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(54) Title: IMAGING METHOD



Fig. 1A

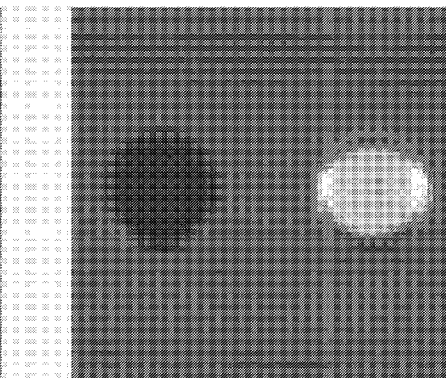


Fig. 1B

(57) Abstract: To provide detailed viscoelastic maps of a target volume, such as soft tissue in a living subject, using an imaging technique that combines magnetic resonance imaging and acoustic imaging techniques, images generated at a plurality of different acoustic frequencies are filtered and post-processed.

IMAGING METHOD

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to an imaging method. In particular, the present invention relates to a technique for combining magnetic resonance imaging and acoustic imaging techniques to image a target volume, such as a human or animal body.

[0002] Magnetic Resonance Elastography (MRE) is an imaging method that combines Magnetic Resonance Imaging (MRI) with acoustics and wave mechanics. In MRE, actuation equipment is configured to propagate shear acoustic waves into a target volume (typically, a volume of soft tissue in a human body, for example) substantially simultaneously with an MRI scan. The MRI scan program is specially adapted to be sensitive to the wave motion and encode the waves in the MRI image: this may be achieved by using an additional gradient waveform in the pulse sequence to sensitize the MRI scan to shear waves in the tissue. The resulting wave field images allow mapping of viscoelastic parameters of the target volume, such as tissue elasticity ($|G^*|$) and viscosity (ϕ). This is because the wavelength of waves travelling through tissue reflects elasticity, and the damping rate of those waves reflects viscosity. Elasticity is considered a measure of the tissue integrity, while viscosity is considered a measure of the tissue complexity.

[0003] There are three main clinical reasons to image elasticity and viscosity:

[0004] 1. Elasticity and viscosity are cell-mechanical properties and disease is a process of cell mechanics. Therefore elasticity and viscosity are highly sensitive to tissue change

associated with disease and recovery. The method of measurement used in MRE, i.e. shear wave elastography, has been shown to be two orders of magnitude more sensitive to tissue change than conventional MRI.

[0005] 2. Elasticity and viscosity change due to events on the microstructural level. Conventional MRI only detects changes large enough to be visible in the image. However, MRE is sensitive to diffuse changes even when they do not result in visible features (such as lesions in soft tissue). For example, brain tissue has been shown to lose overall elasticity by over 20% during the aging process and such a diffuse change can be detected with MRE, even if this loss does not create visible alterations to the brain.

[0006] 3. Elasticity and viscosity do not have any correlates in other forms of MRI measurement. Therefore, for any soft tissue change, MRE adds two kinds of novel information to any diagnostic assessment, the elasticity and viscosity of the tissue.

[0007] MRE has been slow to be adopted for diagnostic use. This is considered to be due principally to MRE remaining a low-resolution technique. It has been too low-resolution an image technique to be relevant to many MRI related diagnostic procedures, especially considering the cost of the additional equipment needed to vibrate the tissue.

[0008] A team of researchers from Berlin has developed a technique called Multi-frequency Magnetic Resonance Elastography (MMRE) that acquires MRE scans at multiple frequencies of vibration, then fuses the results together, to increase signal to noise and create clearer images. The algorithm used by the Berlin team to fuse MRE scans acquired at multiple frequencies

is termed Multi-Frequency Dual ElastoVisco Inversion and abbreviated as MDEV. This technique produces MRE at high-resolution (relative to the previous conventional MRE techniques), not because it increases the original resolution but because it produces distinct details (such as liver blood vessels and brain sulci) not produced by previous MRE techniques. The difference is illustrated when comparing Figures 2A and 2B (and Figures 2D and 2E) below.

[0009] Increased image resolution at a given field strength is a widely sought after goal in MRI. While the increased clarity offered by the MDEV algorithm is welcome, adoption of MRE techniques is still hampered by the underlying perception that the resolution offered is insufficient for radiological applications such as disease diagnosis, lesion diagnosis, or surgical planning.

[0010] It is an aim of certain embodiments of the present disclosure to solve, mitigate or obviate, at least partly, at least one of the problems and/or disadvantages associated with the related art. Certain embodiments aim to provide at least one of the advantages described below.

SUMMARY OF THE INVENTION

[0011] In one aspect of the present disclosure, there is provided an apparatus for creating super-resolution viscoelastic parameter maps of a target volume.

[0012] In another aspect of the present disclosure, there is provided a system for the creation of super-resolution viscoelastic parameter maps of a target volume.

[0013] In yet another aspect of the present disclosure, there is provided a method for processing images of a target volume, the method comprising: acquiring a plurality of wave field images at a plurality of different frequencies; generating a plurality of intermediate images by interpolating and upscaling the respective wave field images; combining the data from the intermediate images; and generating super-resolution elasticity and viscosity maps from the combined data.

[0014] Preferably, the wave field images are wave field images obtained using magnetic resonance elastography, MRE.

[0015] The plurality of different frequencies is conveniently a plurality of different frequencies of acoustic waves.

[0016] Alternatively, the wave field images may be wave field images obtained using ultrasound elastography, USE.

[0017] In certain embodiments, the operation of interpolating and upscaling the respective wave field images may further comprise performing de-noising and interpolation in the complex wavelet domain.

[0018] Certain embodiments may further comprise applying a feature detecting filter to enhance the quality of the

respective maps. The feature detecting filter may be a Gabor filter.

[0019] The above method there by provides for the creation of super-resolution viscoelastic parameter maps of a target volume.

[0020] In accordance with another aspect of the present disclosure there is provided, an apparatus for processing images of a target volume, the apparatus comprising a processor configured to: acquire a plurality of wave field images at a plurality of different frequencies; generate a plurality of intermediate images by interpolating and upscaling the respective wave field images; combine the data from the intermediate images; and generate super-resolution elasticity and viscosity maps from the combined data.

[0021] In accordance with yet one further aspect of the invention there is provided a system for processing images of a target volume comprising: a scanner configured to generate a plurality of wave field images of the target volume; and an apparatus as set out in the preceding aspect.

[0022] By requiring that interpolation of the wave images takes place prior to wave inversion, the method facilitates the interpolation of a plurality of MRE wave field images acquired at different frequencies to larger than original size prior to combining the information from these images to create super-resolution elasticity and viscosity maps. The method achieves super-resolution in MMRE techniques.

[0023] Another aspect of the present disclosure provides a computer program comprising instructions arranged, when executed, to implement a method in accordance with any one of the above-described aspects. A further aspect provides machine-readable storage storing such a program.

[0024] Various further aspects and embodiments of the present disclosure are provided in the accompanying independent and dependent claims.

[0025] It will be appreciated that features and aspects of the present disclosure described above in relation to the first and other aspects of the invention are equally applicable to, and may be combined with, embodiments of the invention according to the different aspects of the invention as appropriate, and not just in the specific combinations described above. Furthermore features of the dependent claims may be combined with features of the independent claims in combinations other than those explicitly set out in the claims.

DESCRIPTION OF THE DRAWINGS

[0026] The invention, together with objects and advantages thereof, may best be understood by reference to the following description of exemplary embodiments together with the accompanying drawings in which:

[0027] Figures 1A and 1B illustrate the operation of Magnetic Resonance Elastography (MRE);

[0028] Figures 2a to 2F compare images resulting from MRE techniques in accordance with the related art with images generated in accordance with the present disclosure;

[0029] Figure 3 illustrates the relation between (a) successive sections through the wave field images, at a plurality of vibrational frequencies, in close-up passing over a grey matter brain feature, (b) elasticity results for the same region using the high-resolution technique in accordance with the related art, and (c) results from the same region using the

super-resolution technique in accordance with the present disclosure; and

[0030] Figures 4A to 4F show brain MRE scans acquired in two subjects diagnosed with brain tumours of different types: a glioblastoma (GBM) and a metastases (MET); and

[0031] Figures 5A and 5B schematically illustrate the operational flow of image processing in accordance with the related art, while Figure 5C schematically illustrates the operational flow of image processing in accordance with an aspect of the present disclosure.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0032] The detailed description set forth below in connection with the appended drawings is intended as a description of certain exemplary embodiments of the invention, and is not intended to represent the only forms in which the present invention may be practised. It is to be understood that the same or equivalent functions may be accomplished by different embodiments that are intended to be encompassed within the scope of the invention. In the drawings, like numerals are used to indicate like elements throughout. Furthermore, terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that module, circuit, device components, structures and method steps that comprises a list of elements or steps does not include only those elements but may include other elements or steps not expressly listed or inherent to such module, circuit, device components or steps. An element or step preceded by "comprises ..." does not, without more constraints, preclude the existence of additional identical elements or steps that comprises the element or step.

[0033] Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0034] MRE is an imaging method that combines MRI imaging with acoustics and wave mechanics. MRE works by propagating acoustic (i.e. shear) waves into soft tissue at the same time as an MRI scan. The propagating acoustic waves vibrate tissue harmonically and the resulting MRI scan encodes the wave motion in the phase image using motion-sensitised gradients. The resulting wave images allow mapping of tissue elasticity and viscosity. This is because the wavelength of waves travelling through tissue reflects elasticity, and the damping rate of those waves reflects viscosity. Elasticity is considered a measure of the tissue integrity, while viscosity is considered a measure of the tissue complexity.

[0035] Figures 1A and 1B illustrate the operation of Magnetic Resonance Elastography (MRE). The wave field generated from vibration of a simulated phantom is shown in Figure 1A (with the wave front propagating from the top of the image). The wavelengths in Figure 1A are mostly uniform, however there are shorter wavelengths in an area image left, and longer wavelengths in an area image right. This change in wavelength is a response to a change in the stiffness of the simulated medium. This is reflected in the elasticity map in Figure 5b. The region with shorter wavelengths is evaluated as less stiff, and the region with longer wavelengths is evaluated as more stiff.

[0036] As noted above, there are three principal, clinical reasons to image elasticity and viscosity: increased sensitivity to tissue change; sensitivity to diffuse changes in tissue; and the provision of novel information in the form of the elasticity and viscosity of the tissue.

[0037] MRE has until recently remained a low-resolution technique: too low-resolution to be practical to many MRI related diagnostic procedures.

[0038] The introduction of the MMRE technique now offers a (relatively) high-resolution MRE scan.

[0039] Multi-frequency MRE (MMRE) fuses acquisitions at several actuation frequencies to enhance resolution and measure frequency-related dispersion.

[0040] In the field of photography, it is known that a combination of images of the same subject captured under slightly varying light conditions (and thus encapsulating non-redundant information that is not perceptible in a single one of those images) may be combined into one or more super-resolution image. This technique is sometimes referred to as motion-free super-resolution (SR). Super-resolution techniques have been contemplated for ultrasound images.

[0041] It has been realised that because each of these multifrequency wave acquisitions in the MMRE technique contains non-redundant information, there was the potential to apply motion-free Super-Resolution (SR) in the MMRE technique: the multiple low-resolution images of the same scene could be interpolated and fused to create a single, higher-resolution image. This realisation has mathematical basis in the Generalised Theorem of Interpolation, which states that if there

are several images of a scene containing non-redundant information, then if the images are interpolated and combined, there will be finer detail in the combined image than that found in any of the original images.

[0042] In the MDEV algorithm, acquisitions are combined to create clearer images at the same resolution. The MDEV combining operation includes an inversion step. It was further realised that if the multifrequency acquisitions could be interpolated prior to the inversion step, the final image will not only be larger, but will also contain detail on a finer scale than that found in any of the individual acquired images.

[0043] In certain embodiments, the interpolation may include, for example, upscaling the acquired images by a factor of two or four.

[0044] Figures 2A to 2F illustrate current results from a low-resolution MRE technique in accordance with the related art (Figures 2A and 2D); the high-resolution MDEV technique in accordance with the related art (Figures 2B and 2E); and results from the super-resolution technique in accordance with the present disclosure (Figures 2C and 2F).

[0045] Figures 2A to 2C show respective images of a liver (the subject being the same in each case). Figures 2D to 2F show respective images of a subject's brain.

[0046] Here the improvement in visible detail between conventional MRE technique (Figures 2A and 2D) and the multifrequency MRE techniques (Figures 2B, 2C, 2E and 2F) is apparent. There is further improvement in the resolution offered by the SR-MDEV images (Figures 2C and 2F), which are considerably less pixelated than (Figures 2B and 2E).

[0047] Figure 3 illustrates the impact of the image processing method in accordance with the present disclosure as applied to a low-stiffness grey matter fold (sulcus) in the brain surrounded by higher-stiffness white matter. The sulcus occurs approximately $1/3$ to $1/2$ of the distance across the plot. Figure 3(a) shows a cross-sectional plot along a line through the wave field at six different acoustic frequencies as it moves across the sulcus. The wave movements change sharply upon reaching the sulcus, then return to longer wavelengths.

[0048] In a corresponding at-resolution elastogram shown in Figure 3(b), a drop in stiffness is detected at the sulcus, at resolution levels comparable to the wave fields.

[0049] Applying an image processing technique in accordance with an embodiment of the present disclosure produces a super-resolution elastogram (shown in Figure 3(c)). In this Figure, information is available on a scale finer than any of the individual images. Grey matter ribbon on both sides of the sulcus is visible in two valleys, with an increase in the middle for the pial membrane. Additionally, the boundaries are sharper, with white matter values near the sulcus recovered on both sides.

[0050] It was not straightforward to apply motion-free SR to MMRE datasets. It was necessary to determine the mathematical and signal processing bases for the application of SR to the MMRE data and to determine at what stage in the image processing to perform the interpolation operation. It was also necessary to determine the most appropriate interpolation, de-noising, and image fusion methods and to develop software (i.e. computer code) that could process these extremely large images in practical time frames.

[0051] Certain embodiments of the present disclosure apply the SR technique to a plurality of MMRE wave field acquisitions, where the acquisitions are generated using the Multi-Frequency Dual Elastovisco Inversion (MDEV) algorithm. MDEV performs an inversion that solves for two viscoelastic parameters, the magnitude $|G^*|$ and the phase angle ϕ of the complex shear modulus G^* , by combining complex-valued displacement fields from multiple acquisitions.

[0052] Conveniently, SR is applied by interpolating the acquired images prior to the image fusion in order to arrive at a higher resolution in the compound image.

[0053] The hybrid technique (SR-MMRE) has been validated in numerical simulations, to demonstrate recovery of subvoxel features in simulated data, and in a pilot brain study, comparing the effect of the SR technique on MDEV images obtained for a number of subjects.

[0054] In the numerical simulations, finite-difference simulations were computed for a viscoelastic SH-wave PDE scheme using Java. Simulated viscoelastic wave field images were obtained at a plurality of frequencies (in one exemplary case, 20, 25, 30, 35, and 40 Hz) with background stiffness of 3KPa, target stiffness of 12 KPa, and viscosity of 0.1 Pa s. Two targets were created: one large (12mm), which would be detected even after 1/4 downsampling, and one small (3mm) which would be below the resolution of the downsampling. The images were then downsampled to 1/4 of original size (8mm voxels). A number of different elastograms were obtained and compared: original resolution: to facilitate comparison, the obtained elastograms included: downsampled; upsampling without SR (to control for the impact of interpolation alone); and upsampling with SR.

[0055] For the evaluation in the pilot brain study using in-vivo MRE Acquisition, full wave fields in 15 axial slices were acquired using an EPI MRE sequence at seven frequencies in the range 30-60 Hz [at 5Hz intervals] for the respective brains of a number of subjects

[0056] The wave fields were Hodge decomposed using divergence-free wavelets and de-noised using complex dual-tree wavelets with overlapping group sparsity (OGS) thresholding. Wave images were then interpolated to 4 times the original resolution using a Lanczos-3 kernel and solved using the MDEV algorithm for $|G^*|$ (i.e. elasticity) and ϕ (i.e. viscosity).

[0057] To demonstrate the clinical potential of the present disclosure, brain MRE scans were acquired in two subjects diagnosed with brain tumours. The images of the brain in Figures 4A to 4C exemplify the resulting images for a subject with a glioblastoma (GBM), while those in Figures 4D to 4F exemplify images for a subject with metastases (MET). In the both cases, the SR-MDEV elastograms contain detail not seen in the standard T2-weighted MR image (Figures 4A and 4D).

[0058] In the glioblastoma, the boundary of the tumour as it appears in the T2 image (Figure 4A) is also seen in the elasticity map (Figure 4B) and the viscosity map (Figure 4C). However, the viscoelasticity maps (Figure 4B and 4C) add considerable information. First, the boundary of the tumour within the oedema is more clearly seen in the viscoelasticity maps. Second, the viscoelasticity maps uncover considerable heterogeneity in the tumour not visible on the T2 image. The left side of the tumour (as viewed in Figures 4B and 4C) shows low viscosity, presumably due to necrosis, but the right side does not. Further, both sides of the tumour show similar viscosity. This would suggest that the necrosis is quite recent,

with the necrotic tissue having lost its mechanical integrity, but not having degraded sufficiently that it has lost its complexity of network.

[0059] In the viscoelasticity maps of the metastases (Figures 4E and 4F), the core is both elastic and viscous, suggesting the cancerous tissue is still growing, and the tumour is surrounded by a ring of gliosis. While the T2 image (Figure 4D) cannot distinguish the boundary between tumour and gliosis, both the $|G^*|$ image (i.e. elasticity image, Figure 4E) and ϕ image (i.e. viscosity image, Figure 4F) show this tumour-gliosis boundary clearly. The interface between the tumour, gliosis and oedema in the metastases is well depicted in the SR-MDEV $|G^*|$ and ϕ images despite both areas having low stiffness.

[0060] SR applied to MDEV-based MMRE thus enables spatially resolved recovery of sub-voxel features, resulting in a new level of radiological detail in both $|G^*|$ and ϕ , and enabling viscoelasticity measurements with reduced partial volume effects. The features in the SR tumour images (Figures 4A to 4F) suggest considerable utility in tumour diagnosis and surgical planning.

[0061] Figure 5A illustrates the flow of functions in a conventional MRE image processing technique. MRE images are acquired at a single acoustic frequency S502. The phases of the imaged waves are "unwrapped" S504. This facilitates de-noising of the image in the frequency domain S506. Finally an estimation of the local frequency of the shear wave at any point in the image is estimated - i.e. local frequency estimation S508 is performed.

[0062] Figure 5B illustrates the flow of functions in a multi-frequency MRE image processing technique, MDEV. MRE

images are acquired at a plurality of different acoustic frequencies S512. The phases of the imaged waves at each acoustic frequency are "unwrapped" S514. Each unwrapped image is then de-noised in the frequency domain S516. The images are then fused (i.e. combined) and inverted S518 to generate the output MMRE viscoelastic maps.

[0063] Figure 5C illustrates the flow of functions in an image processing technique in accordance with the present disclosure. As for the MDEV technique illustrated in Figure 5B, MRE images are acquired at a plurality of different acoustic frequencies S522 and the phases of the imaged waves at each acoustic frequency are "unwrapped" S524. Each unwrapped image is then de-noised using a complex wavelet domain de-noising method S526.

[0064] The de-noised images are then subjected to an interpolation operation S528. For instance, the acquired de-noised images are upsampled by a factor of two or four.

[0065] The interpolated images are then filtered to facilitate the detection of features S530: in Figure 5C, for example, this filtering operation is performed by determining Gabor Filter weightings.

[0066] The filtered images are then combined and inverted S532 (using the same technique as in step S518 of Figure 5B) to generate output SR-MMRE viscoelastic maps.

[0067] While the preceding discussion refers to the use of the MDEV algorithm to perform inversion, the skilled reader will appreciate that there are known alternative inversion techniques that may be applied with similar results, for example, the wave images may be converted to wave speed values, enabling inversion with other equations.

[0068] Other image processing steps may be performed using conventional alternatives. For example, while certain embodiments of the present disclosure perform de-noising and interpolation in the complex wavelet domain, it is contemplated that other kinds of wavelets may be employed for de-noising purposes.

[0069] Furthermore, the skilled reader will appreciate that there are a number of suitable feature detecting filters that may be used to enhance the quality of the final images. Certain embodiments use a feature detecting filter known as a Gabor filter. It is noted that while Gabor filters are known to be deployed at other stages in the inversion process, it is not known to deploy them specifically to feature detection.

[0070] The Gabor filter facilitates a "de-ringing" operation that removes unwanted high-frequency noise.

[0071] The SR-MRE technique described above is a post-processing technique that can be used independently of any other aspect of MRE, and used with the results of any MRE sequence. However, this embodiment of the present disclosure is naturally dependent on MRE data. To acquire MRE data, an MRI machine, actuation equipment to vibrate the tissue, and a specialised MRI program that encodes the wave propagation are all needed.

[0072] In certain embodiments, there is provided software which, when executed, enables analysis of datasets of MRE data obtained at a plurality of different acoustic frequencies to provide super-resolution in *in vivo* measurements of tissue viscoelastic properties.

[0073] While the technique is described in the context of imaging soft tissue in the human brain, the reader will

appreciate that the technique has many other clinical applications while remaining within the scope of the present disclosure. Clinical applications that have been contemplated include diagnosis of liver, heart and breast lesions, characterizing brain tumours and measurement of diffuse changes in, for example, Alzheimer's Disease. In applying this technique use may be made of the Elastography Software Library (ESL). The ESL can also be used for surgical planning.

[0074] While the preceding discussion concerns a methodology that fuses multiple MMRE acquisitions to obtain a single image at greater resolution than any of the individual images, the described technique has wider application in acoustic imaging. For instance, the described technique may be used in ultrasound elastometry (USE) or optical coherence elastography (OCE). Certain specific variations of USE involve a steady-state harmonic vibration: these USE techniques have characteristics that make them good candidates for adaptation to use the techniques of the present disclosure. OCE, which uses sinusoidal compression waves, is also a good candidate.

[0075] It will be appreciated that embodiments of the system can be realized in the form of hardware, software or a combination of hardware and software. Any such software may be stored in the form of volatile or non-volatile storage, for example a storage device like a ROM, whether erasable or rewritable or not, or in the form of memory, for example RAM, memory chips, device or integrated circuits or on an optically or magnetically readable medium, for example a CD, DVD, magnetic disk or magnetic tape or the like. It will be appreciated that the storage devices and storage media are embodiments of machine-readable storage that are suitable for storing a program or programs comprising instructions that, when executed, implement embodiments of the present invention.

[0076] Accordingly, embodiments provide a program comprising code for implementing apparatus or a method as claimed in any one of the claims of this specification and a machine-readable storage storing such a program. Still further, such programs may be conveyed electronically via any medium, for example a communication signal carried over a wired or wireless connection and embodiments suitably encompass the same.

[0077] Features, integers or characteristics described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith.

[0078] It will be also be appreciated that, throughout the description and claims of this specification, language in the general form of "X for Y" (where Y is some action, activity or step and X is some means for carrying out that action, activity or step) encompasses means X adapted or arranged specifically, but not exclusively, to do Y.

[0079] The description of the preferred embodiments of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or to limit the invention to the forms disclosed. It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiment disclosed, but covers modifications within the scope of the present invention as defined by the appended claims.

CLAIMS

1. A method for processing images of a target volume, the method comprising:

- 5 acquiring a plurality of wave field images at a plurality of different frequencies;
 generating a plurality of intermediate images by interpolating and upscaling the respective wave field images;
10 combining the data from the intermediate images; and
 generating super-resolution elasticity and viscosity maps from the combined data.

2. The method of claim 1, wherein the wave field images are
15 wave field images obtained using magnetic resonance elastography, MRE.

3. The method of claim 1 or claim 2, wherein plurality of different frequencies is a plurality of different frequencies of
20 acoustic waves.

4. The method of claim 1, wherein the wave field images are wave field images obtained using ultrasound elastography, USE.

25 5. The method of any one of the preceding claims, wherein the operation of interpolating and upscaling the respective wave field images further comprises performing de-noising and interpolation in the complex wavelet domain.

30 6. The method of any one of the preceding claims, further comprising applying a feature detecting filter to enhance the quality of the respective maps.

7. The method of claim 6, wherein the feature detecting filter is a Gabor filter.

8. An apparatus for processing images of a target volume, the
5 apparatus comprising a processor configured to:

acquire a plurality of wave field images at a plurality of different frequencies;

generate a plurality of intermediate images by interpolating and upscaling the respective wave field images;

10 combine the data from the intermediate images; and

generate super-resolution elasticity and viscosity maps from the combined data.

9. A system for processing images of a target volume
15 comprising:

a scanner configured to generate a plurality of wave field images of the target volume; and

an apparatus as claimed in claim 8.

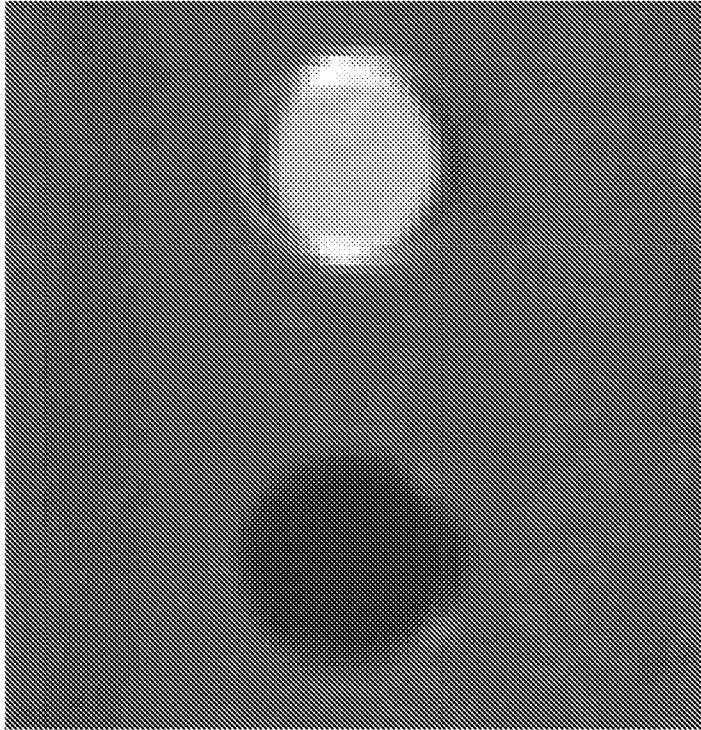


Fig. 1B

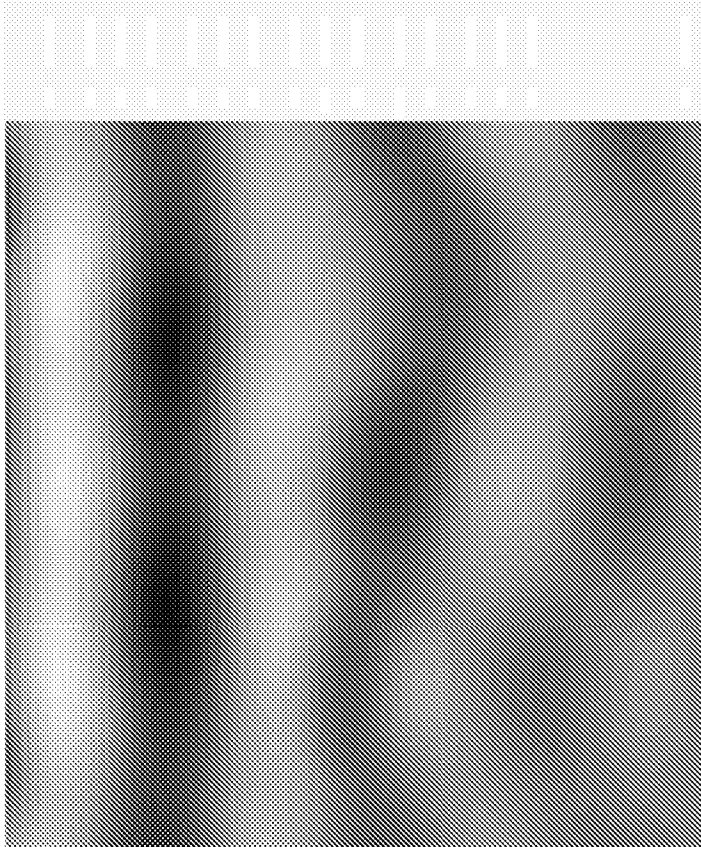


Fig. 1A

Fig.
2A

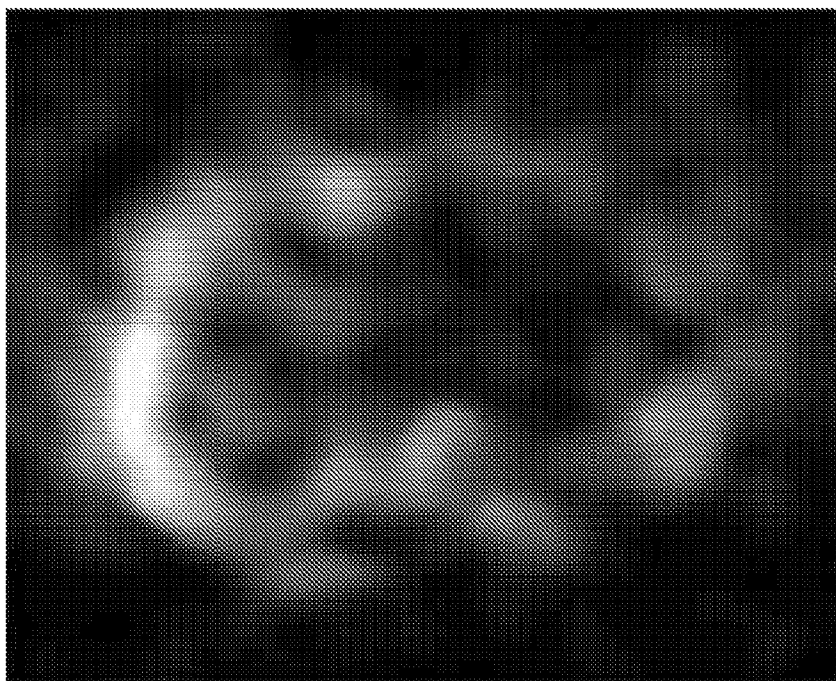


Fig.
2D

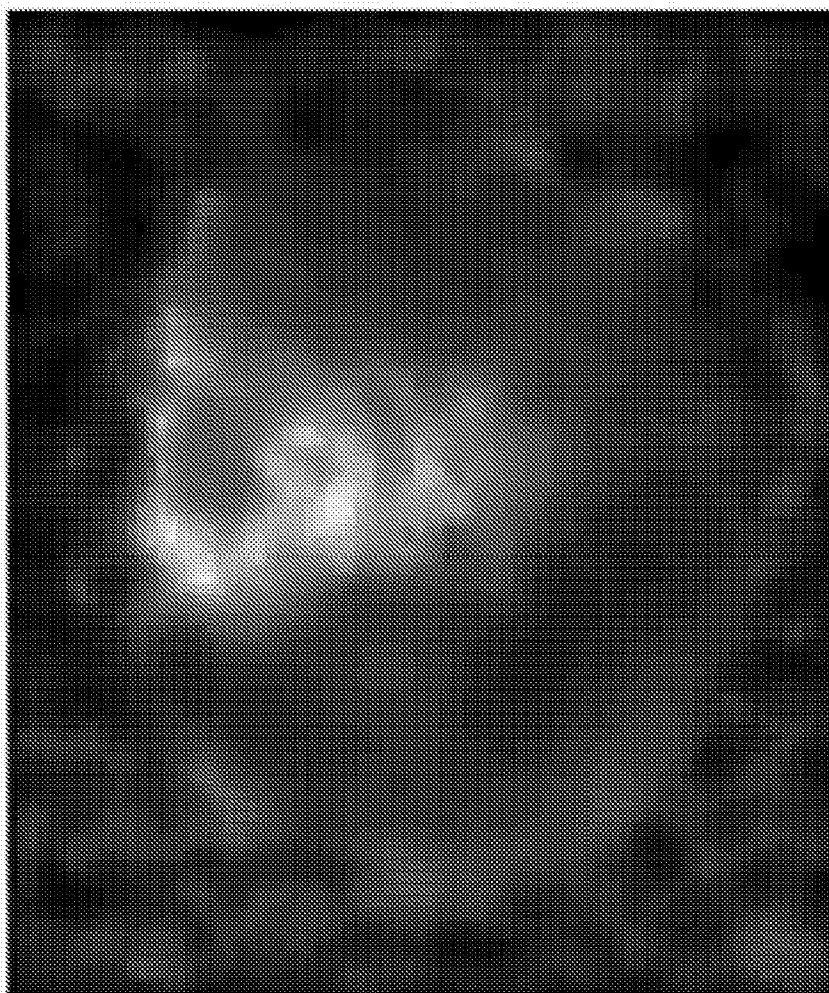


Fig.
2B

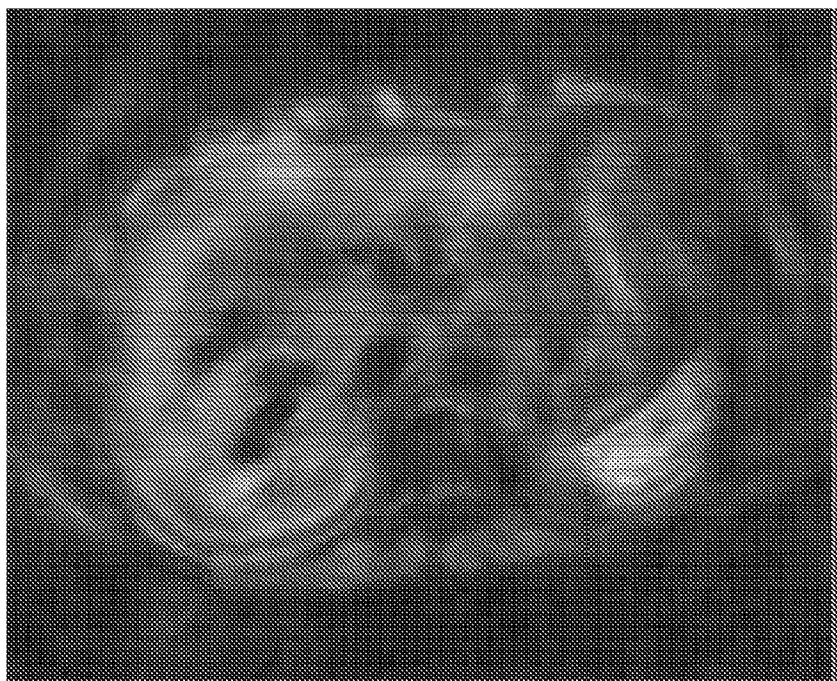


Fig.
2E

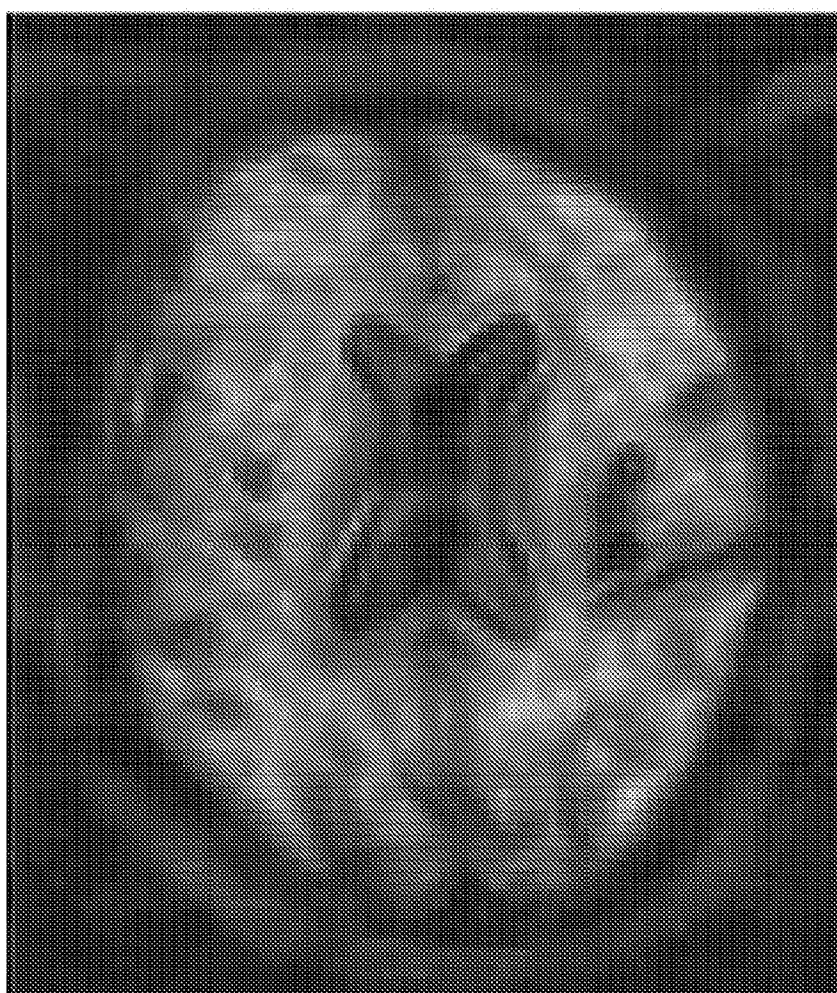


Fig.
2C

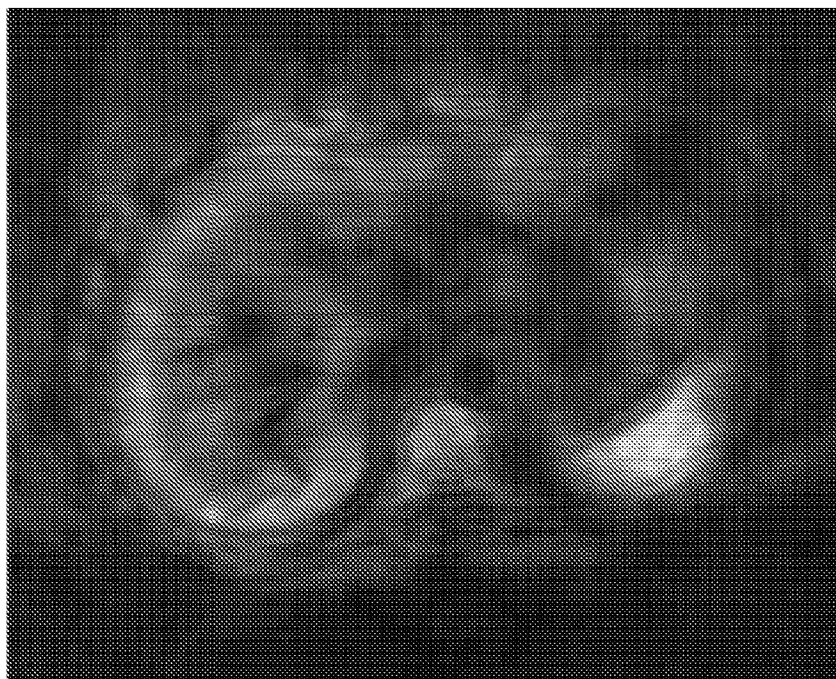
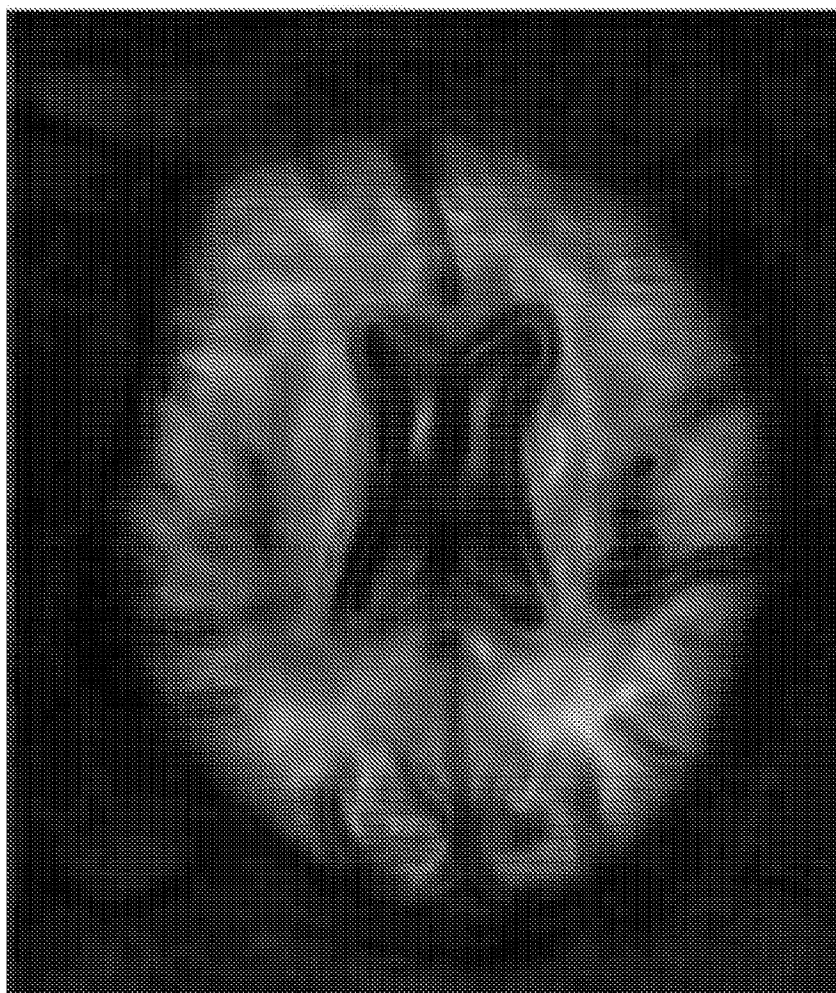


Fig.
2F



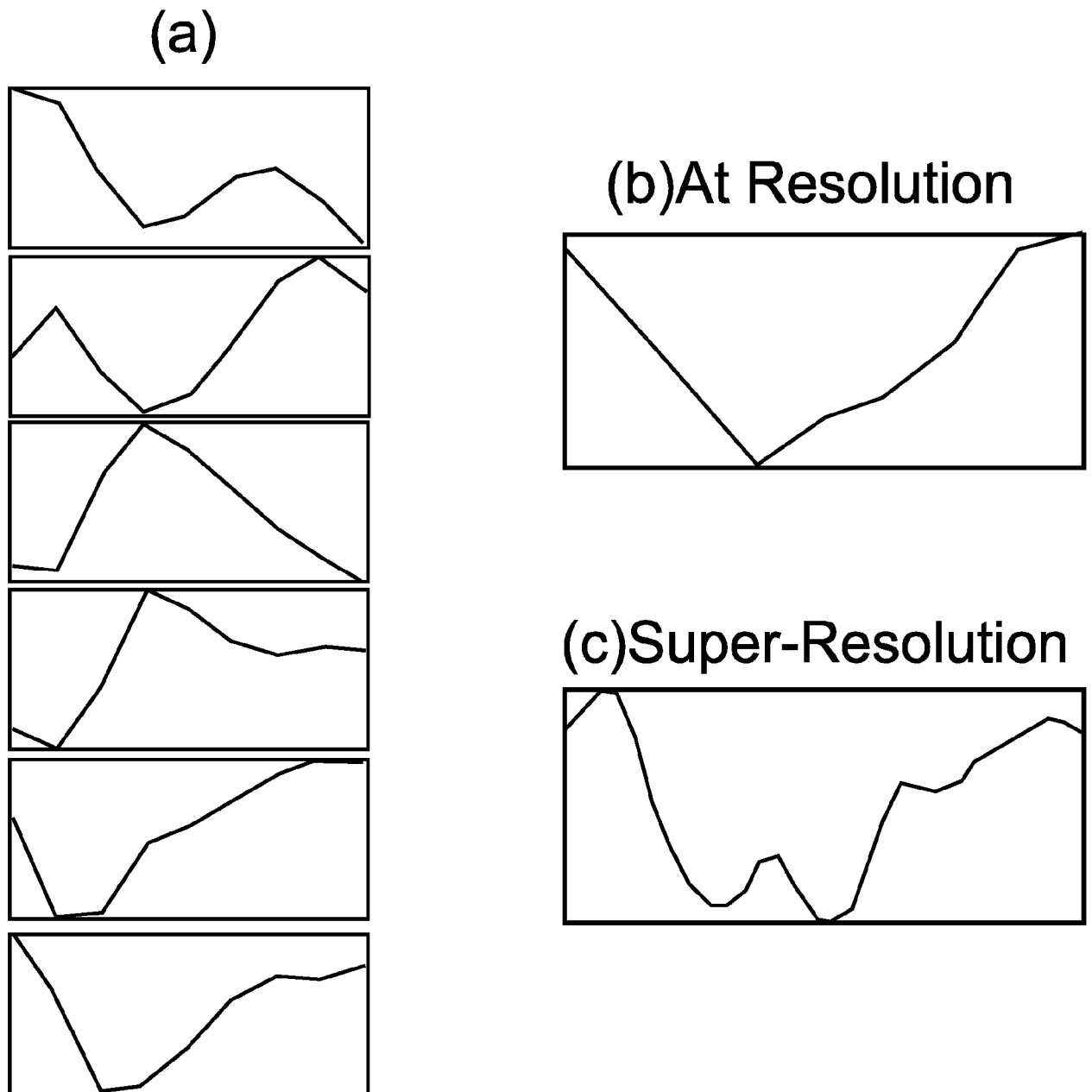
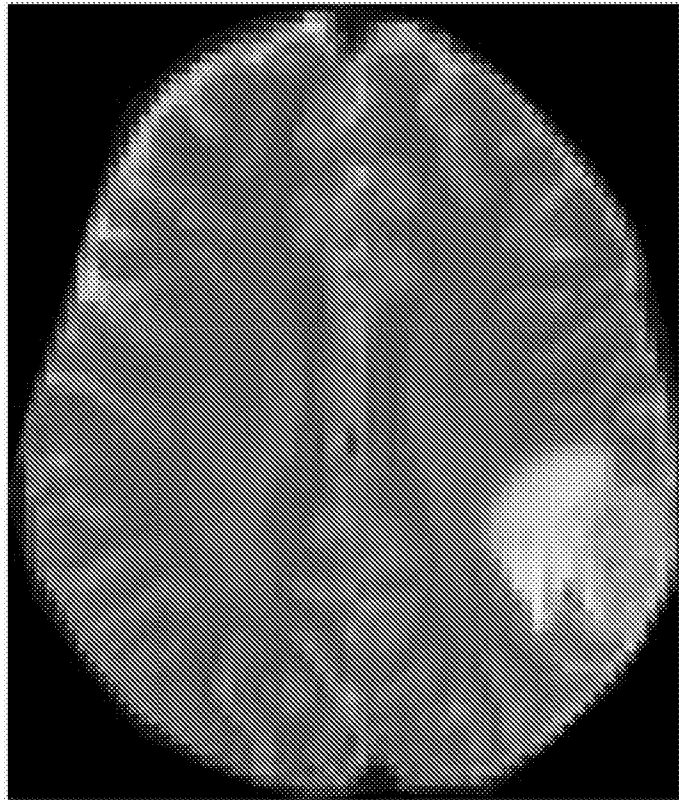


Fig. 3

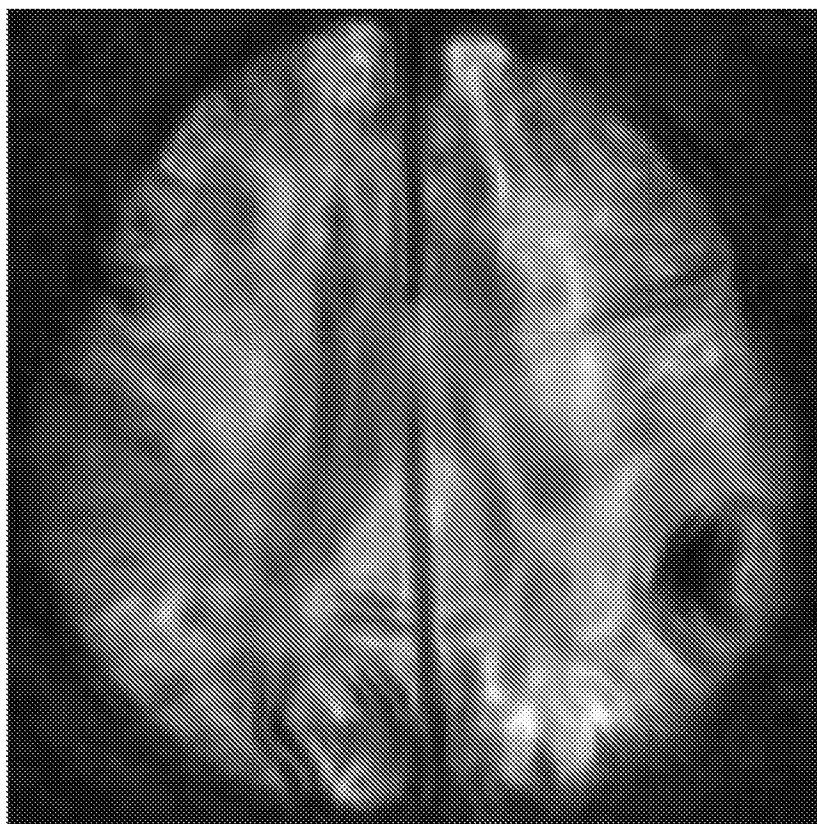
GBM
T2
Fig.
4A



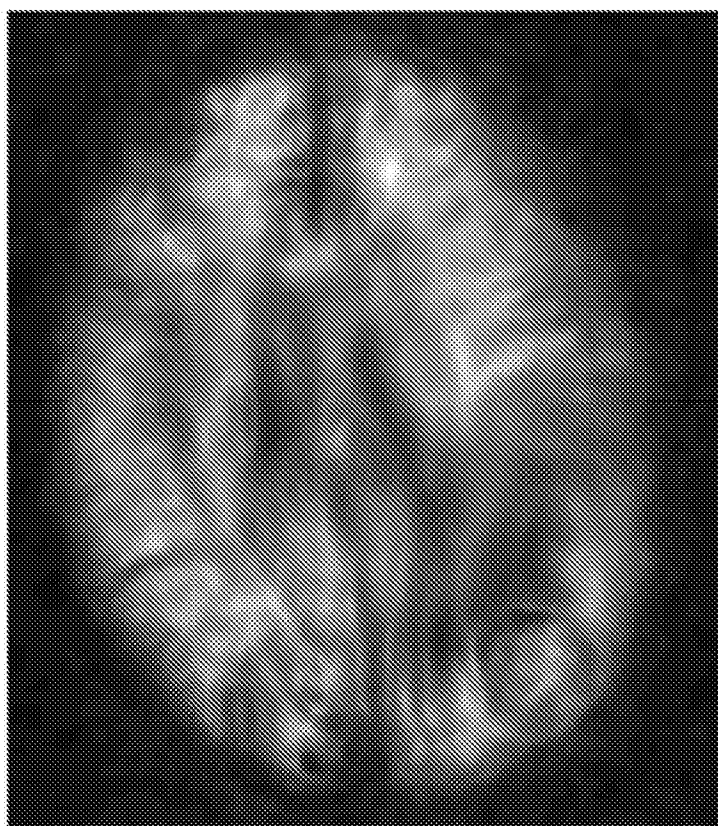
Met
T2
Fig.
4D



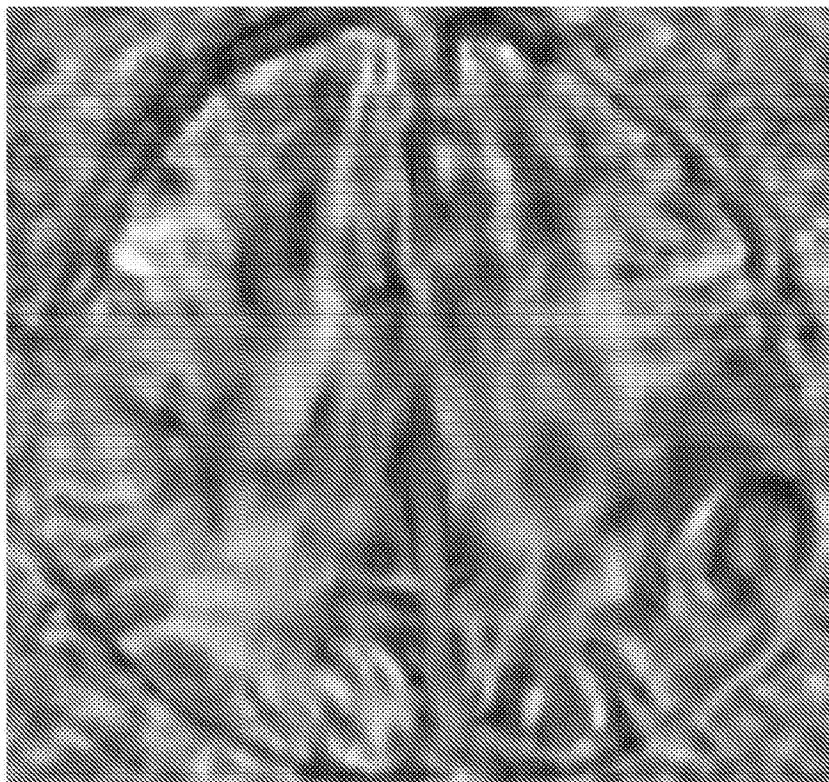
GBM
|G*|
Fig.
4B



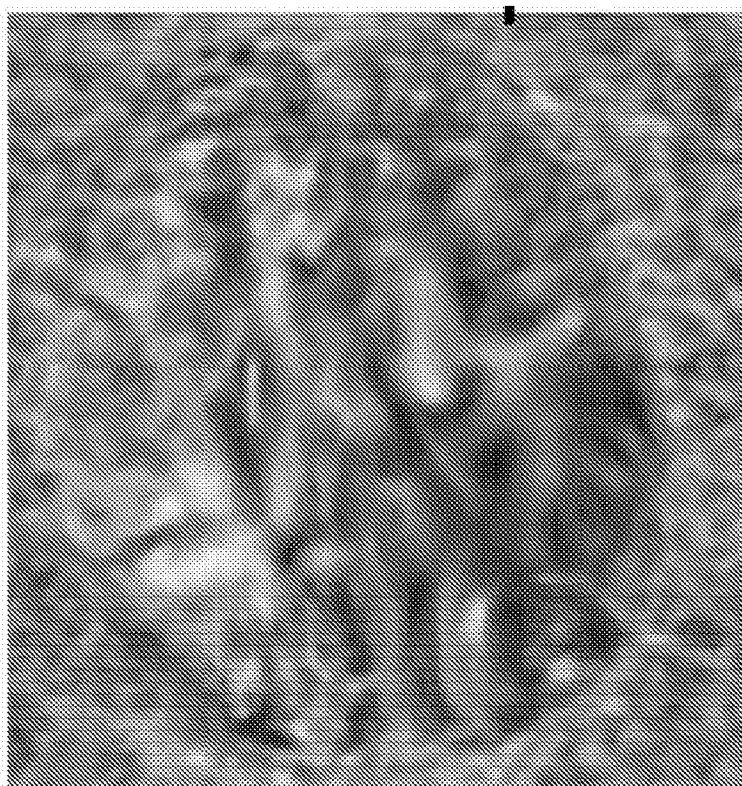
Met
|G*|
Fig.
4E



GBM
|G*|
Fig.
4C



Met
|G*|
Fig.
4F



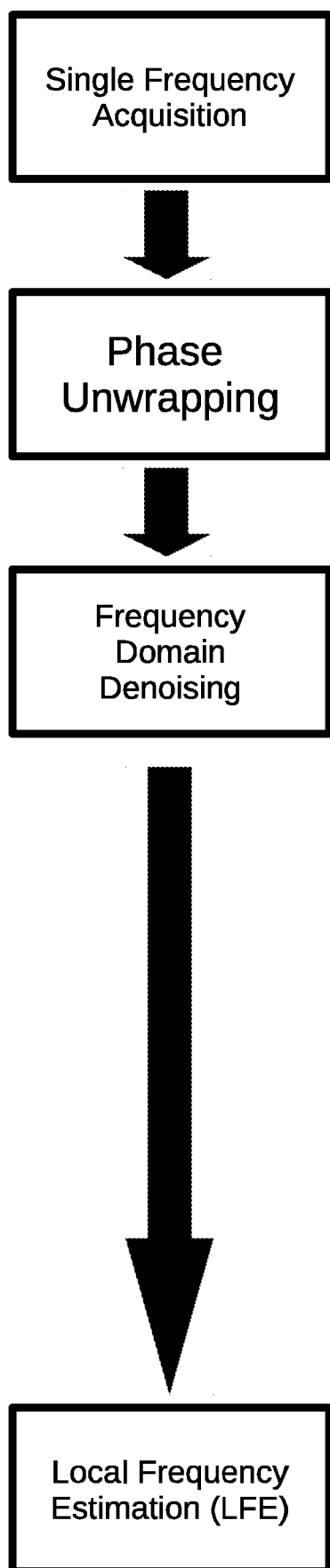


Fig. 5A

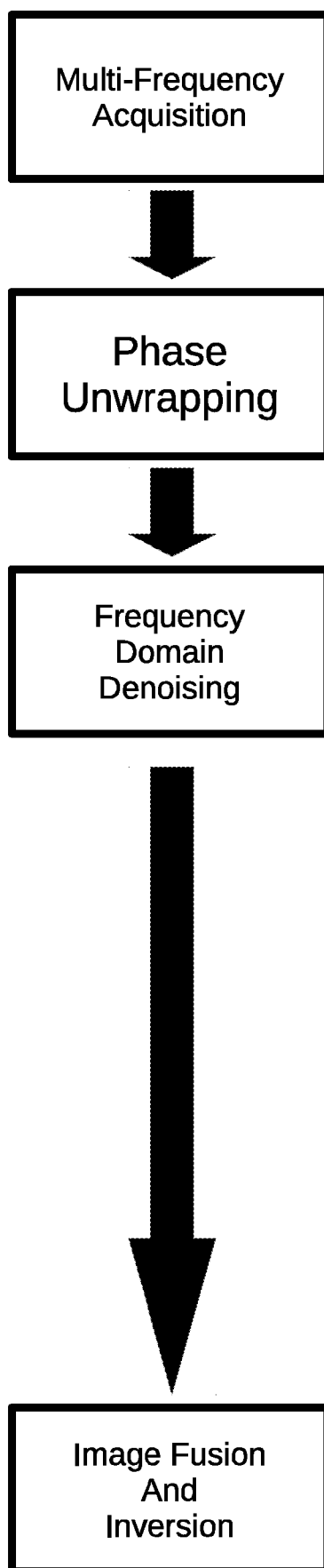


Fig. 5B

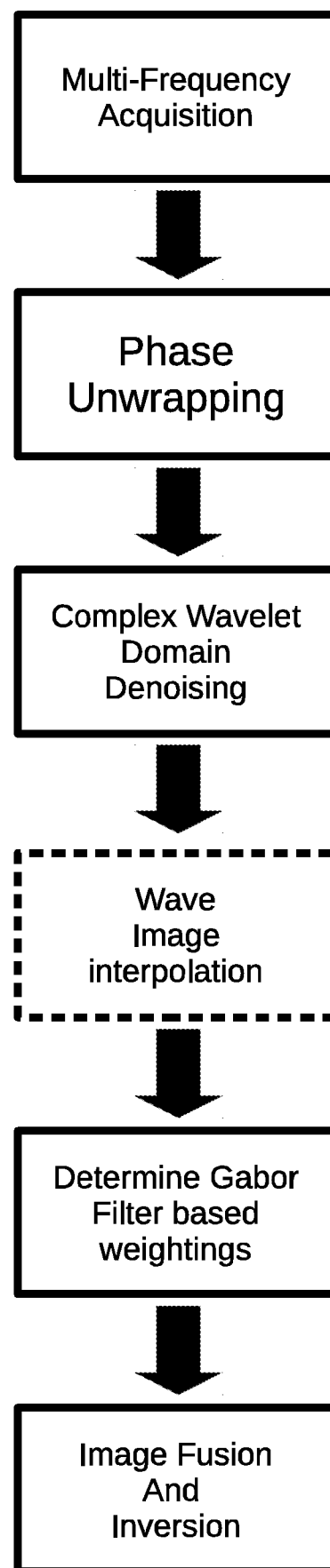


Fig. 5C

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/051407

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/055 G01R33/56
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)
G01R G01S A61B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SEBASTIAN PAPAZOGLU ET AL: "Paper;Multifrequency inversion in magnetic resonance elastography;Multifrequency inversion in magnetic resonance elastography", PHYSICS IN MEDICINE AND BIOLOGY, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL GB, vol. 57, no. 8, 30 March 2012 (2012-03-30), pages 2329-2346, XP020220791, ISSN: 0031-9155, DOI: 10.1088/0031-9155/57/8/2329 abstract page 2330, lines 13,27 page 2331 - page 2333; examples 1,2,4,9,11,12 page 2333, line 7; figures 4,5,6,8,10,12 ----- -/-	1-9



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

5 August 2016

Date of mailing of the international search report

12/08/2016

Name and mailing address of the ISA/

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Authorized officer

Visser, Robert

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/051407

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KAMAL NASROLLAHI ET AL: "Super-resolution: a comprehensive survey", MACHINE VISION AND APPLICATIONS, vol. 25, no. 6, 1 August 2014 (2014-08-01) , pages 1423-1468, XP055193477, ISSN: 0932-8092, DOI: 10.1007/s00138-014-0623-4 page 1423, column 2, paragraph 3 page 1424, column 1, paragraph 1; figure 1; table 1 page 1445, lines 11,12, paragraph 2 -----	1-9
A	US 2004/263169 A1 (MITCHELL J ROSS [CA] ET AL) 30 December 2004 (2004-12-30) paragraph [0006]; figure 2 -----	1,8
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Information on patent family members

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