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(71) Applicant *(for all designated States except DE)*: **KONINKLIJKE PHILIPS ELECTRONICS N.V.** [NL/NL]; High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(71) Applicant *(for DE only)*: **PHILIPS INTELLECTUAL PROPERTY & STANDARDS GMBH** [DE/DE]; Lübeckertordamm 5, 20099 Hamburg (DE).

(72) Inventors: **MANZKE, Robert**; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL). **PROKSA, Roland**; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL). **NEUBAUER, Anne, Morawski**; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL). **SCHIRRA, Carsten, Oliver**; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL).

(74) Agents: **VAN VELZEN, Maaike, M.** et al.; High Tech Campus, Building 44, NL-5656 AE Eindhoven (NL).

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[Continued on next page]

(54) Title: SPECTRAL IMAGING

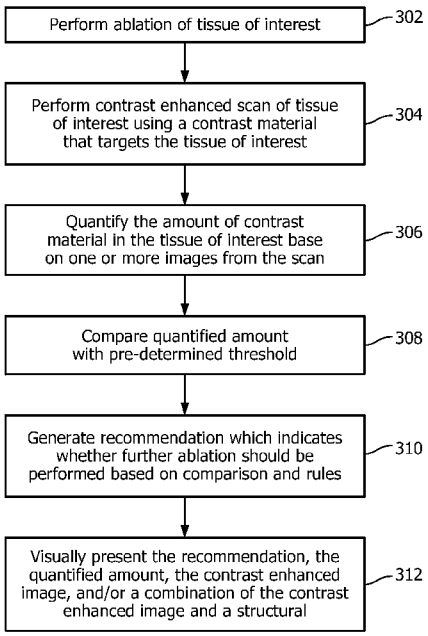

FIG. 3

(57) Abstract: An analyzer (124) includes a quantifier (204) configured to quantify an amount of contrast material representing scar tissue created by ablation for tissue of interest in contrast enhanced imaging data and a recommender (210) configured to generate a signal indicative of a recommendation to further ablate the tissue of interest in response to the quantified amount of the contrast material not satisfying a pre-determined threshold. A method includes obtaining contrast enhanced image data indicative of scar tissue created by ablation of tissue of interest, quantifying an amount of contrast material for the scar tissue in the tissue of interest, and generating a signal indicative of a recommendation to further ablate the tissue of interest in response to the quantified amount of the contrast material not satisfying a pre-determined threshold.

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SPECTRAL IMAGING

The following generally relates to a spectral imaging and is described with particular application to computed tomography (CT); however, the following is also amenable to other imaging modalities such as X-ray and/or other imaging modalities.

Since the absorption of a photon by a material is dependent on the energy of the photon traversing the material, the detected radiation also includes spectral information. A spectral CT scanner additionally captures the spectral information. Generally, a spectral CT scanner includes two or more x-ray tubes configured to emit radiation having different mean spectrums, a single x-ray tube configured to be controllably switched between at least two different emission voltages during scanning, and/or a single broad spectrum x-ray tube and an energy-resolving detector array with energy-resolving detectors (e.g., with photon counting detectors, at least two sets of photodiodes with different spectral sensitivities, etc.) and discrimination electronics. K-edge spectral imaging leverages the phenomena that high-Z elements tend to attenuate photons to a much higher extent above a particular energy (the K-edge energy of the given element) relative to attenuating photons just below the K-edge energy. The discontinuity in the attenuation behavior can be detected using an energy-resolving detector.

Cardiac catheter ablation, generally, is a minimally invasive medical procedure in which a catheter, having a radiofrequency emitter disposed at its tip, is passed within a vessel such as the femoral vein to a particular region of the heart where the emitter is activated to emit an electrical signal to ablate particular tissue such as cardiac cells with abnormal electrical activity, which may lead to arrhythmias. Cardiac catheter ablation has been used to successfully treat supraventricular tachycardia (SVT), atrial flutter, atrial fibrillation (AF) and ventricular tachycardia (VT), and has been performed by human and robot under human control. The success of catheter ablation, for example, of AF, requires continuous lines of scar to encircle the pulmonary veins in the left atrium. Unfortunately, cardiac catheter ablation procedures are often unsuccessful due to the lack of adequate ablation assessment to ensure the suitable ablation of the tissue of interest has been performed.

Aspects described herein addresses the above-referenced problems and others.

In one aspect, an analyzer includes a quantifier configured to quantify an amount of contrast material representing scar tissue created by ablation for tissue of interest in contrast enhanced imaging data and a recommender configured to generate a signal indicative of a recommendation to further ablate the tissue of interest in response to the quantified amount of the contrast material not satisfying a pre-determined threshold.

In another aspect, a method includes obtaining contrast enhanced image data indicative of scar tissue created by ablation of tissue of interest. The method further includes quantifying an amount of contrast material for the scar tissue in the tissue of interest. The method further includes generating a signal indicative of a recommendation to further ablate the tissue of interest in response to the quantified amount of the contrast material not satisfying a pre-determined threshold.

In another aspect, a method includes determining whether ablation of tissue of interest is complete based on contrast enhanced image data indicative of scar tissue created by the ablation for the tissue of interest.

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 schematically illustrates an example imaging system in connection with an analyzer configured to analyze contrast enhanced image data indicative of a contrast material targeted to scar tissue created during and/or after the ablation.

FIGURE 2 schematically illustrates an example of the analyzer illustrated in FIGURE 1.

FIGURE 3 illustrates an example method for evaluating a result of ablation of tissue of interest.

The following generally relates to utilizing imaging to assess ablation of tissue of interest. As discussed above, cardiac catheter ablation procedures are often unsuccessful due to the lack of adequate ablation assessment to ensure the suitable ablation of the tissue of interest has been performed. As described in greater detail below, the approach herein includes performing a contrast enhanced scan of scar tissue created by ablation using a contrast agent targeted to the scar tissue and analyzing the resulting image(s) to assess the ablation. In one non-limiting instance, the assessment can be utilized to determine whether

further ablation should be performed, thereby mitigating unsuccessful ablation due to lack of adequate ablation assessment.

FIGURE 1 illustrates an example imaging system 100 such as a computed tomography (CT) system. The imaging system 100 includes a generally stationary gantry 102 and a rotating gantry 104, which is rotatably supported by the stationary gantry 102. The rotating gantry 104 rotates around an examination region 106 about a longitudinal or z-axis. A subject support 108 such as a couch supports a subject such as a human or animal patient or an object in the examination region 106. The subject support 108 is movable in coordination with scanning so as to guide the subject or object with respect to the examination region 106 for scan of the subject or object.

An injector 110 is configured to administer a contrast material(s) to a subject or object, for example, in connection with a contrast enhanced imaging procedure such as a contrast enhanced imaging procedure performed during and/or after cardiac catheter ablation to image contrast material concentrated in scar tissue resulting from the ablation. The illustrated injector 110 is controlled by the system 100, which activates the injector 110 to administer a contrast material in coordination with scanning. The injector 110 may alternatively be activated by a clinician and/or other authorized personnel. Alternatively, the contrast material is manually administered by the clinician and/or authorized personnel.

A suitable contrast material includes a targeted (tissue-specific) contrast agent with nano-particles having a K-edge within the diagnostic x-ray energy band (e.g., 20-140 keV). The specific tissue, in one non-limiting instance, includes scar tissue, macrophages, inflammation, and/or other physiological change created by cardiac catheter ablation at the time of the ablation. In another instance, the specific tissue is a tumor. The nano-particles can include one or more elements such as bismuth, gold, gadolinium, and/or other elements with K-edge values within the diagnostic x-ray energy band. An example contrast material that targets macrophages is discussed in "Atherosclerotic Plaque Composition: Analysis with Multicolor CT and Targeted Gold Nanoparticles," Cormode, et al., 2010 Radiology: Volume 256: Number 3. Other contrast materials are also contemplated herein.

A radiation source 112, such as an x-ray tube, is supported by and rotates with the rotating gantry 104 and is configured to emit poly-energetic radiation. A detector array 116 includes one or more rows of detector pixels that detect radiation that traverses the examination region 106. The illustrated detector array 116 includes one or more energy-resolving detectors such as direct conversion detectors (e.g., CdTe, CdZnTe, etc.) or a scintillator-based multi-spectral detector with at least two scintillators having different x-ray

energy sensitivities and at least two corresponding photosensors having corresponding optical sensitivities. The detector array 116 generates an electrical signal indicative of the detected radiation.

A signal decomposer 118 decomposes the energy-resolved signals into various energy dependent components. For example, in one instance a detected energy-resolved signal is decomposed into a Compton component, a photo-electric component, and/or one or more K-edge components representative of one or more K-edge materials, for example, in a contrast material. An example decomposition approach is described in application serial number PCT/IB2007/055105, filed on December 14, 2007, which claims the benefit of provisional application serial number EP 06126653.2, filed on December 20, 2006, both of which are incorporated in their entirety herein by reference.

A reconstructor 120 reconstructs signals generated by the detector array 116, generating volumetric image data. In one instance, this includes reconstructing the Compton, photo-electric, and/or K-edge components, individually or in combination. With embodiments in which the contrast agent includes a K-edge material, the K-edge component can be reconstructed to generate a contrast material image representative of the tissue of interest. One or more anatomical structural images of the tissue of interest may also be reconstructed based on one or more of the decomposed components. Furthermore, a contrast material image and a structural image may be combined in a single image and/or displayed next to each other.

A general purpose computer serves as an operator console 122. The console 122 includes a human readable output device such as a monitor or display and an input device such as a keyboard, mouse, etc. Software resident on the console 122 allows the operator to interact with the imaging system 100 via a graphical user interface (GUI) or otherwise. This interaction may include selecting an imaging protocol such as a contrast enhanced imaging protocol, initiating scanning, etc.

An analyzer 124 analyzes volumetric image data. As described in greater detail below, in one non-limiting instance the analysis includes analyzing one or more contrast enhanced images corresponding to a contrast material that targets scar tissue created during and/or after ablation of tissue of interest and generating a signal indicative whether the ablation of the tissue of interest is complete based on the one or more images. The signal can be used to determine whether further ablation should be performed, for example, where the cardiac catheter ablation of the tissue of interest is not suitable. The signal can be presented via a display 126 or the like through quantified indicia (e.g., a numerical value, a color, etc.),

in an image (e.g., a K-edge image, a K-edge image superimposed over a structural image, etc.), in a plot/graph, etc.

A data repository 128 can be used to store the image data generated by the system 100, the signal generated by the analyzer 124 and/or other information from another device. The data repository 128 may include one or more of a picture archiving and communication system (PACS), a radiology information system (RIS), a hospital information system (HIS), an electronic medical record (EMR) database, a sever, a computer, and/or other data repository. The data repository 128 can be local to the system 100 or remote from the system 100.

It is to be appreciated that the analyzer 124 can be implemented via a processor executing one or more computer readable instructions encoded or embedded on computer readable storage medium such as physical memory. Such a processor can be part of the console 122 and/or other computing device such as a dedicated visualization computer, and/or other computing device. The processor can also execute at least one computer readable instructions carried by a carrier wave, a signal, or other non-computer readable storage medium such as a transitory medium.

FIGURE 2 illustrates an example of the analyzer 124.

In this example, the analyzer 124 is described in connection with contrast enhanced image data indicative of a contrast material targeted to scar tissue created during and/or after ablation such as cardiac catheter ablation of tissue of interest, tumor ablation and/or other ablation.

An image combiner 202 combines (e.g., superimposes, overlay, etc.), in one non-limiting instance, the contrast enhanced image representative of the scar tissue and a structural image of the same anatomy into a signal image. The analyzer 124 can output the contrast enhanced image, the structural image and/or the single image.

Optionally, a quantifier 204 quantifies an amount of contrast material in the contrast enhanced image, for example, the amount along the tissue of interest. The analyzer 124 can combine the quantified amount and the contrast enhanced image and/or the single image, and/or output the quantified amount and/or combined data.

Optionally, a comparator 206 compares the quantified amount of contrast material along the tissue of interest with one or more predetermined thresholds 208. A recommender 210 generates a signal indicative of a recommendation based at least on a result of the comparison and one or more rules 212. In the illustrated embodiment, the recommender 210 generates the recommendation based on one or more rules 212.

By way of example, a rule may indicate that if the amount or level of contrast agent is less than a threshold value, then the recommender 210 will generate a signal indicating that the further ablation should be performed. The rule and/or another rule may indicate that if the amount or level of contrast agent is greater than the threshold value, then the recommender 210 will generate a signal indicating that the ablation is complete.

A suitable recommendation may also be no recommendation or absence of a recommendation. In this case, the signal may not even be generated. In some embodiments, the recommender 210 is omitted.

In FIGURE 1, the analyzer 124 analyzes contrast enhanced CT data. In a variation, the analyzer 124 can analyze contrast enhanced x-ray data to evaluate a result of a cardiac catheter ablation.

FIGURE 3 illustrates an example method for evaluating a result of ablation of tissue of interest.

It is to be appreciated that the ordering of the acts in the methods described herein is not limiting. As such, other orderings are contemplated herein. In addition, one or more acts may be omitted and/or one or more additional acts may be included.

At 302, ablation is performed for tissue of interest in a first examination room. The ablation can be radio frequency or cryogenic ablation. The tissue of interest can be, for example, cardiac catheter ablation or ablation of a tumor.

At 304, a contrast enhanced CT or x-ray scan of the tissue of interest is performed to image contrast material targeted to scar tissue created by the ablation in the tissue of interest. The contrast enhanced scan can be performed in the same or a different examination room.

At 306, an amount of the contrast material is quantified for the scar tissue of the tissue of interest based on a contrast enhanced image from the scan.

At 308, the quantified amount of contrast material is compared against one or more pre-determined thresholds.

At 310, a recommendation, which indicates whether further ablation is recommended, is generated based on a result of the comparison and one or more rules.

At 312, optionally, at least one of the recommendation, the quantified amount of contrast material, the contrast enhanced image, or a combination of the contrast enhanced image and a structural image of the tissue of interest from the scan is visually presented.

As discussed herein, the information presented herein can be used to facilitate determining whether or not further cardiac catheter, tumor, etc. ablation should be performed.

The methods described herein may be implemented via one or more processors executing one or more computer readable instructions encoded or embodied on computer readable storage medium such as physical memory which causes the one or more processors to carry out the various acts and/or other functions and/or acts. The one or more processors can also execute instructions carried by transitory medium such as a signal or carrier wave.

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be constructed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. An analyzer (124), comprising:

a quantifier (204) configured to quantify an amount of contrast material representing scar tissue created by ablation for tissue of interest in contrast enhanced imaging data; and

a recommender (210) configured to generate a signal indicative of a recommendation to further ablate the tissue of interest in response to the quantified amount of the contrast material not satisfying a pre-determined threshold.

2. The analyzer of claim 1, further comprising:

a combiner (202) that combines a contrast image representing the contrast material of the tissue of interest and a structural image of the tissue of interest, wherein the combination image is visually presented.

3. The analyzer of claim 2, wherein the contrast image is a K-edge image.

4. The analyzer of any of claims 2 to 3, wherein the contrast image represents a nano-particle contrast material targeted to at least one of the scar tissue.

5. The analyzer of claim 4, wherein the nano-particle contrast material includes one or more of bismuth, gold, or gadolinium nano-particles.

6. The analyzer of any of claims 2 to 5, wherein the quantified amount is presented along with the contrast enhanced image.

7. The analyzer of any of claims 2 to 6, wherein the quantified amount is visually represented in a graph.

8. The analyzer of any of claims 2 to 7, wherein the signal indicative of the recommendation is presented along with the contrast enhanced image.

9. The analyzer of any of claims 1 to 8, further comprising:

a comparator (206) configured to compare the quantified amount with the pre-determined threshold, wherein the recommender generates the signal based on a result of the comparison and one or more rules.

10. The analyzer of any of claims 1 to 9, wherein the contrast enhanced imaging data include computed tomography contrast enhanced imaging data.

11. The analyzer of any of claims 1 to 10, wherein the contrast enhanced imaging data include x-ray contrast enhanced imaging data.

12. The analyzer of any of claims 1 to 11, wherein the ablation is one or more of radio frequency or cryogenic ablation.

13. The analyzer of any of claims 1 to 12, wherein the tissue of interest is cardiac tissue.

14. The analyzer of any of claims 1 to 11, wherein the tissue of interest is a tumor.

15. A method, comprising:

obtaining contrast enhanced image data indicative of scar tissue created by ablation of tissue of interest;

quantifying an amount of contrast material for the scar tissue in the tissue of interest; and

generating a signal indicative of a recommendation to further ablate the tissue of interest in response to the quantified amount of the contrast material not satisfying a pre-determined threshold.

16. The method of claim 15, further comprising:

combining a contrast image representing the contrast material of the tissue of interest and a structural image of the tissue of interest; and

visually presenting at least the combination of the images.

17. The method of claim 16, further comprising presenting at least one of the quantified amount of contrast material or the signal indicative of the recommendation with at least the combination of the images.

18. The method of any of claims 15 to 17, wherein the contrast enhanced imaging data includes at least one of computed tomography contrast enhanced imaging data or x-ray contrast enhanced imaging data.

19. The method of any of claims 15 to 18, wherein the contrast material includes a nano-particle contrast material targeted to at least one of the scar tissue.

20. The method of claim 19, wherein the nano-particles include one or more of bismuth, gold, or gadolinium nano-particles.

21. The method of any of claims 15 to 20, wherein ablation is radio frequency ablation.

22. The method of any of claims 15 to 21, wherein the tissue of interest is one of cardiac tissue or a tumor.

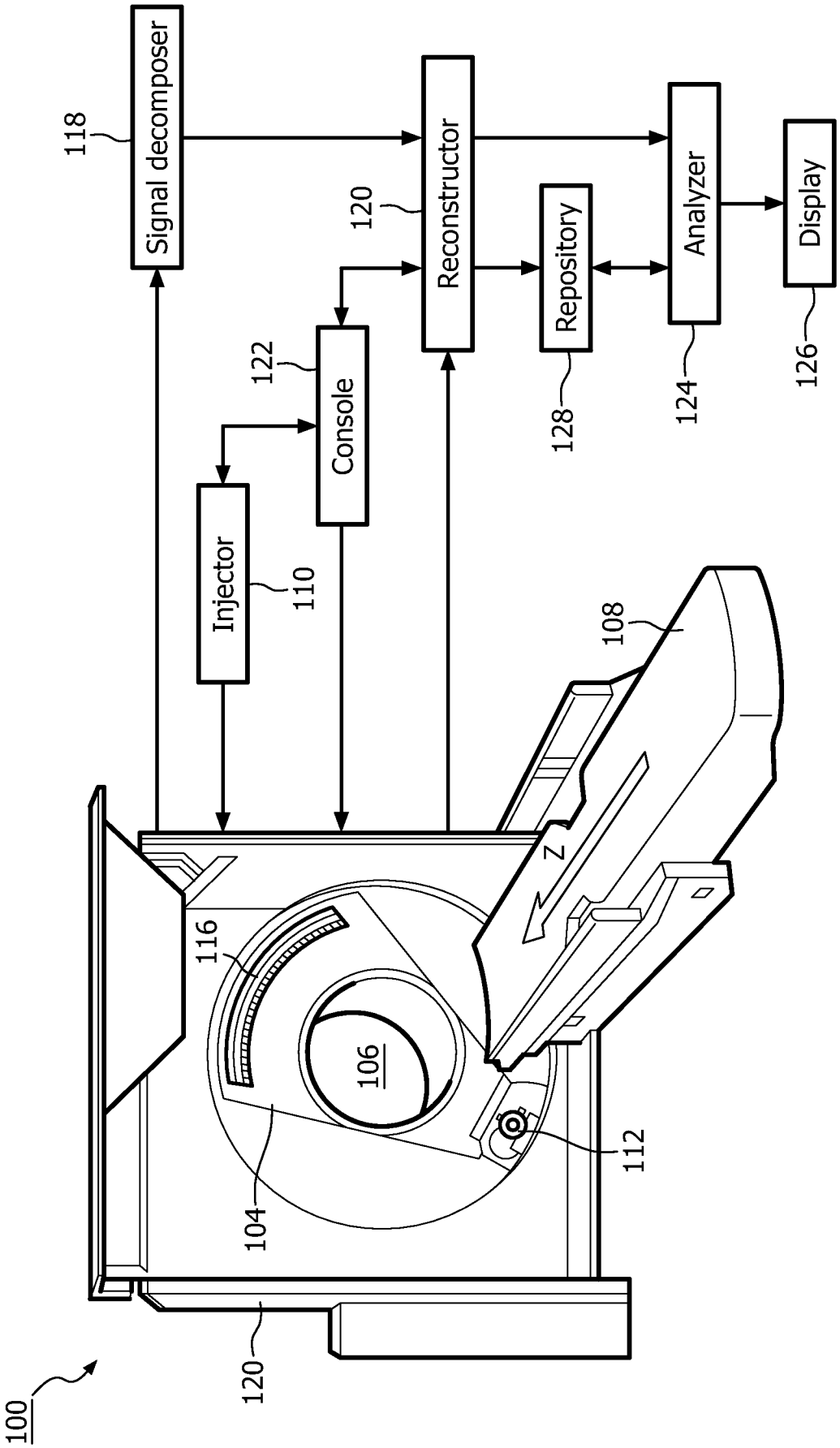
Signal decomposer
118
Reconstructor
120
Repository
128
Analyzer
124
Display
126
Console
122
Injector
110
108
z
116
106
104
112
120
100

FIG. 1

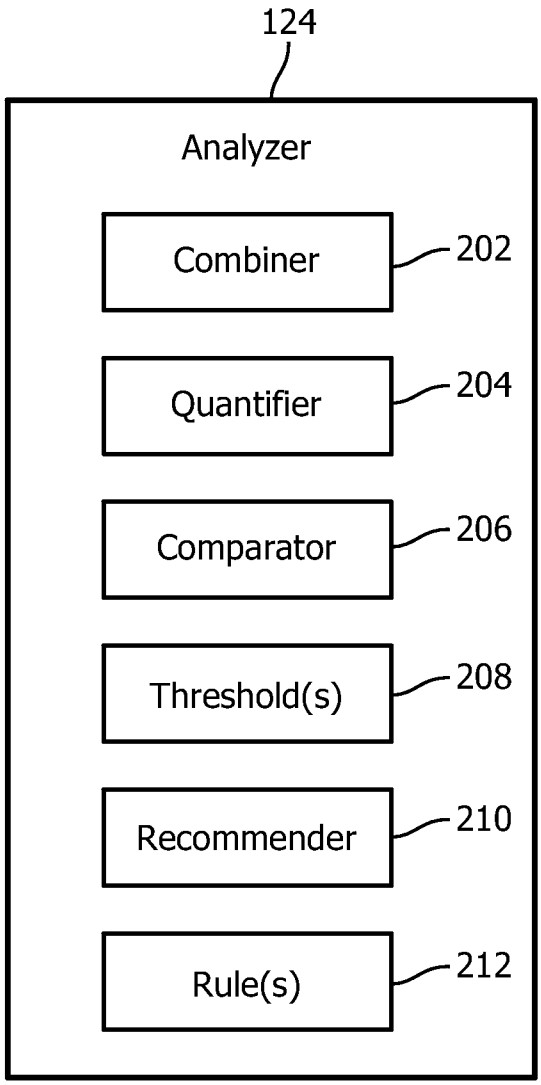
124
Analyzer
Combiner
202
Quantifier
204
Comparator
206
Threshold(s)
208
Recommender
210
Rule(s)
212

FIG. 2

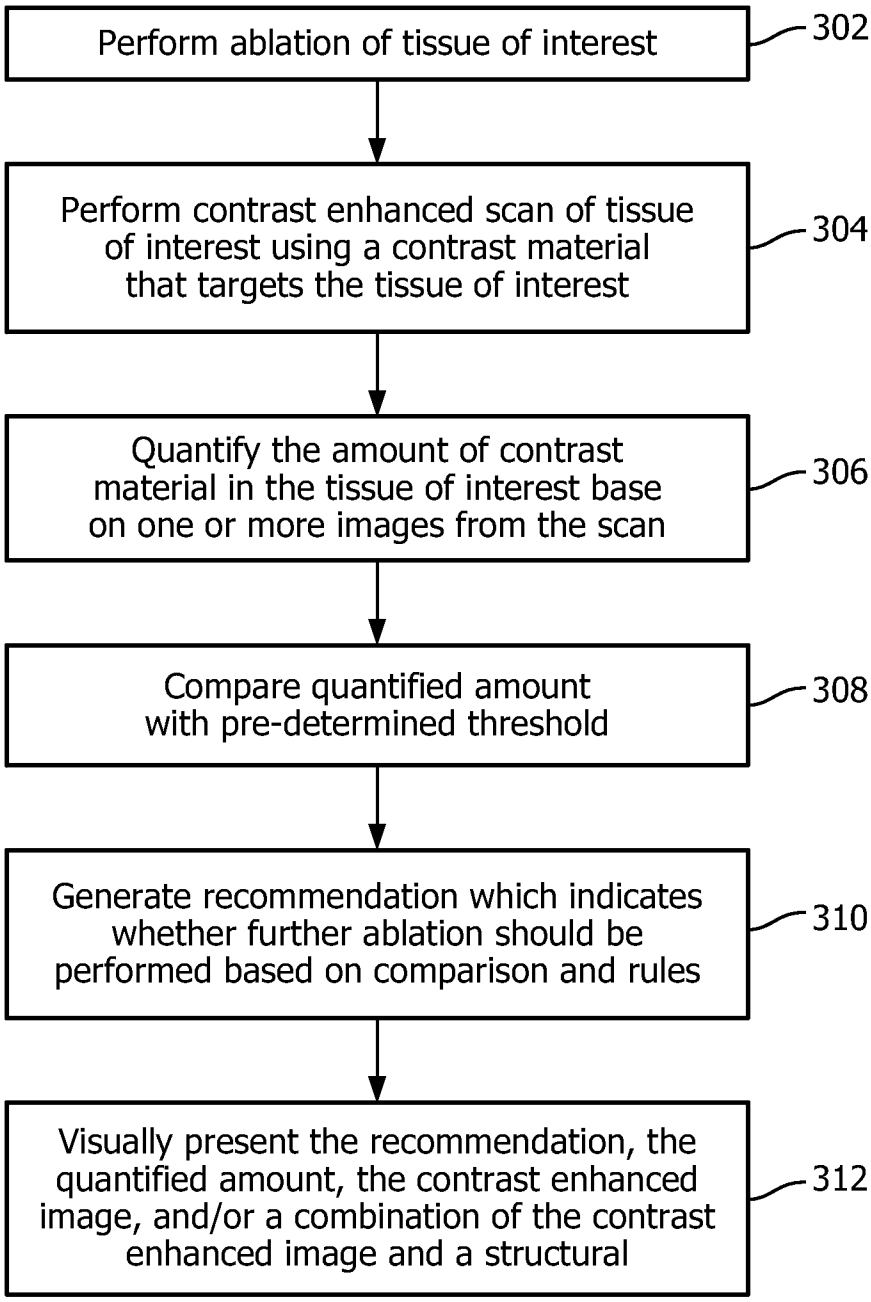
Perform ablation of tissue of interest
302
Perform contrast enhanced scan of tissue of interest using a contrast material that targets the tissue of interest
304
Quantify the amount of contrast material in the tissue of interest base on one or more images from the scan
306
Compare quantified amount with pre-determined threshold
308
Generate recommendation which indicates whether further ablation should be performed based on comparison and rules
310
Visually present the recommendation, the quantified amount, the contrast enhanced image, and/or a combination of the contrast enhanced image and a structural
312

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/056091

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/12 A61B6/03 A61B18/02 A61B18/14 A61K49/00
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)
A61B A61K

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	US 2007/123815 A1 (MARK JOSEPH L [US]) 31 May 2007 (2007-05-31) paragraphs [0127] - [0156], [0162]; figures 31,32,33,33a,34,35,36	1,2,4,5, 10-12,14
X	US 2006/173362 A1 (TOMS STEVEN A [US] ET AL) 3 August 2006 (2006-08-03) paragraphs [0007] - [0009], [0064] - [0077]; claims 8,12	1-5, 10-12,14
X	DE 10 2008 049604 A1 (SIEMENS AG [DE]) 8 April 2010 (2010-04-08)	1
A	paragraphs [0011], [0019] - [0030]; figures 1-3	2-5, 10-12,14

-/--

[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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 February 2013	07/02/2013

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	Daoukou, Eleni

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/056091

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/147056 A1 (VAN DER WEIDE DANIEL WARREN [US] ET AL) 19 June 2008 (2008-06-19) paragraphs [0128] - [0132], [0051] -----	1,2,4-9, 13
X	US 2005/283074 A1 (JACKSON JOHN I [US] ET AL) 22 December 2005 (2005-12-22) paragraphs [0002], [0006], [0016] - [0018], [0025] - [0041]; figures 1-3 -----	1,6-9, 12,13
A	EWALD ROESSL ET AL: "Preclinical spectral computed tomography of gold nano-particles", NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH SECTION A: ACCELERATORS, SPECTROMETERS, DETECTORS AND ASSOCIATED EQUIPMENT, vol. 648, 1 August 2011 (2011-08-01), pages S259-S264, XP055021811, ISSN: 0168-9002, DOI: 10.1016/j.nima.2010.11.072 abstract page N; figures 1-3,8-9 -----	1-5
A	US 2011/123082 A1 (PROKSA ROLAND [DE]) 26 May 2011 (2011-05-26) paragraphs [0027] - [0032]; claim 4; figures 1-5 -----	1-3,10, 11
A	WO 2008/078231 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS INTELLECTUAL PROPERTY [DE) 3 July 2008 (2008-07-03) page 3, line 27 - page 4, line 9 page 7, line 24 - page 8, line 20 -----	2-5,10, 11
A	GB 2 368 843 A (LEUVEN K U RES & DEV [BE]) 15 May 2002 (2002-05-15) page 4, paragraph 3 page 8, paragraph 5 - page 9, paragraph 2 page 1, paragraph 3 - page 2, paragraph 1 -----	1,4,5

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2012/056091

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2008047317 A2	24-04-2008
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GB 2368843 A	15-05-2002	NONE	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2012/056091

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 15-22
because they relate to subject matter not required to be searched by this Authority, namely:

see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 15-22

No examination is carried out on claims 15-22, because they relate to a method, which results into a medical diagnosis (completion of ablation) carried out on a human body (diagnostic method). Moreover, the method disclosed in claim 15 is an isolated step taking place during ablation; the disclosed subject matter makes sense only in the course of an ablation, which is a treatment of the living body by surgery. Therefore, the subject matter of claim 15 and the claims 16-22, which are dependent on claim 15, is covered by the provision of Rule 39(1) (iv) PCT (see also Article 34(4)(a)(i) PCT, PCT Guidelines, 9.08-9.10 and Rule 43bis.1(b) PCT).