un coefficient prédéterminé aux valeurs propres, ou (ii) en soustrayant les valeurs projetées ou les valeurs projetées pondérées avec un coefficient prédéterminé des valeurs propres, afin d'annuler une des formes d'onde de réponse de la dérivée partielle de second ordre de la fonction représentant la sphère solide dans chaque direction, les formes d'onde de réponse apparaissant sur deux positions séparées symétriquement par rapport au centre de la sphère solide.

12. Support d'enregistrement sur lequel est enregistré un programme de traitement d'image qui amène un ordinateur à réaliser :

une étape de filtrage, laquelle réalise un filtrage sur chaque position de voxel dans une image tridimensionnelle par convolution d'un noyau de filtre, lequel représente une dérivée partielle de second ordre d'une fonction représentant une sphère solide, afin de calculer une matrice hessienne, et
une étape d'évaluation, laquelle discrimine une structure, qui est incluse dans l'image et est au moins une structure locale de type point, de type ligne et de type plan, à l'aide de valeurs propres et de vecteurs propres de la matrice hessienne obtenus en réalisant une analyse de valeurs propres sur la matrice hessienne calculée, dans lequel l'étape de filtrage réalise un filtrage sur chaque position de voxel dans l'image par convolution d'un noyau de filtre, lequel représente une dérivée partielle de premier ordre d'une fonction représentant une sphère creuse présentant le même rayon que le rayon de la sphère solide, afin de calculer un vecteur de dérivée partielle de premier ordre, et corrige les valeurs propres de la matrice hessienne (i) en additionnant des valeurs projetées, lesquelles sont obtenues en projetant le vecteur de dérivée partielle de premier ordre sur des directions des vecteurs propres, ou en additionnant les valeurs projetées pondérées avec un coefficient prédéterminé aux valeurs propres, ou (ii) en soustrayant les valeurs projetées ou les valeurs projetées pondérées avec un coefficient prédéterminé des valeurs propres, afin d'annuler une des formes d'onde de réponse de la dérivée partielle de second ordre de la fonction représentant la sphère solide dans chaque direction, les formes d'onde de réponse apparaissant sur deux positions séparées symétriquement par rapport au centre de la sphère solide.

FIG.1

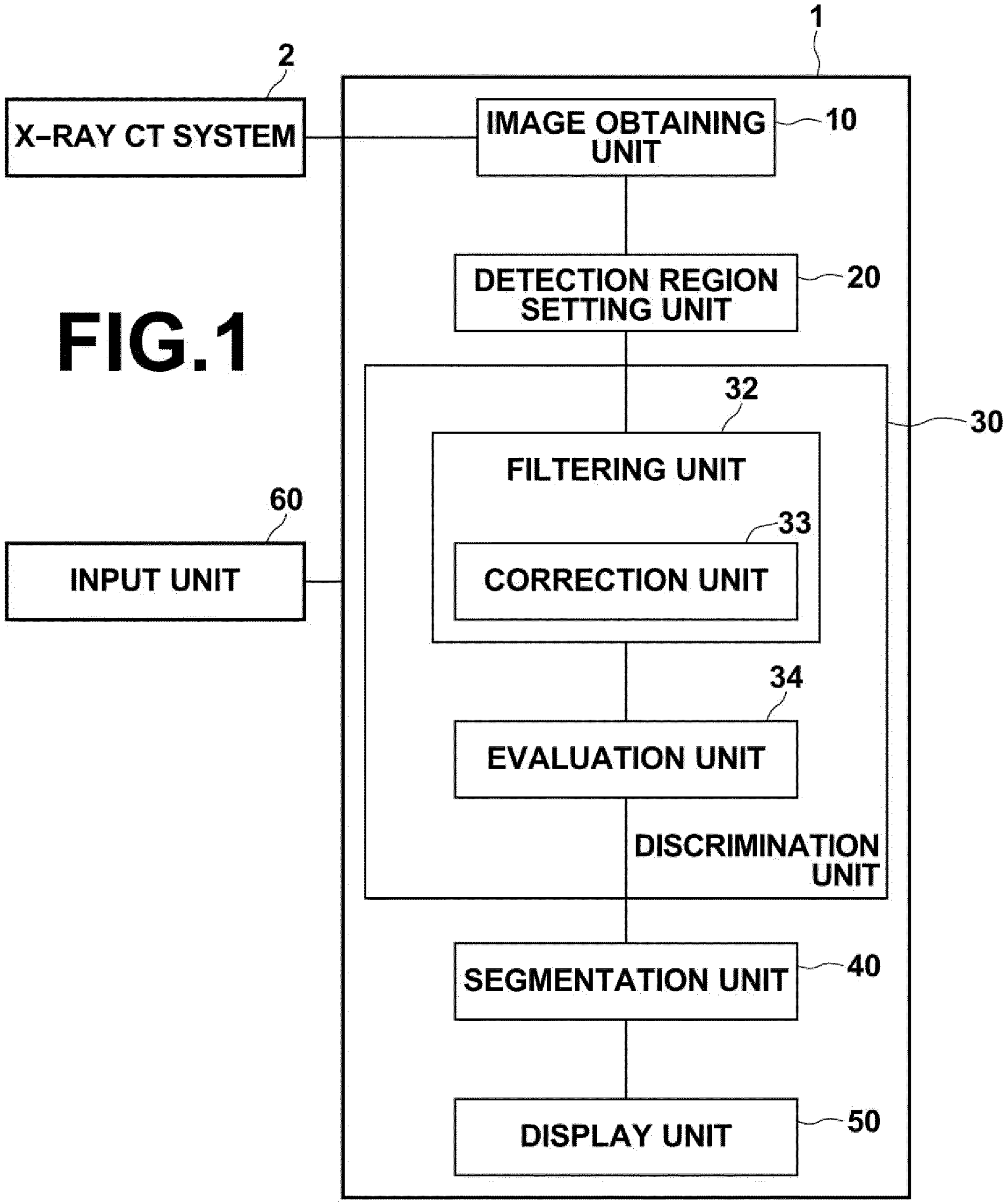

1
2
X-RAY CT SYSTEM
IMAGE OBTAINING UNIT
10
DETECTION REGION SETTING UNIT
20
32
30
FILTERING UNIT
60
33
INPUT UNIT
CORRECTION UNIT
34
EVALUATION UNIT
DISCRIMINATION UNIT
SEGMENTATION UNIT
40
DISPLAY UNIT
50

FIG.2

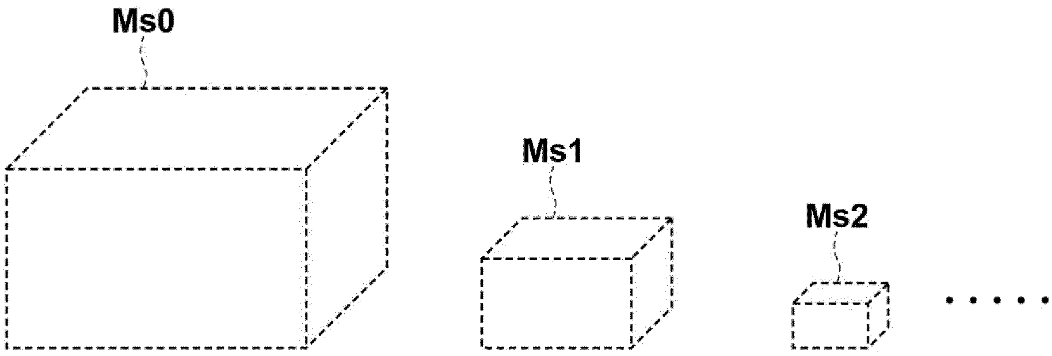

Ms0
Ms1
Ms2
.....

FIG.3

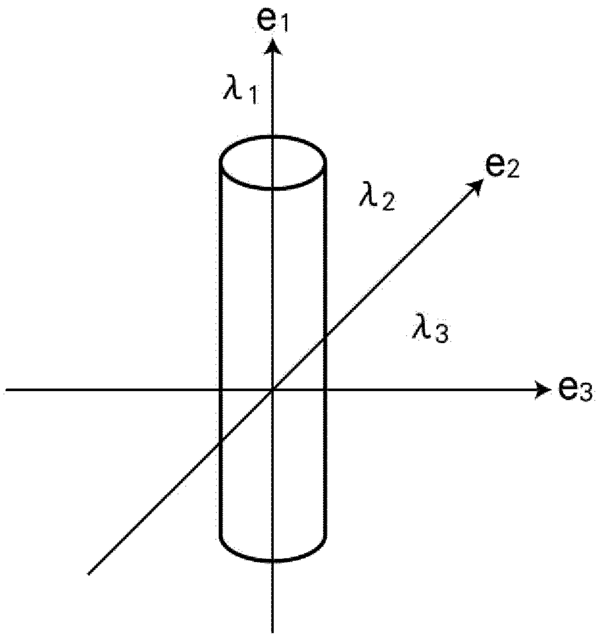
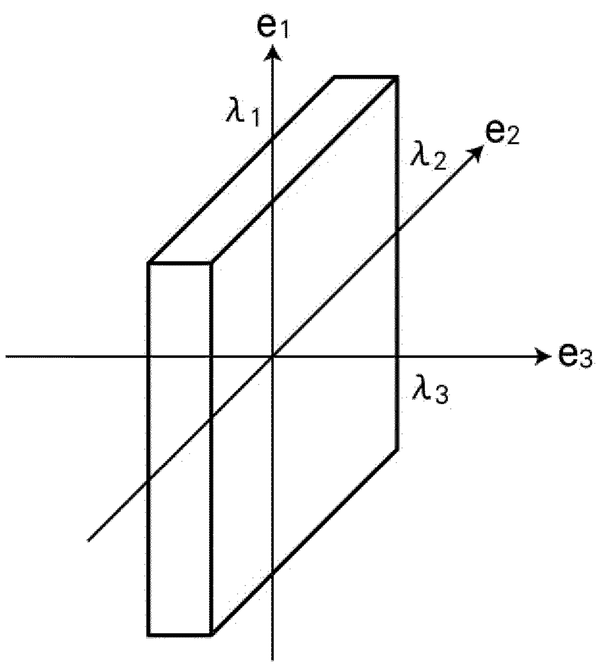


FIG.4



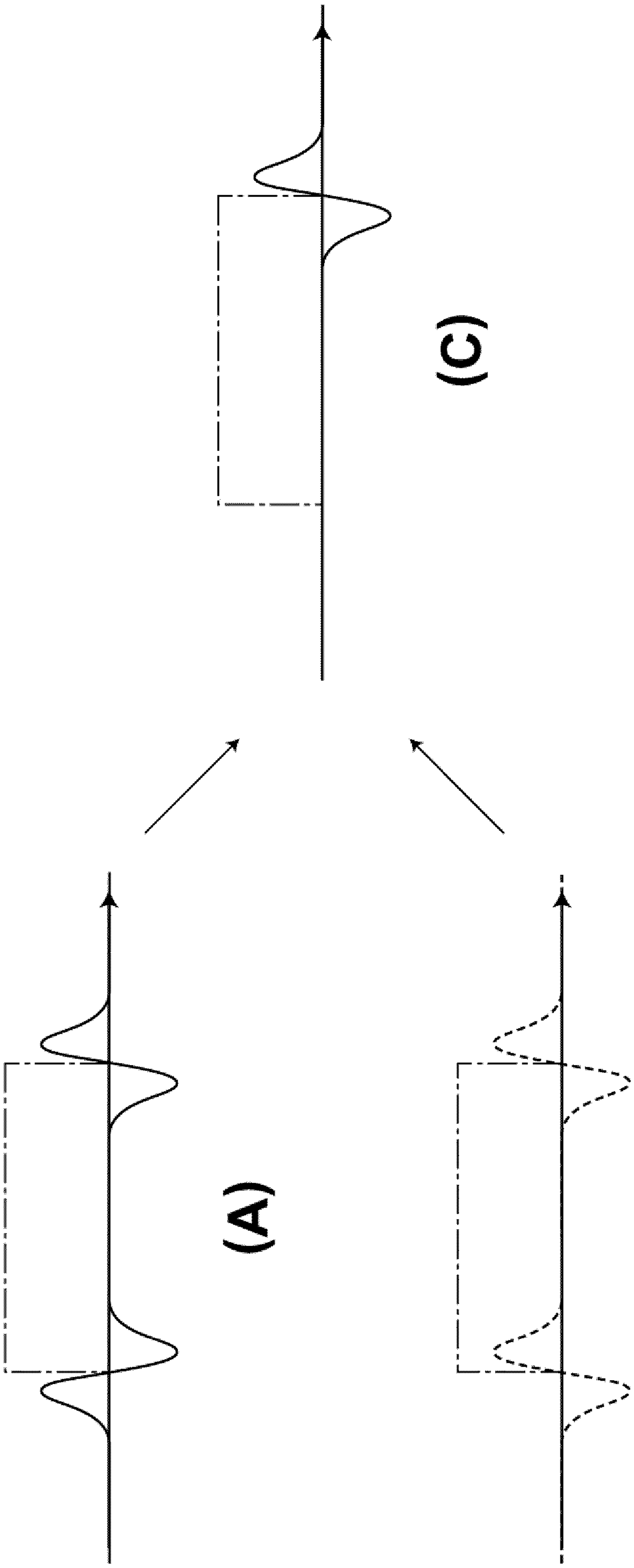
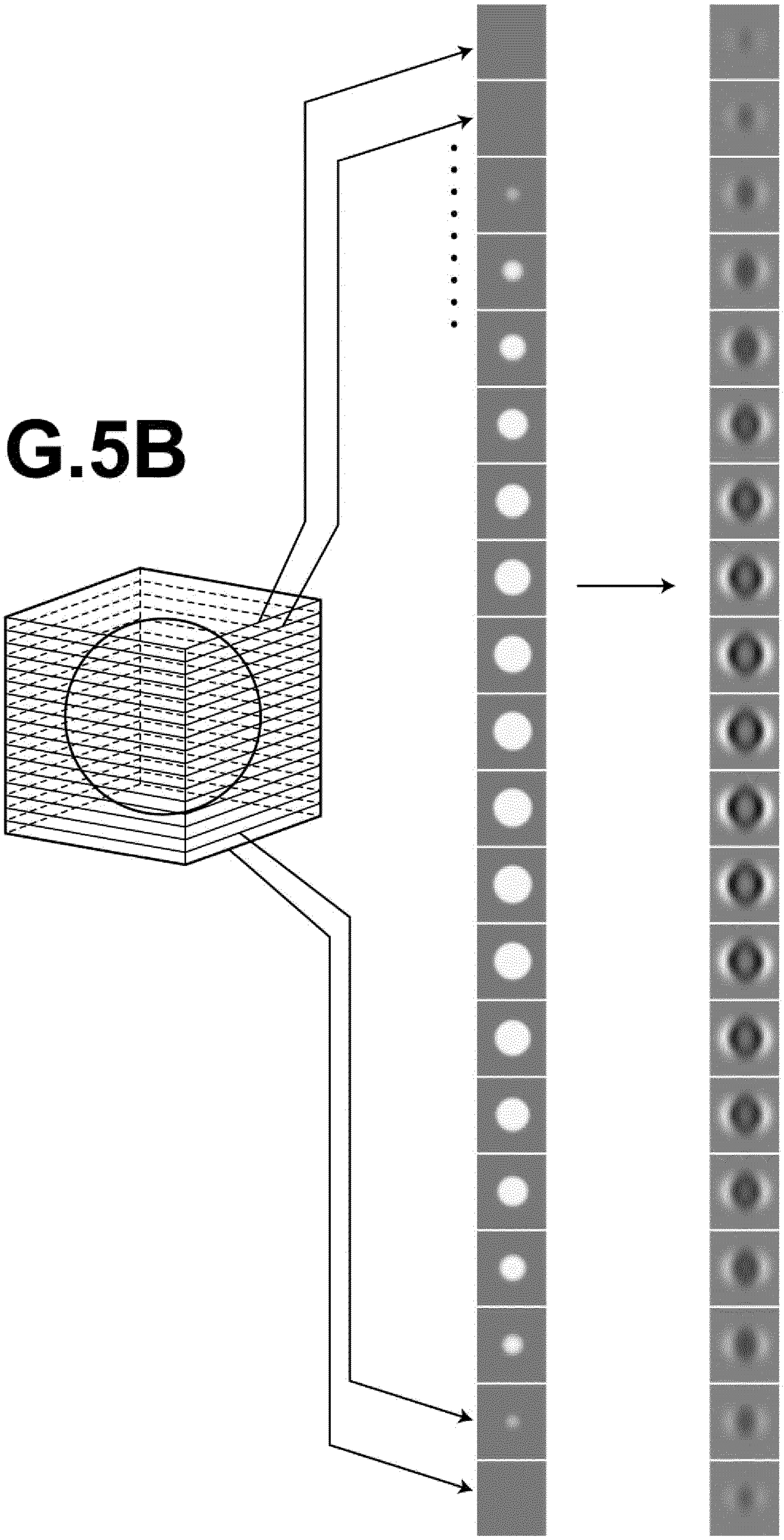


FIG.5A

FIG.5B



(A)

(B)

FIG.5C

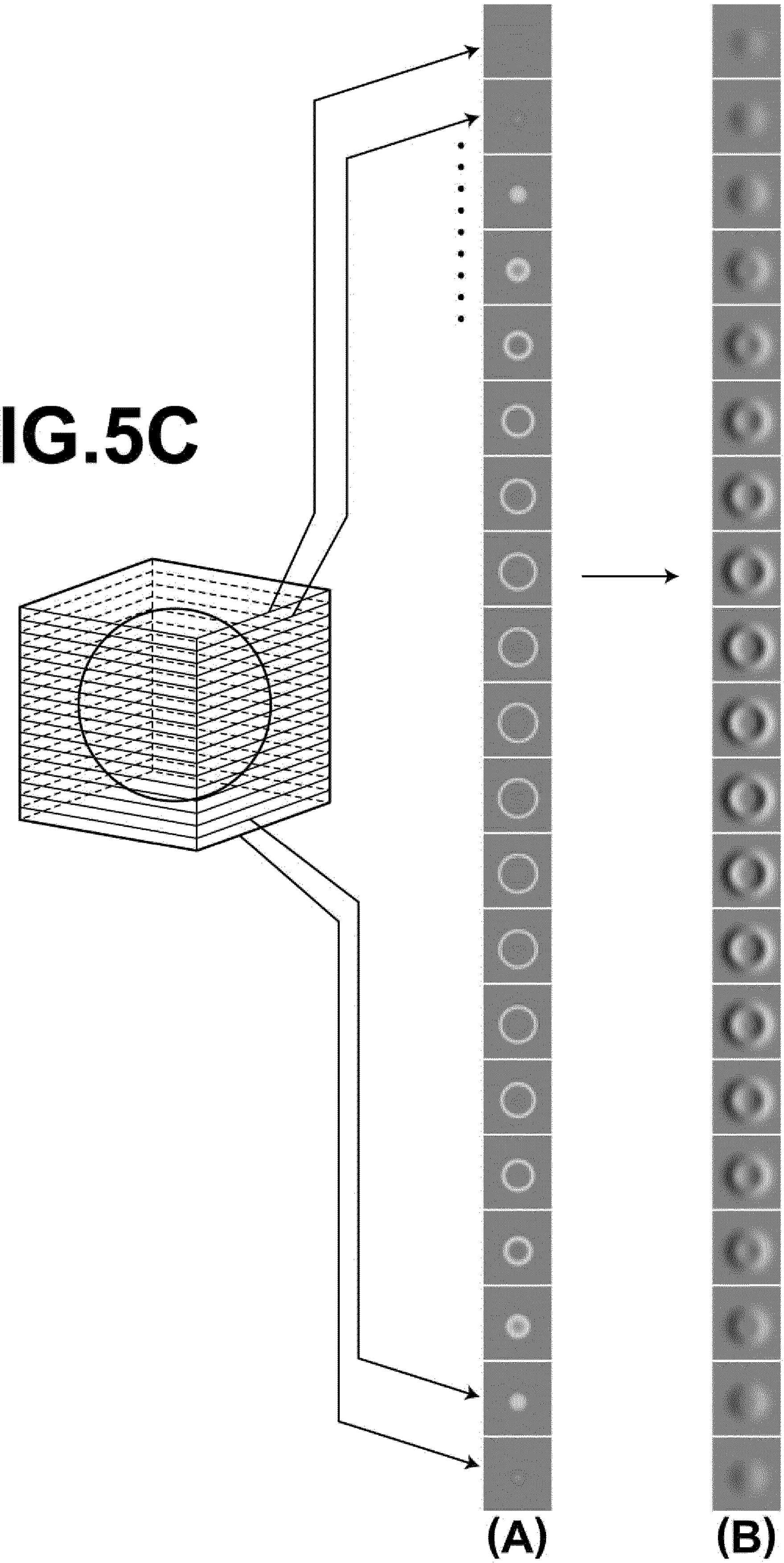


FIG.5D

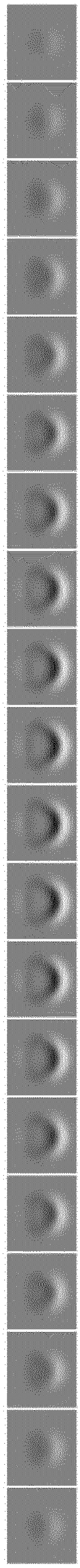
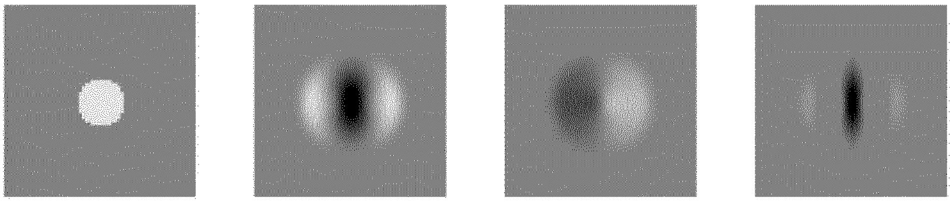
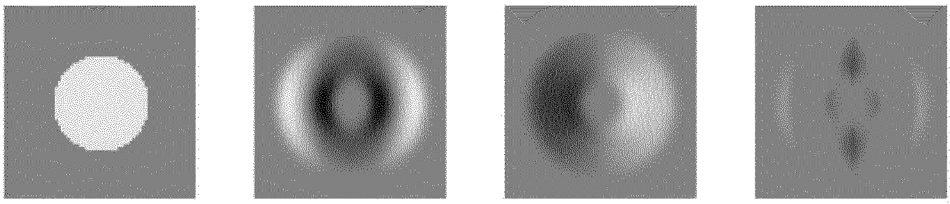


FIG.6A



(A) (B) (C) (D)

FIG.6B



(A) (B) (C) (D)

FIG.7

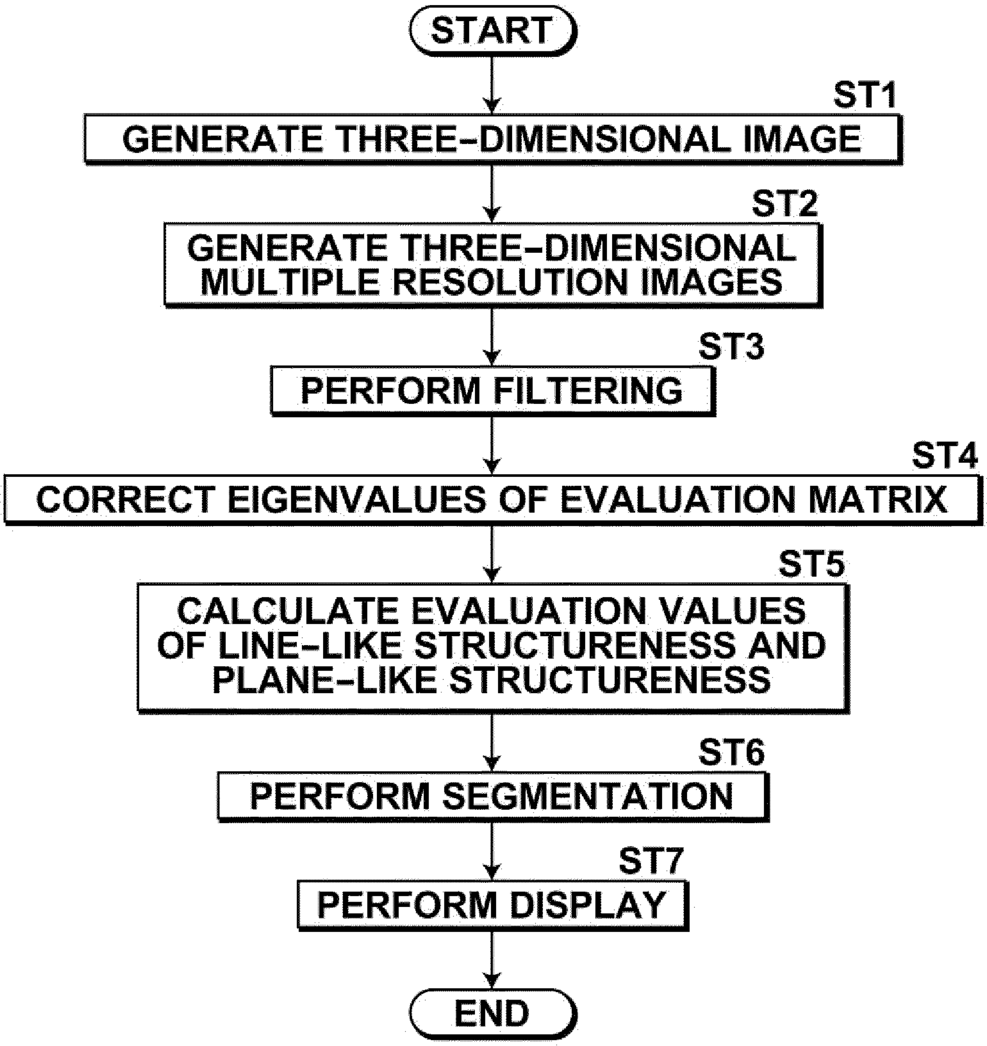

START
ST1
GENERATE THREE-DIMENSIONAL IMAGE
ST2
GENERATE THREE-DIMENSIONAL MULTIPLE RESOLUTION IMAGES
ST3
PERFORM FILTERING
ST4
CORRECT EIGENVALUES OF EVALUATION MATRIX
ST5
CALCULATE EVALUATION VALUES OF LINE-LIKE STRUCTURENESS AND PLANE-LIKE STRUCTURENESS
ST6
PERFORM SEGMENTATION
ST7
PERFORM DISPLAY
END

FIG.8A

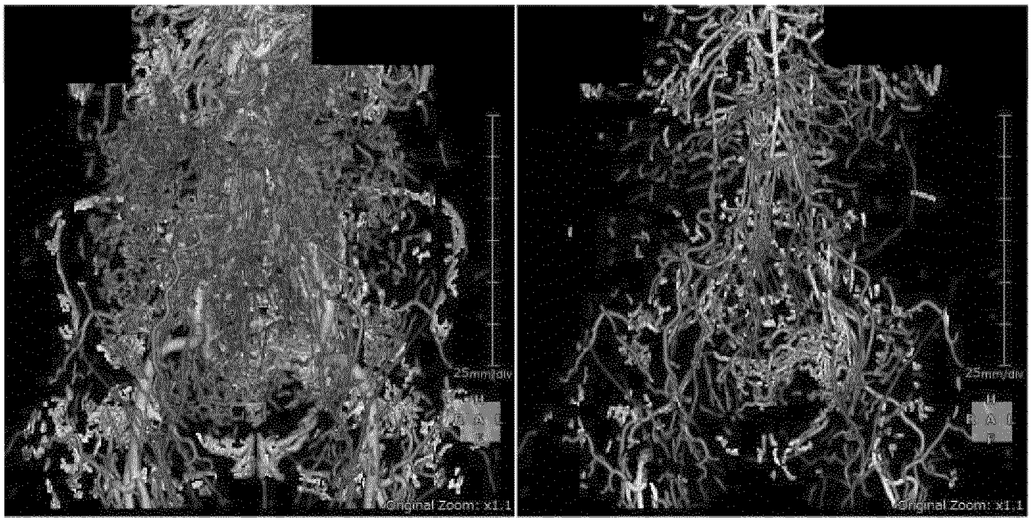
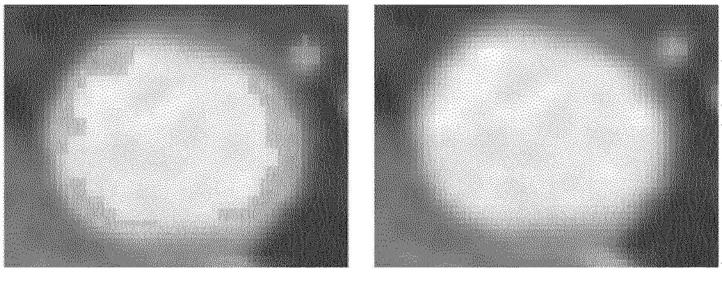


FIG.8B



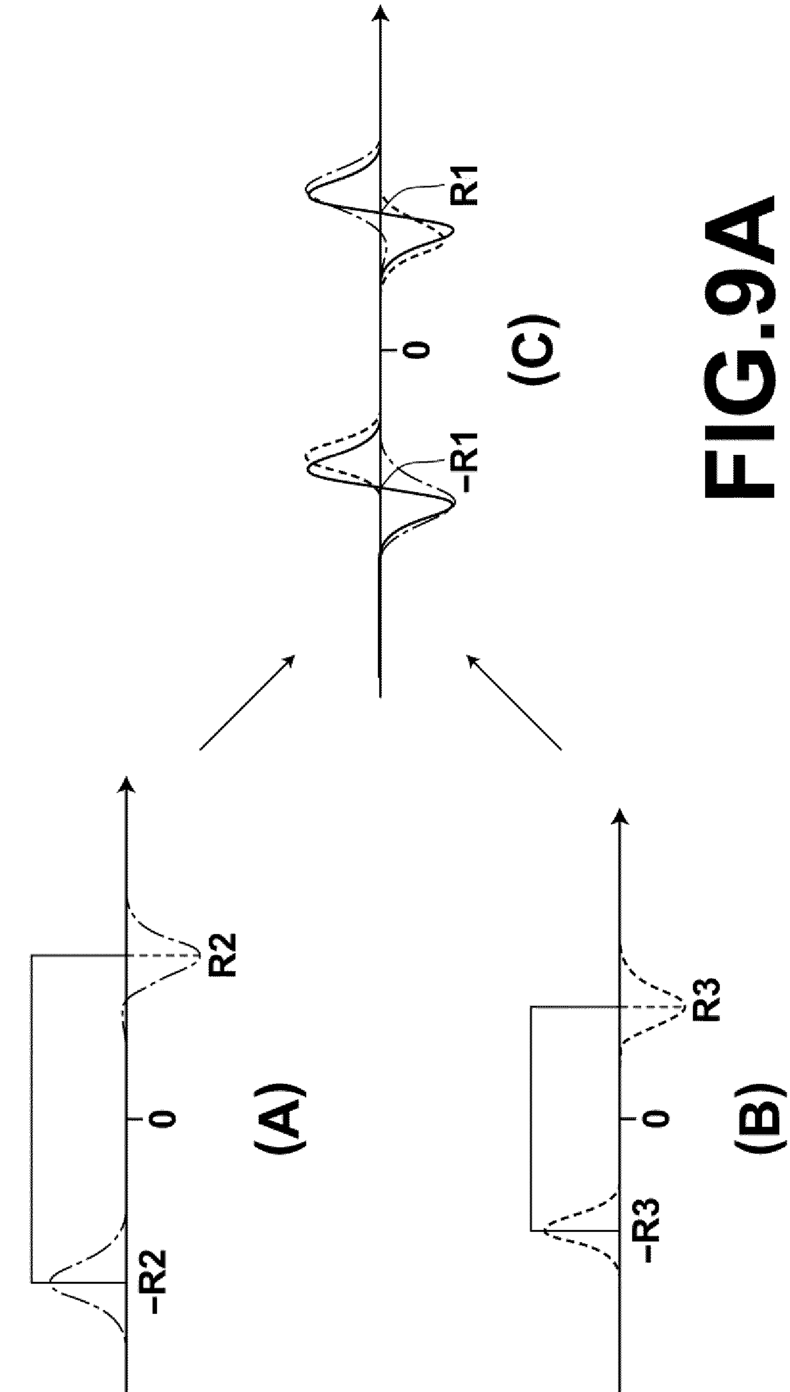
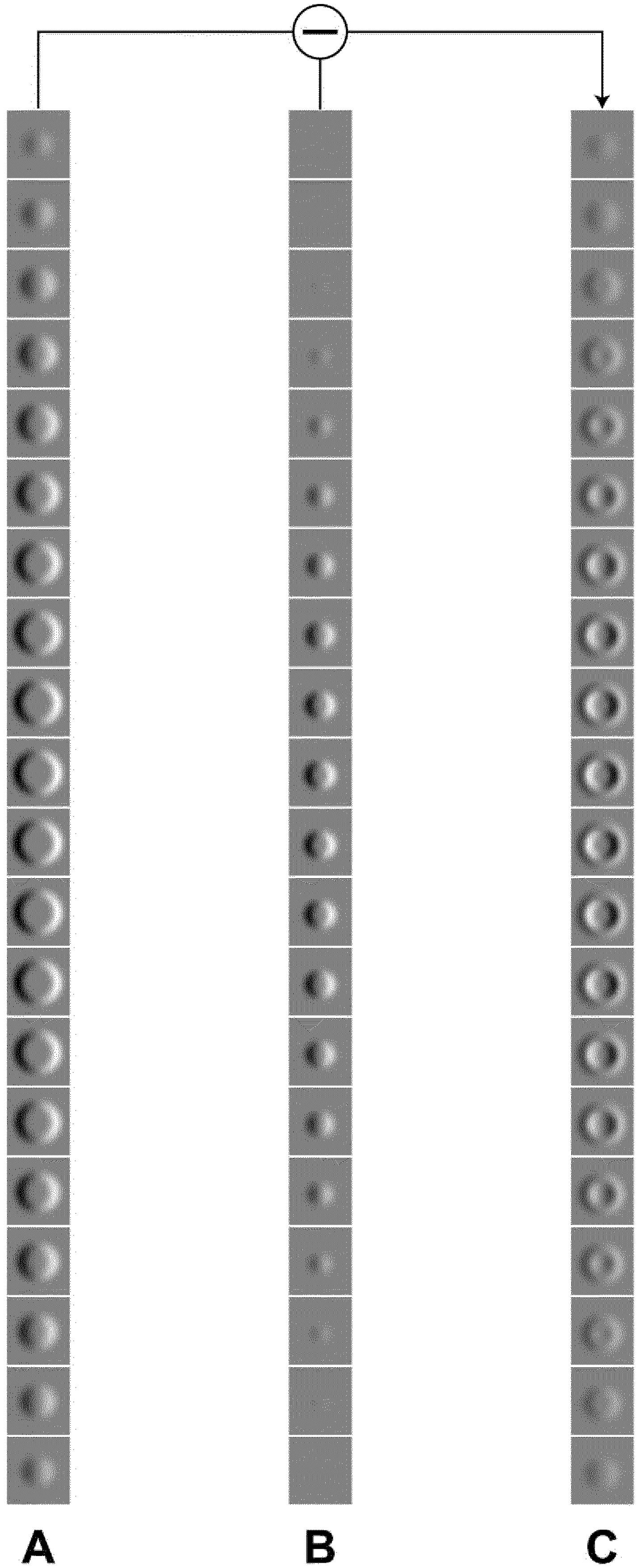


FIG.9A

FIG.9B



REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	图像处理设备，方法和程序		
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优先权	2012056855 2012-03-14 JP		
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外部链接	Espacenet		

摘要(译)

[要解决的问题]抑制图像中包括的结构的错误辨别。 [解决问题的手段]一种图像处理设备，包括：滤波单元，使用二阶偏微分对图像执行滤波并计算Hessian矩阵;以及评估单元，其区分包括在其中的结构。使用Hessian矩阵的特征值和特征向量的图像，其中滤波单元（32）包括校正单元（33），其使用表示具有与半径相同的半径的空心球的函数的一阶偏微分对图像执行滤波。实心球的半径并获得一阶偏微分矢量量，并进行校正以抵消表示每个方向上实心球的函数的响应波形之一，响应波形出现在相对于中心对称分离的两个位置处。实心球，使用通过将一阶偏微分向量投影到方向上获得的值特征向量。

$$\left.\begin{aligned}\rho_1' &= \rho_1 \times X_1 + \rho_2 \times Y_1 + \rho_3 \times Z_1 \\ \rho_2' &= \rho_1 \times X_2 + \rho_2 \times Y_2 + \rho_3 \times Z_2 \\ \rho_3' &= \rho_1 \times X_3 + \rho_2 \times Y_3 + \rho_3 \times Z_3\end{aligned}\right\} \quad (12)$$