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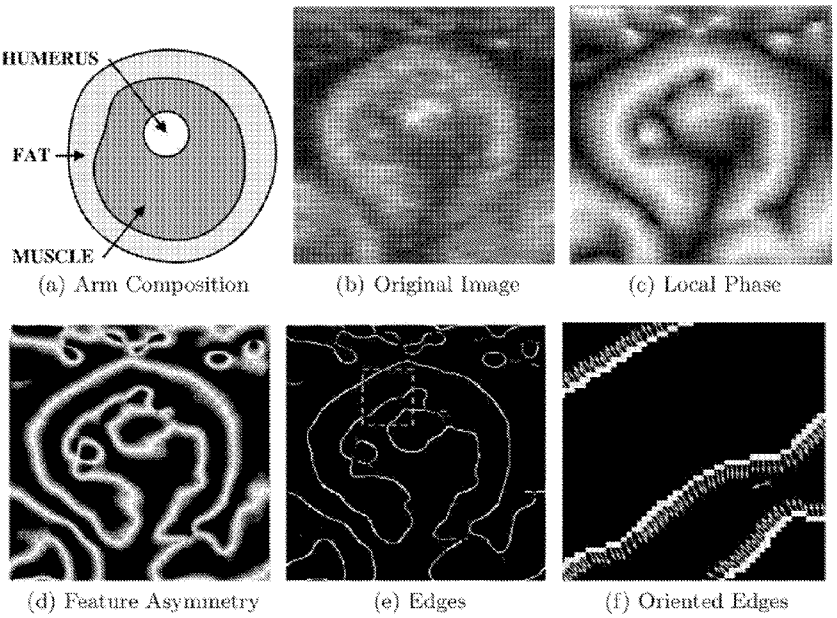


Figure 1

(57) Abstract: An image processing method performed by a processor and comprising: receiving a first image containing one or more objects of interest; deriving local phase and local orientation information from the first image; identifying one or more edge features of the object(s) of interest using the local phase information; and fitting one or more parametric shapes to the edge feature(s) of the object(s) of interest using the local orientation information.

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METHODS AND APPARATUS FOR IMAGE PROCESSING

Field of the Invention

The present invention relates to methods and apparatus for processing images – for example, images of tubular structures and organ/tissue structures. It is particularly applicable, but by no means limited, to the analysis of medical ultrasound images.

Background to the Invention

Imaging techniques, such as those which use ultrasound, are commonly used to study objects of interest within human or animal bodies, or in industrial applications. Once an image has been obtained, it is sometimes necessary to quantify structures/objects within the image, for example in order to measure the objects or to perform some other analysis on them.

Ultrasound is one of the most difficult and challenging among medical imaging modalities for quantification, as the quantification of structures faces multiple challenges including signal dropouts, missing boundaries, shadows, and presence of speckle [1].

In a number of medical imaging applications (including ultrasound, and others), organ/tissue delineation is often essential for underpinning image-based measurements of organ dimensions or tissue region properties. Finding the whereabouts of an object of interest approximately, by fitting ellipses or circles to it, is often sufficient for the purposes of quantification. For example, in the obstetrics field, it is common clinical practice for the size of the head and abdomen of a fetus to be estimated from manually fitting ellipses to the objects of interest within an ultrasound image. This might be the end goal (biometric quantification) or might be a pre-analysis step to identify a region of interest for subsequent analysis (for example myocardial thickness estimation). However, manual delineation of such images is tedious and subjective, and its accuracy is highly related to the image characteristics and the expertise of the observer.

Automatic image analysis techniques also exist. Examples of automated feature detection or measurement techniques using ultrasound imaging are provided in US 2009/0093717 A1, US 2011/0021915 A1 and US 7,995,820 B2.

In particular, automatic ellipse detection is a well-studied problem but most existing methods require the use of intensity-based image features to perform accurately. Some existing methods use a generalised Hough Transform (HT) [2][3] framework, for detecting arbitrary shapes, making use of intensity gradients. However, the contrast within the same object of interest, particularly in ultrasound images, varies considerably, and therefore intensity-gradient-based approaches are not well-suited for extracting image features across the range of image qualities seen in clinical practice (and in the case of fetal analysis a further issue is the change in appearance across gestational age). The development of automatic methods for quantitative analysis is especially challenging in ultrasound images [1], where object boundaries appear fuzzy or are not visible.

There is therefore a desire to be able to automatically quantify structures in images (such as organ/tissue structures in medical ultrasound images) more effectively and efficiently.

Summary of the Invention

According to a first aspect of the present invention there is provided an image processing method as defined in claim 1 of the appended claims.

Thus, there is provided an image processing method performed by a processor and comprising: receiving a first image containing one or more objects of interest; deriving local phase and local orientation information from the first image; identifying one or more edge features of the object(s) of interest using the local phase information; and fitting one or more parametric shapes to the edge feature(s) of the object(s) of interest using the local orientation information.

Local phase information advantageously extracts structural image information while being invariant to contrast, and so is well-suited for a variety of image analysis tasks.

Moreover, the use of local orientation information advantageously enables the method to distinguish between inner and outer contours when fitting the parametric shapes to the objects of interest.

Each image edge feature may be described by its pixel location and a feature attribute vector – in our case, local orientation and local phase. Other image feature descriptors may be included in the feature attribute vector in practice.

Preferably the local phase information is derived from the first image using the monogenic signal.

Preferably the step of identifying the edge feature(s) comprises computing the local phase at multiple scales and applying a feature asymmetry measure, although other ways are also possible. Feature asymmetry on its own can also be used directly for fitting the shape(s).

Preferably the step of identifying the edge feature(s) further comprises applying non-maximal suppression in the local orientation direction.

Preferably the step of fitting parametric shapes to the edge feature(s) comprises fitting ellipses or circles. Advantageously, coupled ellipses or circles (which may be concentric) may be fitted simultaneously to inner and outer contours of the same object of interest. Alternatively, the step of fitting parametric shapes to the edge feature(s) may comprise fitting other two-dimensional shapes, or three-dimensional shapes.

Preferably the method further comprises performing quantitative analysis of the image using the fitted shapes. The results of the quantitative analysis may then

be displayed, for example by superimposing the results on the image(s) to which they relate.

According to a second aspect of the invention there is provided imaging apparatus configured to implement a method in accordance with the first aspect of the invention.

The imaging apparatus may be a medical scanner, such as an ultrasound scanner, a computed tomography (CT) scanner or a magnetic resonance imaging (MRI) scanner. Alternatively, the imaging apparatus may be an industrial scanner, for example of the kind used for the non-destructive testing of aircraft components.

According to a third aspect of the invention there is provided image processing apparatus configured to implement a method in accordance with the first aspect of the invention.

According to a fourth aspect of the invention there is provided a processor configured to implement a method in accordance with the first aspect of the invention.

According to a fifth aspect of the invention there is provided a computer program or set of instruction code for implementing a method in accordance with the first aspect of the invention when executed on a processor.

According to a sixth aspect of the invention there is provided a computer-readable medium or physical carrier signal encoding a computer program in accordance with the fifth aspect of the invention.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, and with reference to the drawings in which:

Figure 1(a) is a schematic diagram of the composition of a fetal arm;

Figure 1(b) is a typical ultrasound image of an arm cross-section of a 25 weeks fetus;

Figure 1(c) is a local phase image derived from the ultrasound image in Figure 1(b);

Figure 1(d) is a feature asymmetry image derived from the ultrasound image in Figure 1(b), and from several scales of the local phase;

Figure 1(e) is an edge representation derived from the image in Figure 1(d);

Figure 1(f) illustrates oriented edges in the selected area (dashed square) of Figure 1(e);

Figure 2 illustrates principles of monogenic signal processing;

Figure 3 illustrates filters that can be used for calculating the monogenic signal;

Figure 4(a) illustrates an ellipse fitted to an inner contour of imaged edge features using the present method;

Figure 4(b) illustrates an ellipse fitted to an outer contour of imaged edge features using the present method;

Figures 5(a) to 5(c) illustrate ellipses fitted to edge maps (left hand images) and to ultrasound images (right hand images) using the present method, with Figure 5(a) showing a fetal mid-arm cross-section at 21 weeks of gestation, Figure 5(b) showing a fetal mid-arm cross-section at 26 weeks of gestation, and Figure 5(c) showing a fetal mid-arm cross-section at 28 weeks of gestation – in each case with manual delineations from the same clinical expert displayed on the ultrasound (right hand) images as dashed lines; and

Figure 6 illustrates ellipses fitted to an ultrasound image (as solid lines) using the present method, and two manual delineations (as dashed lines) obtained by the same clinical expert, showing the intra-expert variability that can exist when delineating the object contour manually.

Detailed Description of Preferred Embodiments

The present embodiments represent the best ways known to the applicants of putting the invention into practice. However, they are not the only ways in which this can be achieved.

It is to be emphasised that, although the present embodiments often refer to the soft tissue quantification of tubular structures (such as fetal limb cross-sections) using ultrasound images, the principles described herein are equally applicable to the analysis of other structures in humans or animals, such as left ventricular short-axis myocardial thickness measurement, or vessel thickness estimation. The principles are also applicable to the imaging of man-made objects (e.g. aircraft engine parts) using non-invasive imaging techniques. Moreover, the principles are applicable to any image modality, such as computed tomography (CT) or magnetic resonance imaging (MRI), as well as ultrasound. Embodiments can be used as a research tool or a clinical tool, for example quantifying the amount of soft tissue for a particular application.

Primarily, the present embodiments take the form of a method or algorithm for processing medical (or other) images. The method or algorithm may be incorporated in a computer program or a set of instruction code capable of being executed by a processor. The processor may be that of a conventional (sufficiently high performance) computer, or some other image processing apparatus or computer system. Alternatively, the processor may be incorporated in, or in communication with, a piece of imaging equipment such as an ultrasound scanner or an MRI scanner.

The computer program or set of instruction code may be supplied on a computer-readable medium or data carrier such as a CD-ROM, DVD or solid state memory device. Alternatively, it may be downloadable as a digital signal from a connected computer, either directly or over a local area network or a wide area network such as the Internet. As a further alternative, the computer program or set of instruction code may be hard-coded in the processor (or memory associated therewith) arranged to execute it.

Initial summary

The present embodiment provides automatic oriented feature-based (coupled) ellipse fitting for image-based quantification.

The presently preferred embodiment is a tool for automatic quantification of imaged tubular structures, applicable to medical image soft tissue quantification. It includes a novel ellipse/circle fitting method, which can automatically and simultaneously fit one, two or more ellipses/circles to an image using image edge features and local orientation, which can be derived from the monogenic signal, instead of intensity gradients. The use of the monogenic signal renders the present technique very useful for ultrasound imaging.

Since a circle is a special case of an ellipse, we will refer only to ellipses in the remainder of this description. However, the term "ellipse" should be interpreted as encompassing a circle as one possibility.

The presently preferred embodiment automatically quantifies the soft tissue of tubular structures using a clinical image-based measurement tool that employs (coupled) ellipse fitting based on structural information and a modified Hough transform.

By using the image edge feature representation derived from local phase and orientation instead of intensity gradients (gradients having been used in previous ellipse fitting methods), the candidate object boundary locations and orientation can be identified in a robust way in any imaging modality. Oriented image edge feature maps, which can be derived from the monogenic signal, guide the process to find a single ellipse or coupled ellipses simultaneously (inner and outer contours) for quantification of tubular structures.

Key features of the presently preferred embodiment are:

- An image-based quantification tool that fits ellipses, effectively simultaneously, to the inner and outer contours of tubular structures. Other shapes or structures are also able to be fitted.
- A novel use of edge orientation to identify the contours of the structure of interest to find (coupled) ellipses in the images. The edge orientation is such that it always points outwards from the object of interest, while being

derived from structural information, and can be obtained from the monogenic signal, making it robust to intensity changes.

- A modified Hough transform keeps track of the sign of the dot product between the local orientation and the fitted ellipse normals to decide between the inner and outer contour for coupled ellipses.

Image processing overview

By way of introduction, we illustrate the embodiment with reference to soft tissue quantification. Figure 1(a) is a schematic diagram of fetal arm composition, showing that the arm consists of a humerus bone surrounded by muscle, which in turn is surrounded by an adipose tissue layer. Figure 1(b) is a typical ultrasound image of the cross-section of such an arm, of a 25 weeks fetus. The ultrasound image of Figure 1(b) will be referred to herein as the "original" or "first" image. It can be seen that the original image of Figure 1(b) is prone to speckle and the objects have fuzzy boundaries. The use of local phase is better suited as it is intensity invariant.

In accordance with the presently preferred embodiment, to obtain a structural representation of the original image, a local phase representation as shown in Figure 1(c) is first obtained using the monogenic signal [4] derived from the original image (Figure 2). Image edge features are detected as points of local phase congruency, obtained from computing the local phase at multiple scales and combined using a feature asymmetry measure, as shown in Figure 1(d). The feature asymmetry image contains thick edges, whereas a good localisation of the edges is desirable. Therefore, non-maximal suppression is applied in the local orientation direction, also obtained from the monogenic signal. Other ways of obtaining the edges can also be incorporated into this framework. Feature asymmetry (without non-maximal suppression) with local orientation could also be directly used to find the ellipses, but would not be as well localised.

From the local orientation and the edge map derived from feature asymmetry, an oriented edge map as shown in Figures 1(e)-(f) is then produced by assigning the corresponding local orientation value to each pixel within the edge map of Figure

1(e). In Figures 1(e)-(f), local orientation vectors point outwards from the structure of interest.

Ellipses, circles or other parametric shapes can then be automatically fitted to the oriented edge map, with the vector information being used to determine whether the fitted shape corresponds to an outer or an inner boundary of the imaged feature. Such a process is illustrated in Figures 4(a) and 4(b), and described in greater detail below. Measurements or other quantitative analysis may then be carried out using the fitted shapes.

Local phase and local orientation estimation

The monogenic signal [4] $I_M(x,y)$ of an image $I(x,y)$ generalises the analytic signal to 2D and higher dimensions using a Riesz transform instead of a Hilbert transform. From the monogenic signal, local energy, local phase, and local orientation can be estimated. The image is initially convolved with a bandpass filter $b(x,y)$, to give $I_b(x,y) = b(x,y) \otimes I(x,y)$, where $\otimes$ denotes the convolution operation. The monogenic signal is then expressed as $I_M(x,y) = (I_b(x,y), h_1(x,y) \otimes I_b(x,y), h_2(x,y) \otimes I_b(x,y))$, where h_1 and h_2 are the convolution kernels of the Riesz transform, which are represented in Figure 3 and defined as

$$h_1(x,y) = \frac{x}{2\pi(x^2+y^2)^{\frac{3}{2}}} \text{ and } h_2(x,y) = \frac{y}{2\pi(x^2+y^2)^{\frac{3}{2}}}, \text{ respectively.}$$

The local energy $E(x,y)$, local phase $\varphi(x,y)$, and local orientation $\theta(x,y)$ of $I(x,y)$ are derived from $I_M(x,y)$ and expressed as

$$E(x,y) = \sqrt{I_b^2 + (h_1 \otimes I_b)^2 + (h_2 \otimes I_b)^2},$$

$$\varphi(x,y) = \arctan\left(\frac{I_b(x,y)}{\sqrt{(h_1(x,y) \otimes I_b(x,y))^2 + (h_2(x,y) \otimes I_b(x,y))^2}}\right), \text{ and}$$

$$\theta(x,y) = \arctan\left(\frac{h_2(x,y) \otimes I_b(x,y)}{h_1(x,y) \otimes I_b(x,y)}\right), \text{ respectively.}$$

Figure 2 illustrates in more detail the operations used to process the monogenic signal derived from the original image, in order to obtain the local phase (e.g. processing the image of Figure 1(b) to obtain the image of Figure 1(c)) and local orientation representations.

The local phase is estimated using the monogenic signal but can be estimated using other approaches. It is invariant to contrast and describes the structure of the object of interest rather than the magnitude.

As shown in Figure 2, h_1 and h_2 provide the quadrature pair of filters required for local phase estimation. In the frequency domain, these filters are defined as $H_1(u,v) = \frac{u}{\sqrt{u^2+v^2}}$ and $H_2(u,v) = \frac{v}{\sqrt{u^2+v^2}}$. $H_1(u,v)$ is a cosine in the Fourier domain and $H_2(u,v)$ is a sine. This pair of filters define the Riesz transform. The scale selected determines the size of the structures detected. The choice of the band-pass filter used also affects the final result.

Feature asymmetry processing

Image edge features can be detected at points of local phase congruency, obtained from computing the local phase (such as that shown in Figure 1(c)) at multiple scales and combined using the feature asymmetry (FA) measure defined as

$$\mathrm{FA} = \frac{1}{N}\sum_s \frac{\left\lfloor \left|\mathrm{I}_{\mathrm{bh}s}\right| - \left|I_{bs}\right| - T_s \right\rfloor}{\sqrt{I_{bs}^{\ 2} + \mathrm{I}_{\mathrm{bh}s}^{\ 2}} + \varepsilon}$$

where

$I_b = I \otimes b,$

$\mathbf{I_{bh}} = (h_1 \otimes I_b, h_2 \otimes I_b),$

s represents the scale,

N is the total number of scales,

T_s is an orientation dependent threshold that controls spurious responses to noise at scale s,

$\lfloor \ldots \rfloor$ sets to zero the negative values, and

$\varepsilon = 0.01$, to avoid division by zero.

Feature asymmetry returns a value between 0 and 1. A feature is defined as a point where there is local phase congruency among scales.

Thinning

The feature asymmetry image (e.g. Figure 1(d)) can be thinned in order to give better localization of the actual edges, resulting in an image such as the one shown in Figure 1(e).

Oriented edge map construction

Having obtained an image with preferably well-localized edges (e.g. by thinning as noted above), such as the one shown in Figure 1(e), an oriented edge map can then be constructed by adding the local orientation information to the edge features, which can be obtained from feature asymmetry. Figure 1(f) shows the local orientation vectors added to the feature edges within the dashed square in Figure 1(e). Local orientation vectors (represented by arrows in Figure 1(f)) point outwards from the object of interest. Being derived from structural information, obtained from the monogenic signal, makes this process robust to intensity changes and independent of the intensity gradient.

Shape fitting and vector analysis

Having determined the orientations of the image edge features, parametric shapes such as (but not necessarily limited to) ellipses or circles can then be automatically fitted to the edge features. Any pixel in the oriented edge map (e.g. as shown in Figure 1(f)) can be a potential ellipse centre. For each potential centre, the parameters of an ellipse (principal axes and orientation) are iteratively varied and, at each iteration, points on the ellipse that match edge features are analysed and

a likelihood score obtained as follows: At each point on the ellipse, the scalar product between the local orientation of each oriented edge feature and the normal to the ellipse at that point is calculated and accumulated. For each potential ellipse centre, the best ellipse parameters for the ellipses fitting the inner and outer contours are obtained using the accumulator values. Coupled ellipses can be identified simultaneously by retaining the two ellipses such that the inner/outer contours have an opposite scalar product sign and minimise/maximise the accumulator at that ellipse centre.

Examples of fitted ellipses are illustrated using dashed lines in Figures 4(a) and 4(b). In Figure 4(a), the scalar product is negative at the image edge features on the inner contour matching the fitted ellipse (the dashed line 42). Conversely, in Figure 4(b), the scalar product is positive at the image edge features belonging to the outer contour matching the fitted ellipse (the dashed line 44).

The scalar product is used to update the accumulator for detecting coupled ellipses on the images. Instead of using intensity gradients, the oriented edge map based on structural information is created. For circle detection only three parameters are necessary, whereas ellipse detection requires five parameters.

The scalar product of an ellipse matching the inner contour of the object is negative, since the local orientation of the inner contour and the normal vectors to the fitted ellipse at those edge points are opposite. The scalar product of an ellipse matching the outer contour is positive because the local orientation and the normal vectors to the ellipse at those points are pointing in the same direction.

The final coupled ellipses are obtained using a likelihood score, which combines the results of inner and outer contours, so the best ellipses are detected simultaneously. The likelihood score can be defined in a number of ways, by using the information from the accumulator. An example is given in the following:

An ellipse is characterised by five parameters, which are the centre (x_0, y_0), the semi-major axis a, the semi-major axis b, and the angle of rotation β. The current implementation is aimed at detecting two concentric ellipses simultaneously. In this particular case, the orientation of both ellipses is set to be the same, making sure that the semi-major axes of the outer ellipse are bigger than the semi-major axes of the inner ellipse. For each potential ellipse centre (x,y) in the image, the best ellipse parameters fitting the inner and outer contours are obtained as $(a_{\text{in}}, b_{\text{in}}, \beta_{\text{in}}) = \underset{a,b,\beta}{\arg\min}\left(H(x,y,a,b,\beta)\right)$ and $(a_{\text{out}}, b_{\text{out}}, \beta_{\text{out}}) = \underset{a \geq a_{\text{in}}, b \geq b_{\text{in}}}{\arg\max}(H(x,y,a,b,\beta_{\text{in}}))$, respectively. In this particular application, the orientation of the best fitted ellipses to inner and outer contours is assumed to be similar. This criteria can be modified depending on the application, and other criteria, such as preserving the eccentricity, can be used instead. Furthermore, the criteria can be modified to find more than two ellipses, concentric or not.

Once the best parameters for inner and outer ellipses are obtained at each image pixel (x,y), a likelihood score $L(x,y)$ can be defined as $L(x,y) = H(x,y,a_{out},b_{out},\beta_{out}) - H(x,y,a_{in},b_{in},\beta_{in})$. $L(x,y)$ is maximised to find the centre (x_0, y_0) of the coupled ellipses that best fit the edges in the oriented edge map.

Parametric shapes other than circles or ellipses may be fitted using this technique. For example, shapes with straight edges (e.g. triangles, hexagons, squares or rectangles) may be fitted, as may irregular shapes. Three-dimensional structures such as spheres/hollow spheres or cylinders/tubes may also be fitted to three-dimensional images using this technique.

Quantitative analysis

Having fitted the shapes, measurements or other quantitative analytical calculations may then be carried out using the fitted shapes. For example, linear,

area or volume measurements relating to the fitted shapes may be evaluated, or ratios or other functions may be calculated. As those skilled in the art will appreciate, the quantitative results may be presented to the user on a display screen (e.g. superimposed on the images to which they relate), printed on paper, or saved in memory or in a data storage device.

Experimental demonstration

The above techniques were used on a dataset of ultrasound images of the fetal arm to quantify adipose tissue across gestation, obtaining good results as presented in Figures 5(a) to 5(c). These figures illustrate ellipses fitted to edge maps (left hand images) and to ultrasound images (right hand images), with Figure 5(a) showing a fetal mid-arm cross-section at 21 weeks of gestation, Figure 5(b) showing a fetal mid-arm cross-section at 26 weeks of gestation, and Figure 5(c) showing a fetal mid-arm cross-section at 28 weeks of gestation. The dashed line contours in the left hand images and the solid line contours in the right hand images correspond to the fitted ellipses. The dashed lines on the right hand images correspond to manual delineations by the same trained clinician at two different time points. Figure 6 displays the fitted ellipses (solid line contours) over the manually delineated contours (dashed lines) by the same clinical expert. This example shows how difficult it is to manually delineate the contours of the object of interest, since the two manual delineations have a high variability among themselves, due to fuzzy regions in the ultrasound image. This shows the necessity of automated tools for soft tissue quantification, and how well the present ellipse fitting method performs using the image information.

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CLAIMS

1. An image processing method performed by a processor and comprising:

receiving a first image containing one or more objects of interest;

deriving local phase and local orientation information from the first image;

identifying one or more edge features of the object(s) of interest using the local phase information; and

fitting one or more parametric shapes to the edge feature(s) of the object(s) of interest using the local orientation information.

2. A method as claimed in claim 1, wherein the local phase information is derived from the first image using the monogenic signal.

3. A method as claimed in claim 1 or claim 2, wherein the step of identifying the edge feature(s) comprises computing the local phase at multiple scales and applying a feature asymmetry measure.

4. A method as claimed in claim 3, wherein the step of identifying the edge feature(s) further comprises applying non-maximal suppression in the local orientation direction.

5. A method as claimed in any preceding claim, wherein the step of fitting parametric shapes to the edge feature(s) comprises fitting ellipses or circles.

6. A method as claimed in claim 5, wherein coupled ellipses or circles are fitted simultaneously to inner and outer contours of the object(s) of interest.

7. A method as claimed in claim 6, wherein the coupled ellipses or circles are concentric.

8. A method as claimed in any of claims 1 to 4, wherein the step of fitting parametric shapes to the edge feature(s) comprises fitting three-dimensional shapes.

9. A method as claimed in any preceding claim, further comprising performing quantitative analysis of the image using the fitted shapes.

10. A method as claimed in claim 9, further comprising displaying the results of the quantitative analysis.

11. A method as claimed in claim 10, further comprising superimposing the results of the quantitative analysis on the image(s) to which they relate.

12. Imaging apparatus configured to implement a method as claimed in any preceding claim.

13. Imaging apparatus as claimed in claim 12, being a medical scanner.

14. Imaging apparatus as claimed in claim 13, being an ultrasound scanner.

15. Imaging apparatus as claimed in claim 13, being a computed tomography scanner or a magnetic resonance imaging scanner.

16. Imaging apparatus as claimed in claim 12, being an industrial scanner.

17. Image processing apparatus configured to implement a method as claimed in any of claims 1 to 11.

18. A processor configured to implement a method as claimed in any of claims 1 to 11.

19. A computer program or set of instruction code for implementing a method as claimed in any of claims 1 to 11 when executed on a processor.

20. A computer-readable medium or physical carrier signal encoding a computer program as claimed in claim 19.

21. An image processing method substantially as herein described with reference to and as illustrated in any combination of the accompanying drawings.

22. Imaging apparatus, image processing apparatus, or a processor substantially as herein described with reference to and as illustrated in any combination of the accompanying drawings.

23. A computer program or set of instruction code substantially as herein described with reference to and as illustrated in any combination of the accompanying drawings.

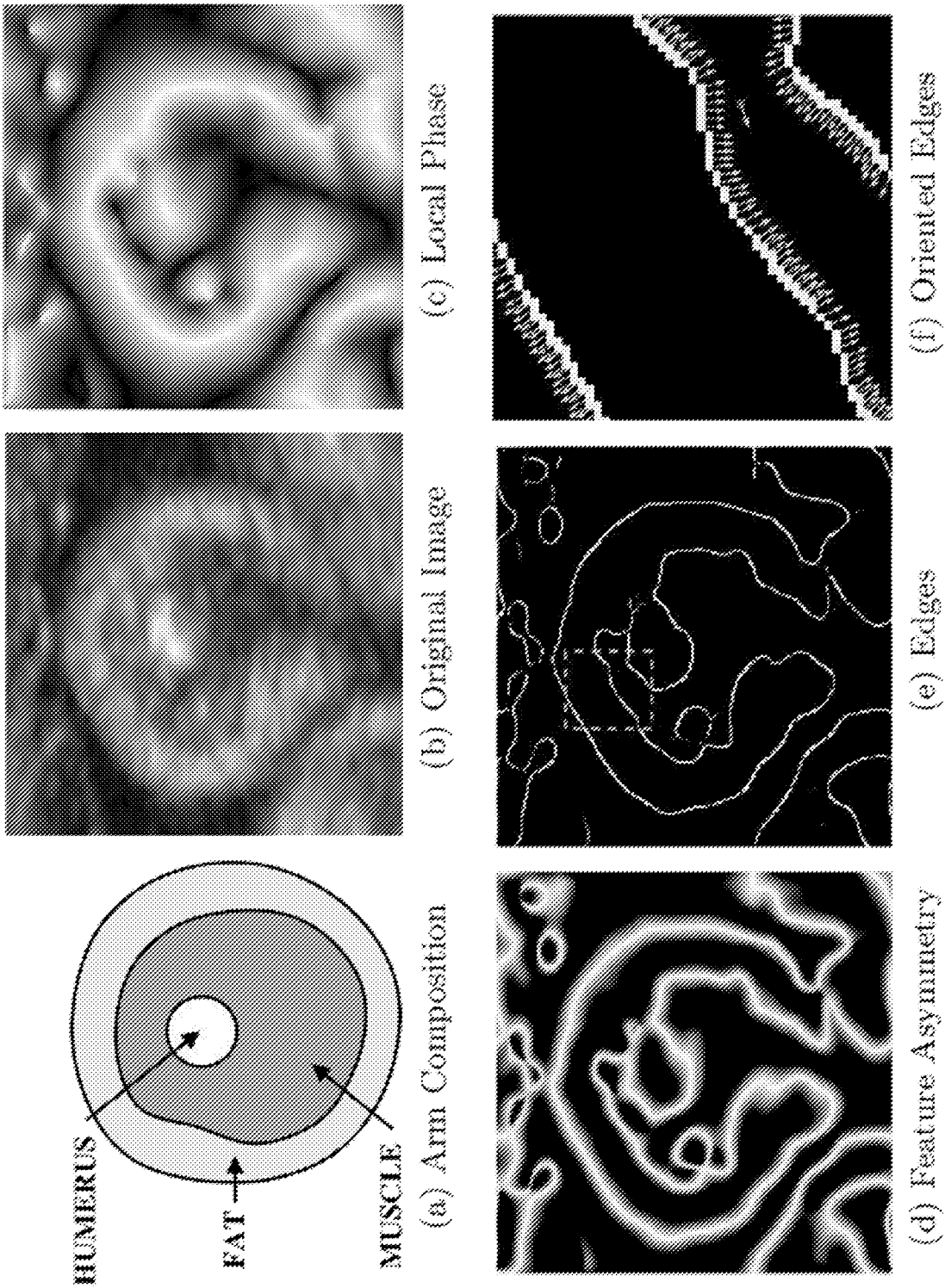

HUMERUS
FAT
MUSCLE
(a) Arm Composition
(b) Original Image
(c) Local Phase
(d) Feature Asymmetry
(e) Edges
(f) Oriented Edges

Figure 1

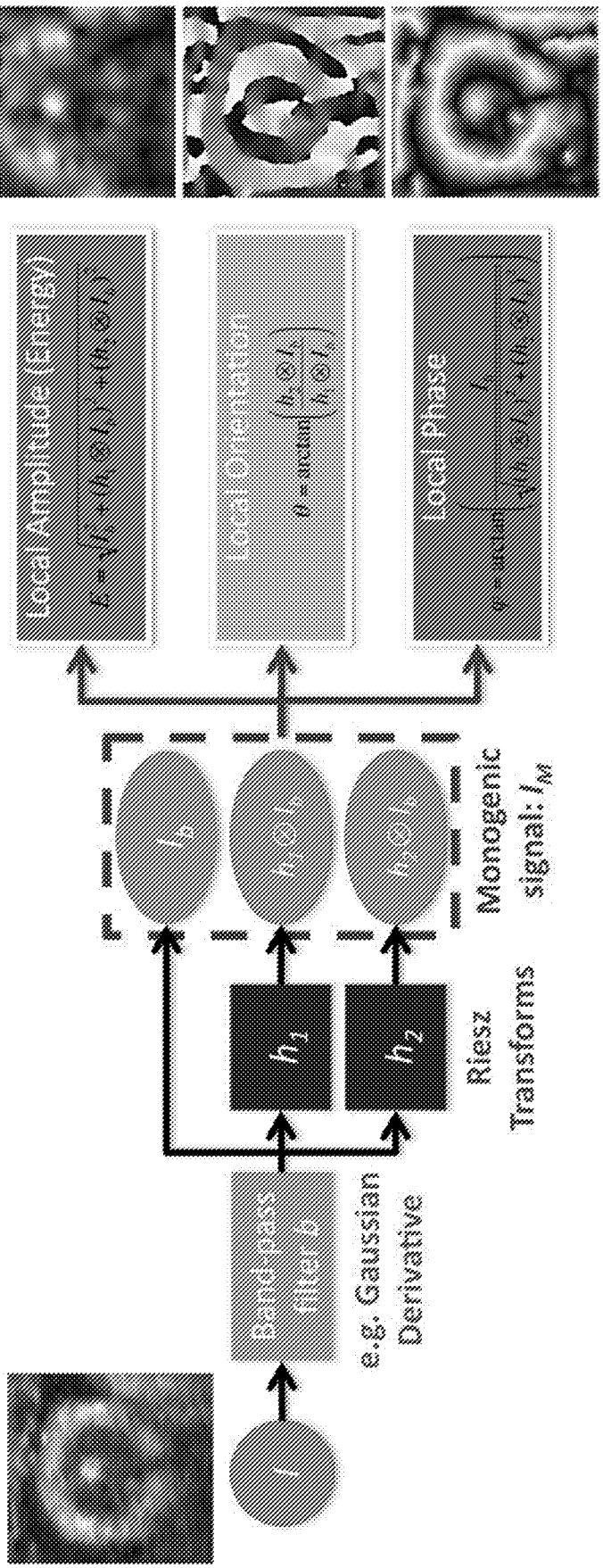

Local Amplitude (Energy)
Local Orientation
Local Phase
Monogenic signal: I_M
Riesz Transforms
h_1
h_2
e.g. Gaussian Derivative
Bandpass filter b
I

Figure 2

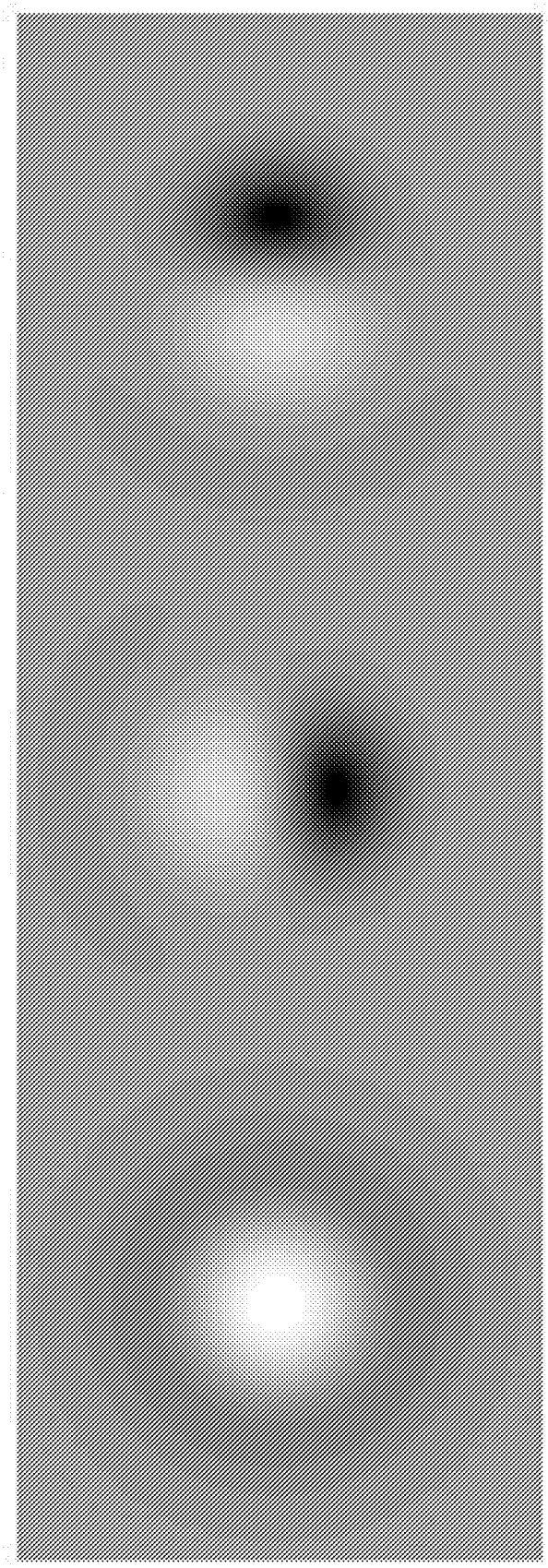


Figure 3

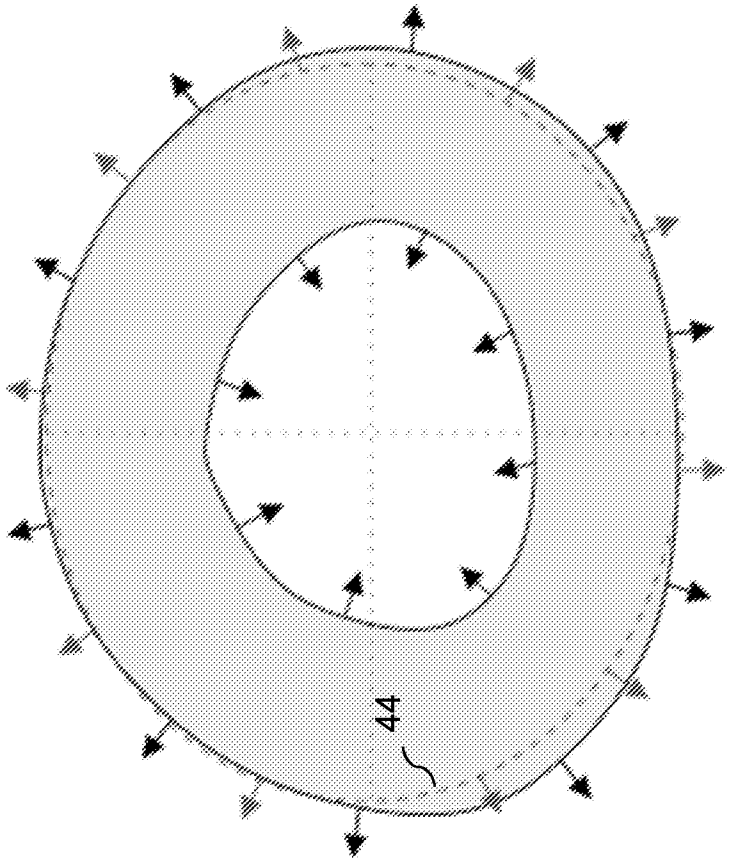


Figure 4(b)

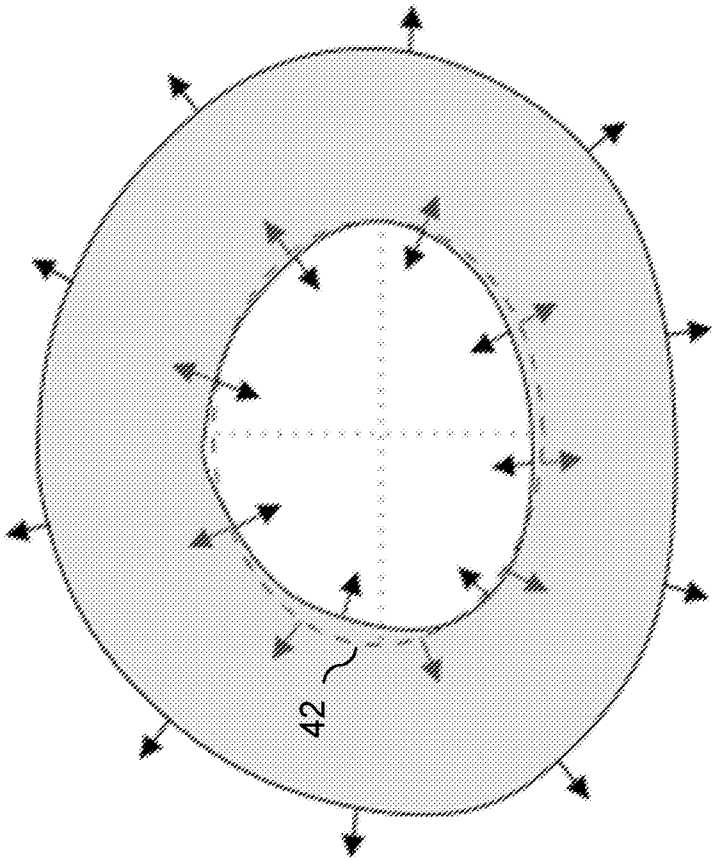
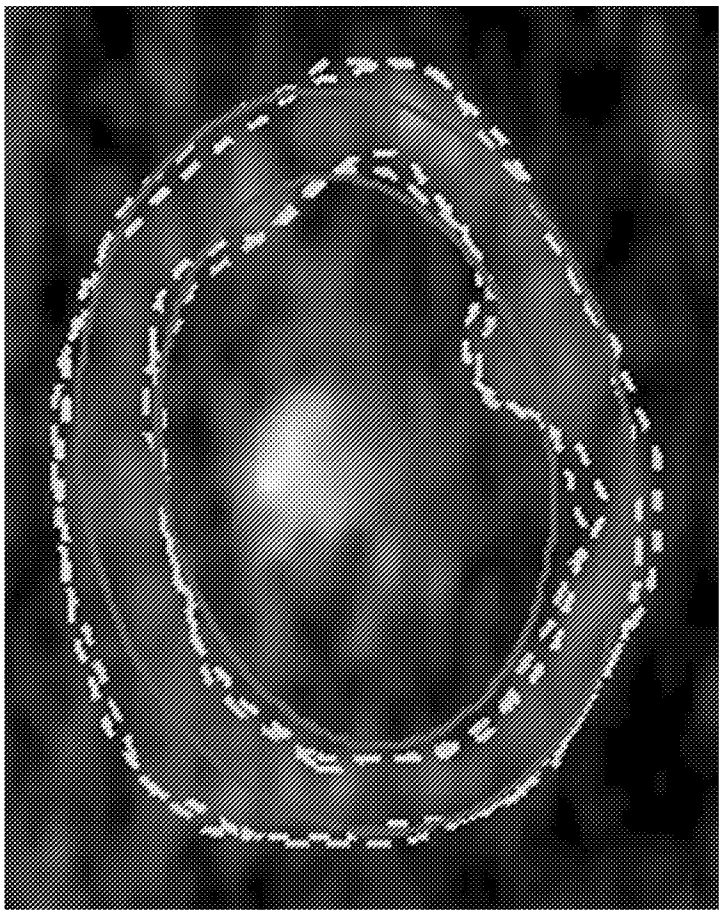


Figure 4(a)



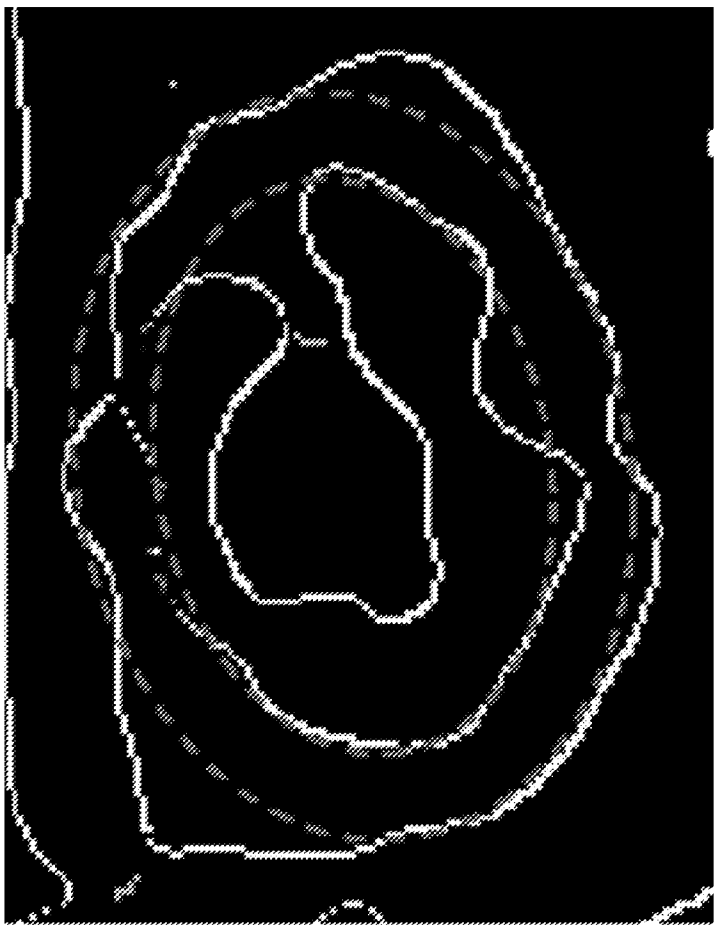


Figure 5(a)

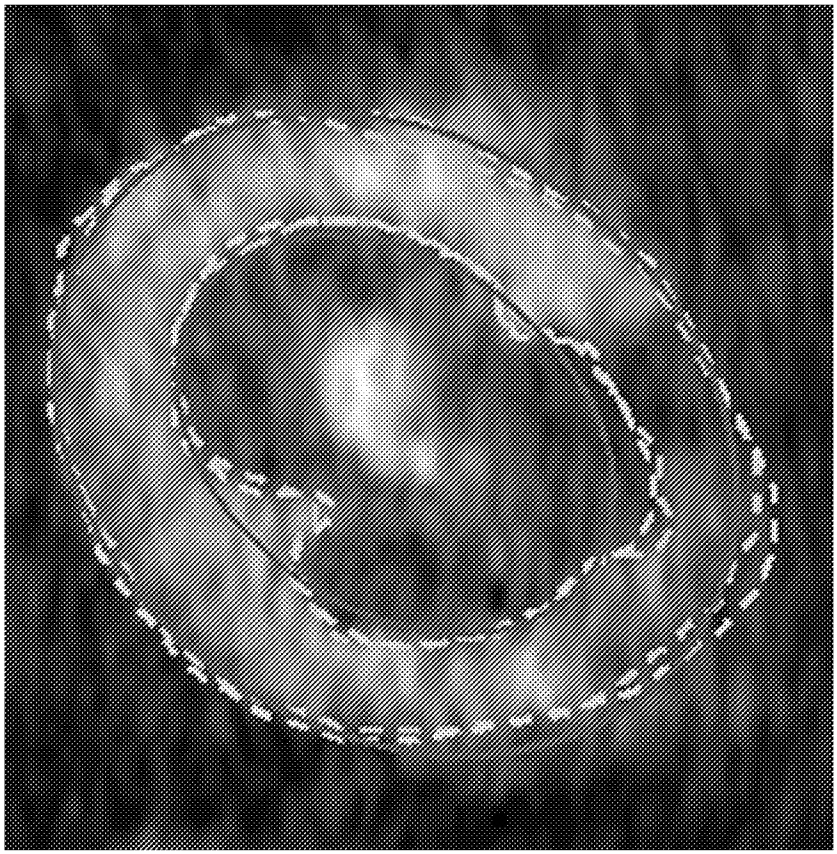




Figure 5(b)

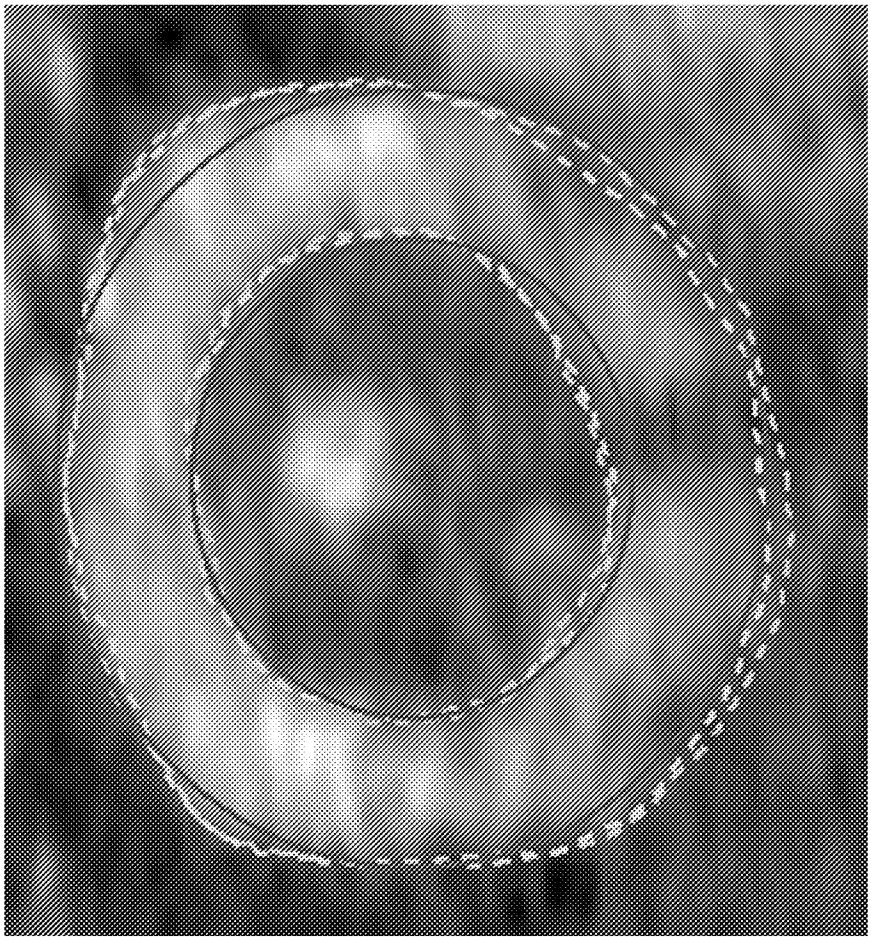




Figure 5(c)

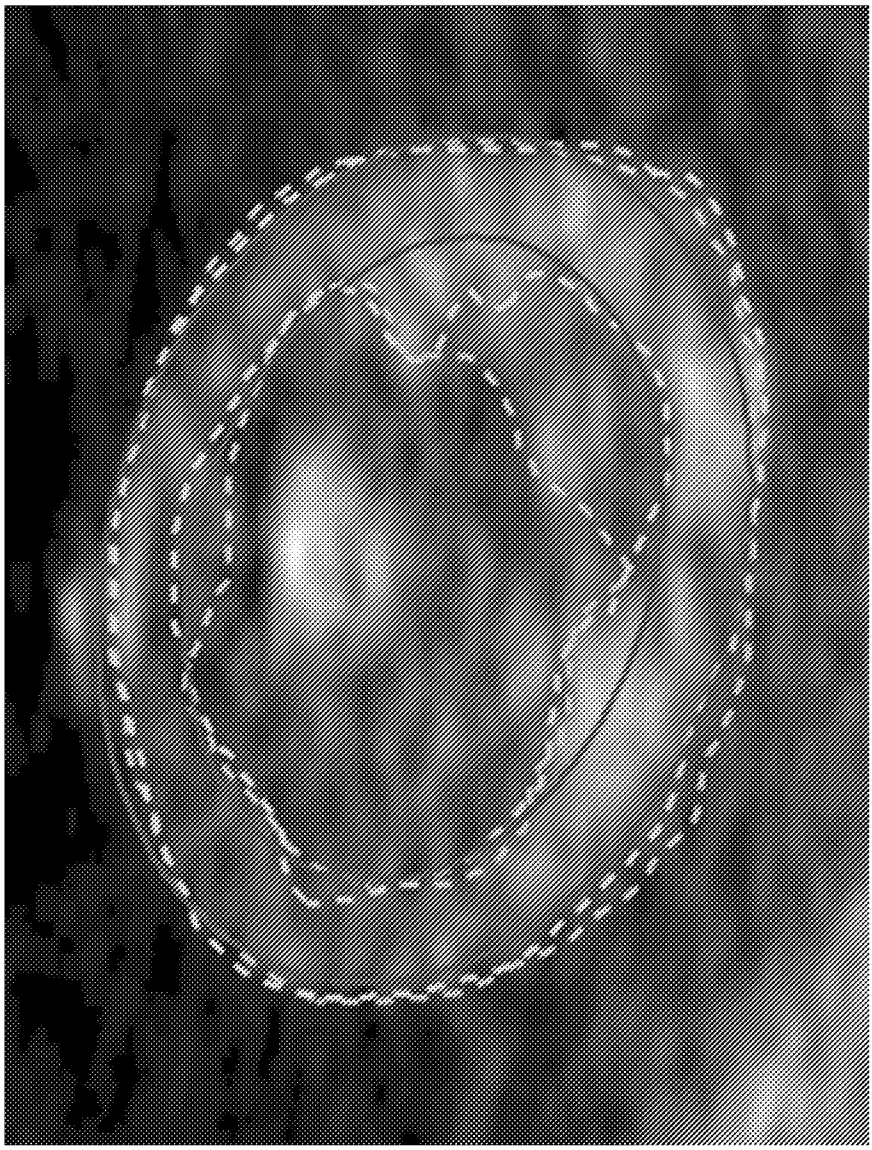


Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2014/050010

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T7/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06T

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BELAID A ET AL: "Phase-Based Level Set Segmentation of Ultrasound Images", IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, IEEE SERVICE CENTER, LOS ALAMITOS, CA, US, vol. 15, no. 1, 1 January 2011 (2011-01-01), pages 138-147, XP011373644, ISSN: 1089-7771, DOI: 10.1109/TITB.2010.2090889 abstract; figures 10,11 section II BACKGROUND subsection II.C Edge Detection Measure ----- -/--	1-23

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 March 2014	02/04/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Blaszczyk, Marek

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	UNSER M ET AL: "Multiresolution Monogenic Signal Analysis Using the Rieszâ Laplace Wavelet Transform", IEEE TRANSACTIONS ON IMAGE PROCESSING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 18, no. 11, 1 November 2009 (2009-11-01), pages 2402-2418, XP011294582, ISSN: 1057-7149 the whole document	1-23
A	MARTIN STORATH: "Directional Multiscale Amplitude and Phase Decomposition by the Monogenic Curvelet Transform", SIAM JOURNAL ON IMAGING SCIENCES, vol. 4, no. 1, 1 January 2011 (2011-01-01) , pages 57-78, XP055109315, DOI: 10.1137/100803924 the whole document	1-23
A	WO 2007/010206 A1 (ISIS INNOVATION [GB]; GRAU VICENTE [GB]; NOBLE JULIA ALISON [GB]) 25 January 2007 (2007-01-25) the whole document	1-23
A	FATHIMA SANA ET AL: "A novel local-phase method of automatic atlas construction in fetal ultrasound", MEDICAL IMAGING 2011: IMAGE PROCESSING, SPIE, 1000 20TH ST. BELLINGHAM WA 98225-6705 USA, vol. 7962, no. 1, 3 March 2011 (2011-03-03), pages 1-10, XP060009541, DOI: 10.1117/12.878317 [retrieved on 2011-04-06] the whole document	1-23

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2014/050010

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2007010206 A1	25-01-2007	AT 456841 T	15-02-2010
		EP 1904971 A1	02-04-2008
		JP 2009501587 A	22-01-2009
		US 2009208080 A1	20-08-2009
		WO 2007010206 A1	25-01-2007