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

(11) EP 2 296 550 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
28.03.2018 Bulletin 2018/13

(21) Application number: **09786437.5**

(22) Date of filing: **22.06.2009**

(51) Int Cl.:
G01N 23/087 (2018.01)
A61B 6/03 (2006.01)
A61B 5/00 (2006.01)
A61B 6/00 (2006.01)

(86) International application number:
PCT/IB2009/052670

(87) International publication number:
WO 2010/004460 (14.01.2010 Gazette 2010/02)

(54) **K-EDGE IMAGING**

K-KANTEN-BILDGEBUNG

IMAGERIE DE BORD K

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK TR

(30) Priority: **07.07.2008 US 78575 P**

(43) Date of publication of application:
23.03.2011 Bulletin 2011/12

(73) Proprietors:
- **Koninklijke Philips N.V.**
  5656 AE Eindhoven (NL)
  Designated Contracting States:
  AT BE BG CH CY CZ DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK TR
- **Philips Intellectual Property & Standards GmbH**
  20099 Hamburg (DE)
  Designated Contracting States:
  DE

(72) Inventors:
- **ROESSL, Ewald**
  Cleveland
  Ohio 44143 (US)
- **PROKSA, Roland**
  Cleveland
  Ohio 44143 (US)
- **SCHLOMKA, Jens-Peter**
  Cleveland
  Ohio 44143 (US)

(74) Representative: **van Velzen, Maaike Mathilde**
Philips Intellectual Property & Standards
High Tech Campus 5
5656 AE Eindhoven (NL)

(56) References cited:
WO-A-2006/084382
WO-A-2008/078255
US-A1- 2008 137 803

- **SCHLOMKA J P ET AL: "Experimental feasibility of multi-energy photon-counting K-edge imaging in pre-clinical computed tomography; Experimental feasibility of multi-energy photon-counting K-edge imaging in pre-clinical CT" PHYSICS IN MEDICINE AND BIOLOGY, TAYLOR AND FRANCIS LTD. LONDON, GB, vol. 53, no. 15, 7 August 2008 (2008-08-07), pages 4031-4047, XP020141344 ISSN: 0031-9155**
- **FIRSCHING M ET AL: "A method for stoichiometric material reconstruction with spectroscopic X-ray pixel detectors" NUCLEAR SCIENCE SYMPOSIUM CONFERENCE RECORD, 2004 IEEE, IEEE, PISCATAWAY, NJ, USA, vol. 7, 16 October 2004 (2004-10-16), pages 4116-4119, XP010819606 ISBN: 978-0-7803-8700-3**
- **ROESSL E ET AL: "K-edge imaging in x-ray computed tomography using multi-bin photon counting detectors; K-edge imaging based on photon counting detectors" PHYSICS IN MEDICINE AND BIOLOGY, TAYLOR AND FRANCIS LTD. LONDON, GB, vol. 52, no. 15, 7 August 2007 (2007-08-07), pages 4679-4696, XP020113001 ISSN: 0031-9155 cited in the application**

EP 2 296 550 B1

• S. Feuerlein ET AL: "Multienergy Photon-counting K-edge Imaging: Potential for Improved Luminal Depiction in Vascular Imaging", Radiology, vol. 249, no. 3, 10 October 2008 (2008-10-10), pages 1010-1016, XP055075557, ISSN: 0033-8419, DOI: 10.1148/radiol.2492080560

Description

[0001] The following generally relates to K-edge imaging. While it is described with particular application to computed tomography (CT), it also relates to other medical imaging and non-medical imaging applications.

[0002] US 2008/0137803 A1 discloses a diagnostic imaging system comprising a high frequency electromagnetic energy source that emits a beam of high frequency electromagnetic energy toward an object to be imaged and be resolved by the system. The system further comprises a detector that receives high frequency electromagnetic energy emitted by the high frequency electromagnetic energy source and a data acquisition system operably connected to the detector. The system also comprises a computer operably connected to the data acquisition system and programmed to employ an inversion table or function to convert N+2 measured projections at different incident spectra into material specific integrals for N+2 materials that comprise two non K-edge basis materials and N K-edge contrast agents, wherein N comprises an integer greater than or equal to 1.

[0003] WO 2008/078255 A2 discloses an energy-resolving detection system for detecting radiation, wherein the detection system comprises a first layer for absorbing a part of the radiation, a radiation quanta counting unit comprising a second layer for counting radiation quanta of the radiation, and a read-out unit coupled with the radiation quanta counting unit for reading out the radiation quanta counting unit, wherein the first layer and the second layer are arranged such that the radiation, which is incident on the detection system and which reaches the second layer, has passed the first layer.

[0004] WO 2006/084382 A1 discloses an image signal modifier composition for imaging of biological tissue, wherein the composition comprises a) two or more signal modifying agents, each of the agents being specific for at least one imaging modality, and b) a carrier comprising the two or more signal modifying agents, wherein the carrier is capable of retaining a sufficient amount of the agents for a time sufficient to acquire imaging data using the composition.

[0005] A conventional computed tomography (CT) scanner includes an x-ray tube mounted on a rotatable gantry opposite one or more detectors. The x-ray tube rotates around an examination region located between the x-ray tube and the one or more detectors and emits polychromatic radiation that traverses the examination region and a subject and/or object disposed in the examination region. The one or more detectors detect radiation that traverses the examination region and generate a signal or projection data indicative of the examination region and the subject and/or object disposed therein. The projection data is used to reconstruct volumetric image data thereof, and the volumetric data can be used to generate one or more images of the subject and/or object. The resulting image(s) includes pixels that typically are represented in terms of grey scale values corresponding to relative radiodensity.

[0006] The grey scale values reflect the attenuation characteristics of the scanned subject and/or object, and generally show structure such as anatomical structures within a patient, physical structures within an inanimate object, and the like. However, 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, which provides additional information such as information indicative of the elemental or material composition (e.g., atomic number) of the tissue and/or material of the subject and/or object. Unfortunately, conventional CT projection data does not reflect the spectral characteristics as the signal output by the one or more detectors as proportional to the energy fluence integrated over the energy spectrum. In spectral CT, the spectral characteristics are leveraged to provide further information such as information indicative of elemental composition.

[0007] A spectral CT system may include an energy resolving photon counting detector such as a direct conversion CZT detector (or CdTe, Si, GaAs, etc) that produces an electrical signal for each photon that it detects, wherein the electrical signal is indicative of the energy of that photon. A pulse shaper processes the signal and produces a voltage or current pulse with the peak amplitude indicative of the energy of the detected photon. A discriminator compares the amplitude of the pulse with one or more thresholds that are set in accordance with different energy levels. A counter counts, for each threshold, the number of times the amplitude exceeds the threshold. A binner bins or assigns a detected photon to an energy window based on the counts. The resulting energy-resolved detected photons provide information that can be used for spectral reconstruction of the signals for the detected photons.

[0008] K-edge imaging leverages the fact 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 behaviour of the element can be detected using an energy resolving photon counting detector such as the one noted above. Generally, since the K-edge of iodine is located at a rather low energy of around 33 keV, iodine is not well suited for K-edge imaging when the total attenuation is large and the x-ray spectrum is hardened considerably upon passage through the patient. One way to improve the sensitivity is to use an element with higher Z than iodine such as gadolinium, which has a K-edge at around 50 keV. Beam hardening at this energy is much less important and yields relative good results even for high attenuation.

[0009] However, there is an unresolved need to further improve the sensitivity in K-edge imaging.

[0010] Aspects of the present application address the above-referenced matters and others.

[0011] According to one aspect, an imaging system includes a radiation source that emits poly-chromatic radiation that traverses an examination region and a detector that detects radiation traversing the examination region and produces a signal indicative of the energy of a detected photon. The system further includes an energy discriminator that energy resolves the signal based on a plurality of different energy thresholds, wherein at least two of the energy thresholds have values correspondable to at least two different K-edge energies of two different elements in a mixture disposable in the examination region. The system also includes a signal decomposer that decomposes the energy-resolved signal into at least a multi K-edge component representing the at least two different K-edge energies to which the values of the at least two energy thresholds are correspondable.

[0012] The mixture is a contrast agent and a stoichiometric ratio of the two different elements in the contrast agent is known and substantially constant. The stoichiometric ratio and the K-edge energies can provide a unique finger print for the mixture of the two different elements. It is preferred that the two different elements are part if a single contrast agent.

[0013] In another aspect, a method includes detecting poly-chromatic radiation emitted by a radiation source that traverses an examination region and generating a signal indicative of the energy of a detected photon. The method further includes energy-resolving the signal based on a plurality of different energy thresholds, wherein at least two of the energy thresholds have values corresponding to at least two different K-edge energies of two different elements of a mixture disposed in the examination region, wherein a stoichiometric ratio of the two different elements of the mixture is known. The method further includes decomposing the energy-resolved signal into at least a multi K-edge component representing the at least two different K-edge energies. The method further includes reconstructing a multi K-edge image based on the multi K-edge component and the stoichiometric ratio to generate volumetric image data indicative of the two different elements.

[0014] In another aspect, a computer readable storage medium containing instructions which, when executed by a computer, cause the computer to perform the steps of: detecting poly-chromatic radiation traversing the examination region; producing a signal indicative of an energy of a detected photon; energy discriminating the signal based on a plurality of different energy thresholds, wherein at least two of the energy thresholds have values correspondable to at least two different K-edge energies of two different elements disposable in the examination region; and decomposing the energy-resolved signal into a multi K-edge component representing the at least two different K-edge energies to which the values of the at least two energy thresholds are correspondable. The mixture is a contrast agent, wherein a stoichiometric ratio of the two different elements in the contrast agent is known and substantially constant.

[0015] It is preferred that the instructions, when executed by the computer, cause the computer to further perform the steps of: reconstructing the multi K-edge component based on a stoichiometric ratio of the two different elements in a contrast agent, wherein the stoichiometric ratio is known and substantially constant.

[0016] Still further aspects of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description.

[0017] 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 illustrates an imaging system.
FIGURE 2 illustrates an example pulse energy discriminator.
FIGURE 3 illustrates an example component decomposer.
FIGURE 4 illustrates an example multi K-edge attenuation curve.
FIGURE 5 illustrates a method.

[0018] With reference to FIGURE 1, a computed tomography (CT) 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 108. An x-ray source 110, such as an x-ray tube, is supported by the rotating gantry 104 and emits poly-energetic radiation. A collimator 112 collimates the radiation beam to produce a generally cone, fan, wedge or other shaped radiation beam that traverses the examination region 106.

[0019] A radiation sensitive detector array 116 detects photons that traverse the examination region 106. The illustrated detector 116 is an energy-resolving detector such as a direct conversion detector (e.g., Si, Ge, GaAs, CdTe, CdZnTe, etc.) or a scintillator-based detector that includes a scintillator in optical communication with a photosensor. The detector 116 generates an electrical signal, such as electrical currents or voltages, for each detected photon.

[0020] A pre-amplifier 118 amplifies the electrical signal output by the detector 116. A pulse shaper 120 processes the amplified electrical signal and generates a pulse such as voltage or other pulse indicative of the energy of the detected photon. An energy discriminator 122 energy discriminates the pulse. In the illustrated example, the energy discriminator 122 includes a comparator 124 that compares the amplitude of the pulse with two or more different energy thresholds, which correspond to different energies of interest. The comparator 124 produces an output signal indicative of the energy of the photon based on the comparison.

[0021] A threshold setter 126 sets the thresholds. As described in greater detail below, the threshold setter 126 may be used to set two or more of the thresholds in accordance with the K-edge energies of elements of interest, such as different contrast elements in a contrast agent administered to a patient to be scanned. Using two or more thresholds tuned to the K-edges of two or more different Z elements in a given contrast agent may increase the sensitivity of the K-edge imaging technique. As such, when the system 100 is configured with tuneable thresholds, it may be desirable to tune the thresholds to the K-edge energies. Of course, thresholds may also be set to distinguish between Compton effect and photo-electric effect components.

[0022] A counter 128 increments a count value for each threshold based on the output of the energy discriminator 122. For instance, when the output of the comparator 124 for a particular threshold indicates that the amplitude of the pulse exceeds the corresponding threshold, the count value for that threshold is incremented. A binner 130 energy bins the signals and, hence, the photons into two or more energy bins based on the counts. An energy bin encompasses an energy range or window. For example, a bin may be defined for the energy range between two thresholds, where a photon resulting in a count for the lower threshold but not for higher threshold would be assigned to that bin.

[0023] A signal decomposer 132 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 a multi K-edge component representative of two or more K-edge materials in a contrast agent. It is to be appreciated that a maximum likelihood or another decomposition technique may alternatively be used.

[0024] A reconstructor 134 selectively reconstructs the detected signals. In one instance, this includes reconstructing the Compton, photo-electric, and/or multi K-edge components, individually or in combination. For the multi K-edge component, the stoichiometric ratio of the contrast elements in the contrast agent should be known and constant in order to characterize the attenuation of the elements as a function of energy.

[0025] A characterization bank 136 includes information that characterizes the elements contributing to the multi K-edge component as such. This information may include a K-edge energy of the two or more elements, the stoichiometric ratio of the elements, etc. Such information is used when reconstructing the multi K-edge component as described in greater detail below.

[0026] A general purpose computer serves as an operator console 138. The console 138 includes a human readable output device such as a monitor or display and an input device such as a keyboard and mouse. Software resident on the console 138 allows the operator to interact with the scanner 100 via a graphical user interface (GUI) or otherwise. Such interaction may include selecting a scan protocol such as a multi K-edge imaging protocol, setting an energy-discriminating threshold, etc.

[0027] An object support 140 such as a couch supports a patient or other object in the examination region 106. The object support 140 is movable so as to guide the object with respect to the examination region 106 for performing a scanning procedure.

[0028] As briefly discussed above, the scanner 100 may be used for multi K-edge component imaging of at least two different contrast elements in a contrast agent in a subject or object where the stoichiometric ratio of the elements is known and constant. With such an application, at least two of the thresholds of the comparator 124 are set in accordance with the K-edge energies of the at least two different contrast elements. The following describes an example for a contrast agent that includes both iodine and gadolinium for explanatory purposes and sake of brevity. It is to be understood that other contrast agents including the same or more and/or similar or different contrast materials are also contemplated herein.

[0029] FIGURE 2 illustrates a non-limiting example of the comparator 124 with two thresholds set in accordance with two different K-edge energies for two different elements in a contrast agent. As illustrated, the comparator 124 includes N sub-comparators 124_1, ..., 124_2, ..., 124_3, ..., 124_N, wherein N is an integer equal to or greater than four. Each of the sub-comparators 124 includes a first input, which receives the output of the pulse shaper 120. Each of the comparators 124 also includes a second input, which receives a corresponding threshold value TH_1, ... TH_2, ... TH_3, ..., TH_N.

[0030] In this example, two of the thresholds are respectively set based on the K-edge energies of iodine (K-edge ≈ 33 keV) and gadolinium (K-edge ≈ 50 keV). Two other thresholds are set to distinguish between the Compton effect and the photo-electric effect. Where more or different elements having a desired K-edge are present in the contrast, one or more other thresholds may be set accordingly. For example, where the contrast agent includes Gold (K-edge ≈ 80 keV), a threshold can be set accordingly. Generally, the K-edge energies should fall within the diagnostic imaging range of about 25 keV to about 150 keV. In one instance, the threshold setter 126 sets at least one of the thresholds based on a selected scan protocol. In another instance, an operator uses the threshold setter 126 to set at least one of the thresholds.

[0031] For each of the comparators 124_1, ..., 124_2, ..., 124_3, ..., 124_N, when the amplitude of the incoming pulse exceeds the corresponding threshold, the output of the comparator 124_1, ..., 124_2, ..., 124_3, ..., 124_N changes state, for example, goes from low to high, 0 to 1, or other transition. The output of the comparator 124 is fed to the counter 128, which increments a count for each threshold based on a state transition.

[0032] FIGURE 3 illustrates an example signal decomposer 132. The following provides an example for the four threshold case, which includes two thresholds that can be used to distinguish between the Compton effect and the photo-electric effect, a threshold for a first K-edge energy and a threshold for a second K-edge energy. In this example, the signal decomposer 132 receives at least three energy-resolved detection signals d_i, wherein i is an integer, for the different energy bins. The detection signal d_i shows a spectral sensitivity D_1 (E) of the i-th energy bin b_i. Furthermore, the emission spectrum T (E) of the polychromatic radiation source 110 is generally known.

[0033] The signal decomposer 132 models the information as a combination of the photo-electric effect with spectrum P(E), the Compton effect with spectrum C(E) and the multi K-edge contrast agent with spectrum K(E). The density length product for each of the components, in particular the photo-effect component p, the Compton-effect component c and the multi K-edge component k, in each detection signal d_i is modeled in a discrete system in accordance with Equation 1:

Equation 1:

$$d_n = \int dE\, T(E)\, D_n(E) exp(- (p\, P(E) + c\, C(E) + k\, K(E))).$$

[0034] Since at least three detection signals d_i, d_2 and d_3 are available for the at least three energy bins b_1, b_2 and b_3, a system of at least three equations is formed having three unknowns, which can thus be solved with known numerical methods. Generally, three energy bins are sufficient in this case. However, using more detection signals for more energy bins may increase the sensitivity and noise robustness. If more than three energy bins are available, a maximum likelihood approach that takes into account the noise statistics of the measurements may be used. A suitable maximum likelihood approach is described in connection with "K-edge imaging in x-ray computed tomography using multi-bin photon counting detectors," E. Roessl and R. Proksa, 2007 Phys. Med. Biol. 52 4679-4696.

[0035] The results, in particular the components p, c and k, can then be used in order to reconstruct a desired component image with conventional reconstruction methods, in particular for reconstructing a multi K-edge component image. A conventional CT image as well as a Compton component image and/or a photo-electric component image may also be reconstructed.

[0036] When the stoichiometric ratio of the elements in the contrast agent is unknown, Equation 1 can be modified to include a K-edge component for each K-edge, for instance, one for Iodine, one for Gadolinium, etc. A suitable decomposition for the individual K-edge components 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. When the stoichiometric ratio of the elements in the contrast agent is known and substantially constant, the stoichiometric ratio of the elements in the contrast agent, along with K-edge energies thereof, characterizes the attenuation of the combination of the elements as a function of energy. As a consequence, the stoichiometric ratio and K-edge energies are used during reconstruction to generate a multi K-edge component image. The stoichiometric ratio and K-edge energy information can be stored in the characterization bank 136 for use by the reconstructor 134.

[0037] Generally, the stoichiometric ratio and K-edge energies provide a unique signature or fingerprint for the combination of elements. This is illustrated in connection with FIGURE 4, which shows an attenuation curve 400 as a function of photon energy for a 1:1 mixture that includes Iodine and Gadolinium. Of course, other mixture ratios (e.g., up to 1:5 or more), another number of materials, and/or other materials are contemplated herein, and the mixture including Iodine and Gadolinium are shown for explanatory purposes.

[0038] In FIGURE 4, the x-axis, axis 402, represents energy (E) in units of keV, and the y-axis, axis 404, represents attenuation (μ) as a function of energy (E). The K-edge of Iodine (K-edge $\approx$ 33 keV) is shown at 406, and the K-edge of Gadolinium (K-edge $\approx$ 50 keV) is shown at 408. As such, the attenuation of the contrast agent can be characterized by two discontinuities at respective K-edge energies with fixed respective heights. If the stoichiometric ratio were different (not 1:1), for example, two units (e.g., atoms, etc.) of Iodine to one unit of Gadolinium, then a height-ratio of the K-edge 406 and 408 in FIGURE 4 would be twice as high. As a consequence, the curve 400 can be used as a unique signature for a particular combination of elements.

[0039] FIGURE 5 illustrates a multi K-edge component imaging method. At 502, poly-chromatic radiation emitted by a radiation source and traversing an examination region is detected. At 504, the detected radiation is energy-resolved and binned across different energy windows based on a plurality of threshold corresponding to different energies in which at least two of the thresholds are set in accordance with the K-edge energies of at least two elements in a contrast agent provided to a patient prior to scanning the patient. As discussed above, this may include four (4) energy thresholds in which two (2) of the thresholds are tuned to two different K-edge energies in accordance with the dual K-edge material contrast agent. At 506, the energy-resolved data is decomposed into constituent components, including a multi K-edge component representing two or more K-edge energies corresponding to the at least two elements in the contrast agent. At 508, at least the K-edge component is reconstructed using the stoichiometric ratio of the elements in the contrast agent to generate a multi K-edge component image.

[0040] 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 imaging system, comprising:

a radiation source (110) that emits poly-chromatic radiation that traverses an examination region;
a detector (116) that detects radiation traversing the examination region and produces a signal indicative of the energy of a detected photon;
an energy discriminator (122) that energy resolves the signal based on a plurality of different energy thresholds, wherein at least two of the energy thresholds have values correspondable to at least two different K-edge energies of two different elements in a mixture disposable in the examination region; **characterized by**
a signal decomposer (132) that decomposes the energy-resolved signal into at least a multi K-edge component representing the at least two different K-edge energies to which the values of the at least two energy thresholds are correspondable, wherein the mixture is a contrast agent, wherein a stoichiometric ratio of the two different elements in the contrast agent is known and substantially constant.

2. The imaging system of claim 1, wherein the imaging system further includes a reconstructor (134) that reconstructs the multi K-edge component to generate a multi K-edge image, representative of the different materials, based on the stoichiometric ratio.

3. The imaging system of claim 1, wherein the stoichiometric ratio is in a range of about 1:1 to about 1:5.

4. The imaging system of any of claims 1 to 3, wherein the signal decomposer (132) further decomposes the energy-resolved signal into a Compton component and a photo-electric component.

5. The imaging system of claim 4, wherein the reconstructor (134) reconstructs the Compton component and the photo-electric component to generate a Compton component image and a photo-electric component image.

6. The imaging system of any of claims 1 to 5, wherein the K-edge energies are within a range from about 25 keV to about 150 keV.

7. The imaging system of any of claims 1 to 6, wherein at least one of the K-edge energies is about 33 keV.

8. The imaging system of any of claims 1 to 7, wherein at least one of the K-edge energies is about 50 keV.

9. A method, comprising:

detecting poly-chromatic radiation emitted by a radiation source (110) that traverses an examination region;
generating a signal indicative of the energy of a detected photon;
energy-resolving the signal based on a plurality of different energy thresholds, wherein at least two of the energy thresholds have values corresponding to at least two different K-edge energies of two different elements of a mixture disposed in the examination region, wherein a stoichiometric ratio of the two different elements of the mixture is known and substantially constant; **characterized by**
decomposing the energy-resolved signal into at least a multi K-edge component representing the at least two different K-edge energies; and
reconstructing a multi K-edge image based on the multi K-edge component and the stoichiometric ratio to generate volumetric image data indicative of the two different elements.

10. The method of claim 9, wherein the stoichiometric ratio is in a range of about 1:1 to about 1:5.

11. The method of any of claims 9 and 10, wherein the stoichiometric ratio and the K-edge energies uniquely characterize the attenuation behavior of the elements as a function of photon energy.

12. The method of any of claims 9 to 11, further including decomposing the energy-resolved signal into a Compton effect component and a photo-electric effect component.

13. The method of any of claims 9 to 12, wherein the mixture includes at least a third contrast element, and further including at least a third threshold corresponding to the third contrast element; decomposing the energy-resolved signal into at least a multi K-edge component representing the at least three different K-edge energies; and reconstructing a multi K-edge image based on the multi K-edge component and the stoichiometric ratio to generate volumetric image data indicative of the three different elements.

14. A computer readable storage medium containing instructions which, when executed by a computer, cause the computer to perform the steps of:

detecting poly-chromatic radiation traversing the examination region;
producing a signal indicative of an energy of a detected photon;
energy discriminating the signal based on a plurality of different energy thresholds, wherein at least two of the energy thresholds have values correspondable to at least two different K-edge energies of two different elements disposable in the examination region; **characterized in that** the computer readable storage medium further contains instructions which, when executed by the computer, cause the computer to perform the step of:

decomposing the energy-resolved signal into a multi K-edge component representing the at least two different K-edge energies to which the values of the at least two energy thresholds are correspondable, wherein the mixture is a contrast agent, wherein a stoichiometric ratio of the two different elements in the contrast agent is known and substantially constant.

Patentansprüche

1. Bildgebungssystem, umfassend:

eine Strahlungsquelle (110), die polychromatische Strahlung emittiert, welche eine Untersuchungsregion durchquert;
einen Detektor (116), der die Untersuchungsregion durchquerende Strahlung detektiert und ein die Energie eines detektierten Photons angebendes Signal erzeugt;
einen Energiediskriminator (122), der das Signal basierend auf einer Vielzahl von verschiedenen Energieschwellenwerten nach Energie auflöst, wobei mindestens zwei der Energieschwellenwerte Werte haben, die mindestens zwei verschiedenen K-Kanten-Energien von zwei verschiedenen Elementen in einer Mischung entsprechen, die in der Untersuchungsregion angeordnet werden kann; **gekennzeichnet durch**
eine Signalzerlegungseinheit (132), die das energie-aufgelöste Signal in mindestens eine Multi-K-Kanten-Komponente zerlegt, die die mindestens zwei verschiedenen K-Kanten-Energien darstellt, denen die Werte der der mindestens zwei Energieschwellenwerte entsprechen, wobei die Mischung ein Kontrastmittel ist, wobei ein stöchiometrisches Verhältnis der beiden verschiedenen Elemente in dem Kontrastmittel bekannt und im Wesentlichen konstant ist.

2. Bildgebungssystem nach Anspruch 1, wobei das Bildgebungssystem weiterhin eine Rekonstruktionseinheit (134) umfasst, die die Multi-K-Kanten-Komponente rekonstruiert, um basierend auf dem stöchiometrischen Verhältnis ein Multi-K-Kanten-Bild zu erzeugen, das die verschiedenen Materialien darstellt.

3. Bildgebungssystem nach Anspruch 1, wobei das stöchiometrische Verhältnis in einem Bereich von ca. 1:1 bis ca. 1:5 liegt.

4. Bildgebungssystem nach einem der Ansprüche 1 bis 3, wobei die Signalzerlegungseinheit (132) weiterhin das energie-aufgelöste Signal in eine Compton-Komponente und eine photoelektrische Komponente zerlegt.

5. Bildgebungssystem nach Anspruch 4, wobei die Rekonstruktionseinheit (134) die Compton-Komponente und die photoelektrische Komponente rekonstruiert, um ein auf der Compton-Komponente basierendes Bild und ein auf der photoelektrischen Komponente basierendes Bild zu erzeugen.

6. Bildgebungssystem nach einem der Ansprüche 1 bis 5, wobei die K-Kanten-Energien in einem Bereich von ca. 25 keV bis ca. 150 keV liegen.

7. Bildgebungssystem nach einem der Ansprüche 1 bis 6, wobei mindestens eine der K-Kanten-Energien ca. 33 keV beträgt.

8. Bildgebungssystem nach einem der Ansprüche 1 bis 7, wobei mindestens eine der K-Kanten-Energien ca. 50 keV beträgt.

9. Verfahren, umfassend:

Detektieren von polychromatischer Strahlung, die durch eine Strahlungsquelle (110) emittiert wird und eine Untersuchungsregion durchquert;
Erzeugen eines Signals, das die Energie eines detektierten Photons angibt;
Auflösen des Signals nach Energie basierend auf einer Vielzahl von verschiedenen Energieschwellenwerten, wobei mindestens zwei der Energieschwellenwerte Werte haben, die mit mindestens zwei verschiedenen K-Kanten-Energien von zwei verschiedenen Elementen einer Mischung entsprechen, die in der Untersuchungsregion angeordnet ist, wobei ein stöchiometrisches Verhältnis der beiden verschiedenen Elemente der Mischung bekannt und im Wesentlichen konstant ist; **gekennzeichnet durch**
Zerlegen des energie-aufgelösten Signals in mindestens eine Multi-K-Kanten-Komponente, die die mindestens zwei verschiedenen K-Kanten-Energien darstellt; und
Rekonstruieren eines Multi-K-Kanten-Bilds basierend auf der Multi-K-Kanten-Komponente und dem stöchiometrischen Verhältnis, um volumetrische Daten zu erzeugen, die die beiden verschiedenen Elemente angeben.

10. Verfahren nach Anspruch 9, wobei das stöchiometrische Verhältnis in einem Bereich von ca. 1:1 bis ca. 1:5 liegt.

11. Verfahren nach einem der Ansprüche 9 und 10, wobei das stöchiometrische Verhältnis und die K-Kanten-Energien das Abschwächungsverhalten der Elemente als eine Funktion der Photonenenergie eindeutig charakterisieren.

12. Verfahren nach einem der Ansprüche 9 bis 11, weiterhin umfassend das Zerlegen des energie-aufgelösten Signals in eine auf dem Compton-Effekt basierende Komponente und eine auf dem photoelektrischen Effekt basierende Komponente.

13. Verfahren nach einem der Ansprüche 9 bis 12, wobei die Mischung mindestens ein drittes Kontrastelement umfasst, und weiterhin umfassend mindestens einen dritten Schwellenwert, der dem dritten Kontrastelement entspricht; Zerlegen des energie-aufgelösten Signals in mindestens eine Multi-K-Kanten-Komponente, die mindestens drei verschiedene K-Kanten-Energien darstellt; und Rekonstruieren eines Multi-K-Kanten-Bilds basierend auf der Multi-K-Kanten-Komponente und dem stöchiometrischen Verhältnis, um volumetrische Bilddaten zu erzeugen, die die drei verschiedenen Elemente angeben.

14. Computerlesbares Speichermedium umfassend Anweisungen, die, wenn sie durch einen Computer ausgeführt werden, den Computer veranlassen, die folgenden Schritte durchzuführen:

Detektieren von polychromatischer Strahlung, die die Untersuchungsregion durchquert;
Erzeugen eines Signals, das die Energie eines detektierten Photons angibt;
Auflösen des Signals nach Energie basierend auf einer Vielzahl von verschiedenen Energieschwellenwerten, wobei mindestens zwei der Energieschwellenwerte Werte haben, die mit mindestens zwei verschiedenen K-Kanten-Energien von zwei verschiedenen Elementen entsprechen, die in der Untersuchungsregion angeordnet werden können, **dadurch gekennzeichnet, dass** das computerlesbare Medium weiterhin Anweisungen umfasst, die, wenn sie durch den Computer ausgeführt werden, den Computer veranlassen, die folgenden Schritte durchzuführen:

Zerlegen des energie-aufgelösten Signals in mindestens eine Multi-K-Kanten-Komponente, die die mindestens zwei verschiedenen K-Kanten-Energien darstellt, denen die Werte der mindestens zwei Energieschwellenwerte entsprechen, wobei die Mischung ein Kontrastmittel ist, wobei ein stöchiometrisches Verhältnis der beiden verschiedenen Elemente in dem Kontrastmittel bekannt und im Wesentlichen konstant ist.

Revendications

1. Système d'imagerie, comprenant:

une source de rayonnement (110) qui émet un rayonnement polychromatique qui traverse une région d'examen ;
un détecteur (116) qui détecte le rayonnement traversant la région d'examen et produit un signal indicatif de l'énergie d'un photon détecté ;
un discriminateur en énergie (122) qui entraîne une résolution en énergie du signal sur la base d'une pluralité de seuils d'énergie différents, dans lequel au moins deux des seuils d'énergie ont des valeurs pouvant correspondre à au moins deux énergies de bord K différentes de deux éléments différents dans un mélange disponible dans la région d'examen ; **caractérisé par**
un décomposeur de signal (132) qui décompose le signal de résolution en énergie en au moins un composant de bord K multiple représentant les au moins deux énergies de bord K différentes auxquelles les valeurs des au moins deux seuils d'énergie peuvent correspondre, dans lequel le mélange est un agent de contraste, dans lequel un rapport stoechiométrique des deux éléments différents dans l'agent de contraste est connu et sensiblement constant.

2. Système d'imagerie selon la revendication 1, dans lequel le système d'imagerie inclut en outre un reconstructeur (134) qui reconstruit le composant de bord K multiple pour générer une image de bord K multiple, représentative des différents matériaux, sur la base du rapport stoechiométrique.

3. Système d'imagerie selon la revendication 1, dans lequel le rapport stoechiométrique se situe dans une plage d'environ 1:1 à environ 1:5.

4. Système d'imagerie selon l'une quelconque des revendications 1 à 3, dans lequel le décomposeur de signal (132) décompose en outre le signal de résolution en énergie en composant de Compton et en composant photo-électrique.

5. Système d'imagerie selon la revendication 4, dans lequel le reconstructeur (134) reconstruit le composant de Compton et le composant photo-électrique pour générer une image de composant de Compton et une image de composant photo-électrique.

6. Système d'imagerie selon l'une quelconque des revendications 1 à 5, dans lequel les énergies de bord K se situent dans une plage d'environ 25 keV à environ 150 keV.

7. Système d'imagerie selon l'une quelconque des revendications 1 à 6, dans lequel au moins l'une des énergies de bord K est d'environ 33 keV.

8. Système d'imagerie selon l'une quelconque des revendications 1 à 7, dans lequel au moins l'une des énergies de bord K est d'environ 50 keV.

9. Procédé, comprenant :

la détection d'un rayonnement polychromatique émis par une source de rayonnement (110) qui traverse une région d'examen ;
la génération d'un signal indicatif de l'énergie d'un photon détecté ;
la résolution en énergie du signal sur la base d'une pluralité de seuils d'énergie différents, dans lequel au moins deux des seuils d'énergie ont des valeurs correspondant à au moins deux énergies de bord K différentes de deux éléments différents d'un mélange disposé dans la région d'examen, dans lequel un rapport stoechiométrique des deux éléments différents du mélange est connu et sensiblement constant ; **caractérisé par**
la décomposition du signal de résolution en énergie en au moins un composant de bord K multiple représentant les au moins deux énergies de bord K différentes ; et
la reconstruction d'une image de bord K multiple sur la base du composant de bord K multiple et du rapport stoechiométrique pour générer des données d'image volumétriques indicatives des deux éléments différents.

10. Procédé selon la revendication 9, dans lequel le rapport stoechiométrique se situe dans une plage d'environ 1:1 à environ 1:5.

11. Procédé selon l'une quelconque des revendications 9 et 10, dans lequel le rapport stoechiométrique et les énergies de bord K caractérisent uniquement le comportement d'atténuation des éléments en fonction de l'énergie photonique.

12. Procédé selon l'une quelconque des revendications 9 à 11, incluant en outre la décomposition du signal de résolution en énergie en un composant à effet de Compton et un composant à effet photo-électrique.

13. Procédé selon l'une quelconque des revendications 9 à 12, dans lequel le mélange inclut au moins un troisième élément de contraste, et incluant en outre au moins un troisième seuil correspondant au troisième élément de contracte ; la décomposition du signal de résolution en énergie en au moins un composé de bord K multiple représentant les au moins trois énergies de bord K différentes ; et la reconstruction d'une image de bord K multiple sur la base du composant de bord K multiple et du rapport stoechiométrique pour générer des données d'image volumétriques indicatives des trois éléments différents.

14. Support de stockage pouvant être lu par un ordinateur contenant des instructions qui, lorsqu'elles sont exécutées par un ordinateur, entraînent la réalisation par l'ordinateur des étapes de :

détection d'un rayonnement polychromatique traversant la région d'examen ;
production d'un signal indicatif d'une énergie d'un photon détecté ;
discrimination en énergie du signal sur la base d'une pluralité de seuils d'énergie différents, dans lequel au moins deux des seuils d'énergie ont des valeurs pouvant correspondre à au moins deux énergies de bord K différentes de deux éléments différents disponibles dans la région d'examen ; **caractérisé en ce que** le support de stockage pouvant être lu par un ordinateur contient des instructions qui, lorsqu'elles sont exécutées par l'ordinateur, entraînent la réalisation par l'ordinateur des étapes de :

décomposition du signal de résolution en énergie en un composant de bord K multiple représentant les au moins deux énergies de bord K différentes auxquelles les valeurs des au moins deux seuils d'énergie peuvent correspondre, dans lequel le mélange est un agent de contraste, dans lequel un rapport stoechiométrique des deux éléments différents dans l'agent de contraste est connu et sensiblement constant.

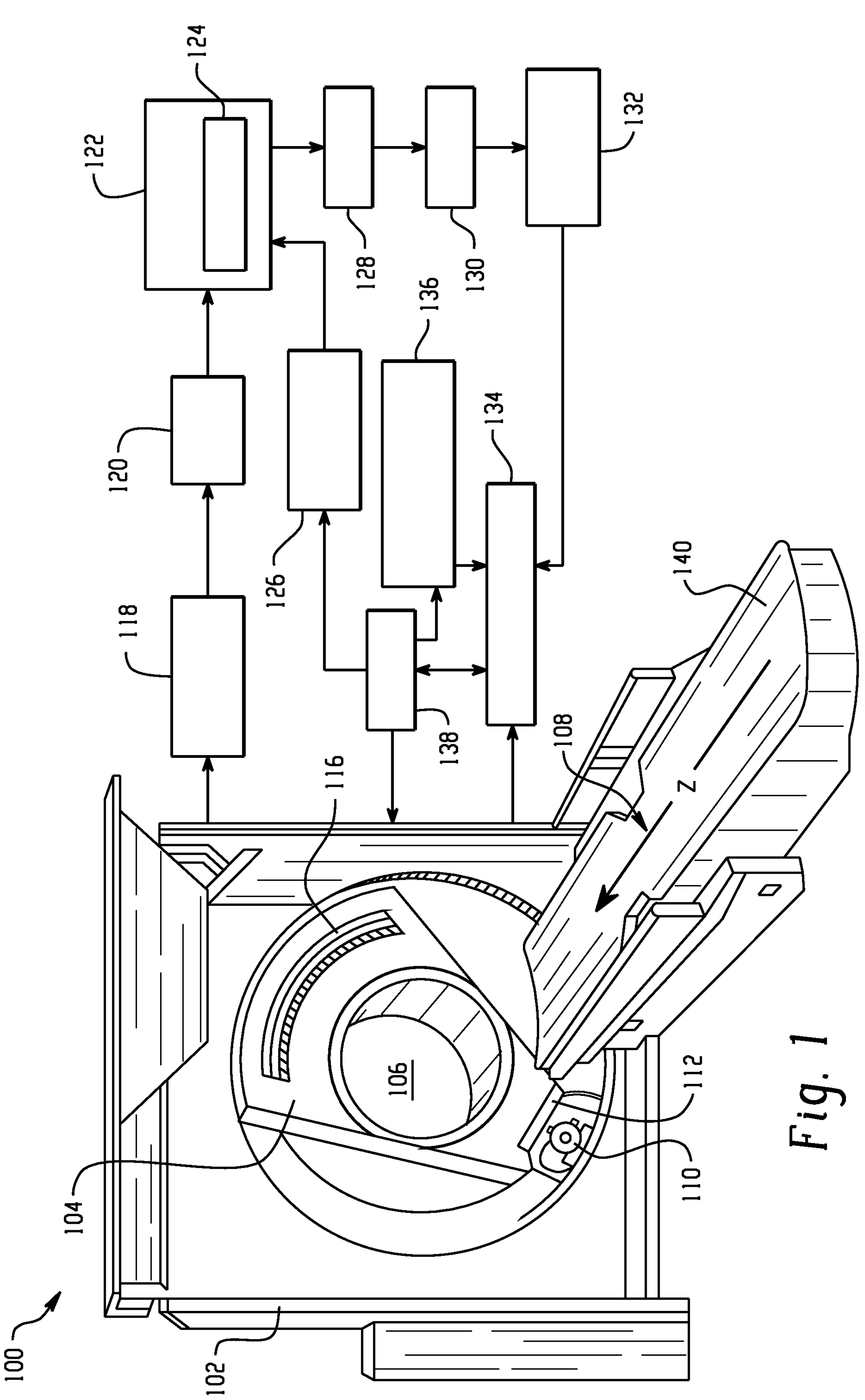
100
102
104
106
108
110
112
116
118
120
122
124
126
128
130
132
134
136
138
140
Z

Fig. 1

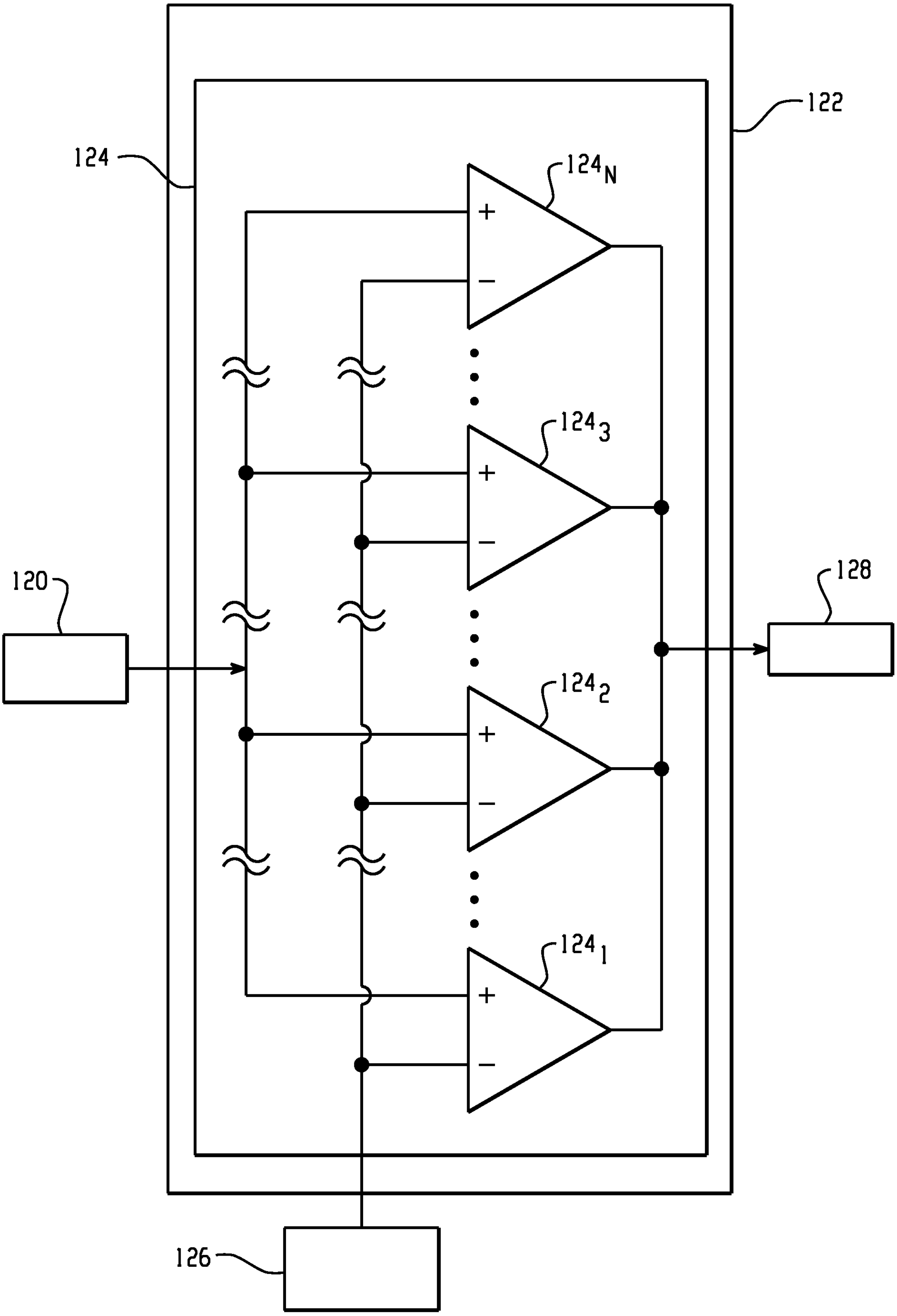

Fig. 2

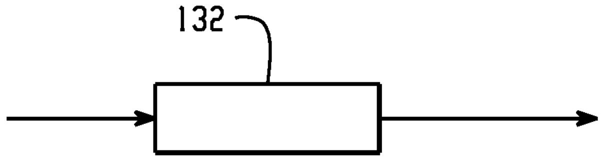

Fig. 3

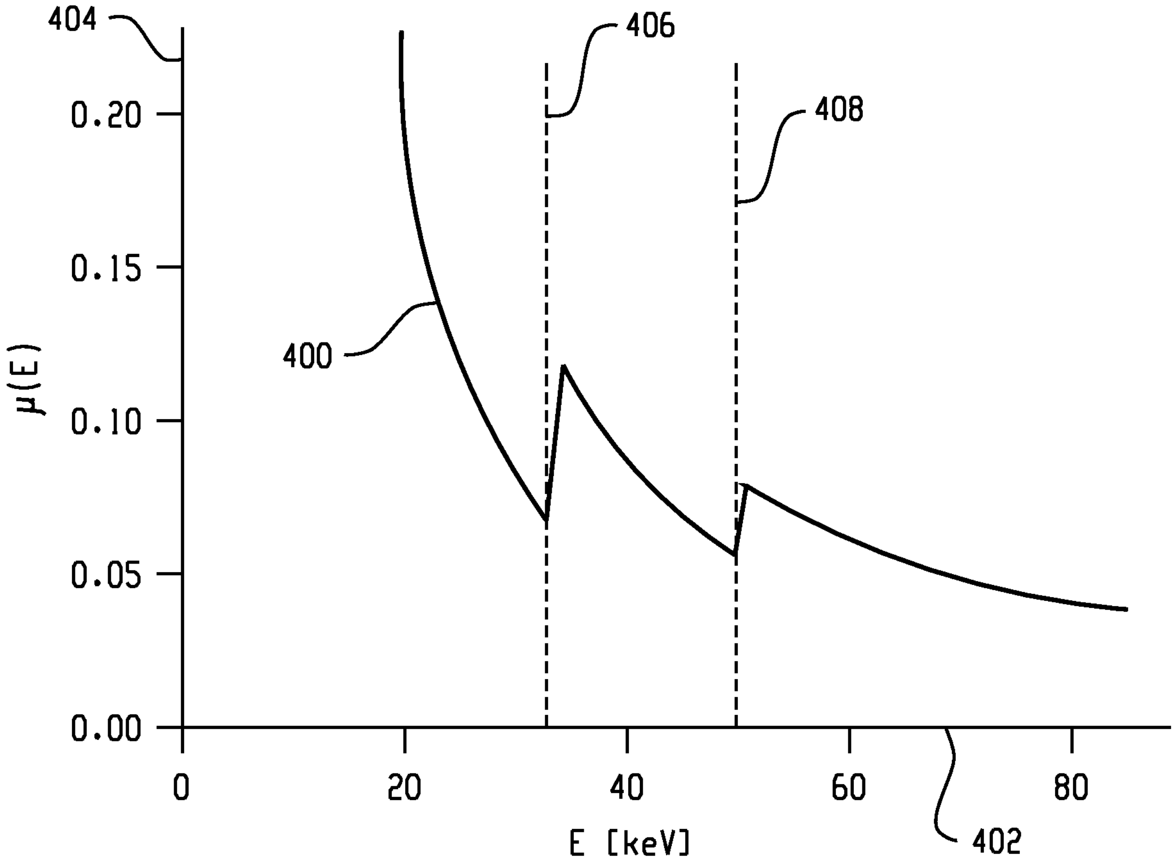

Fig. 4

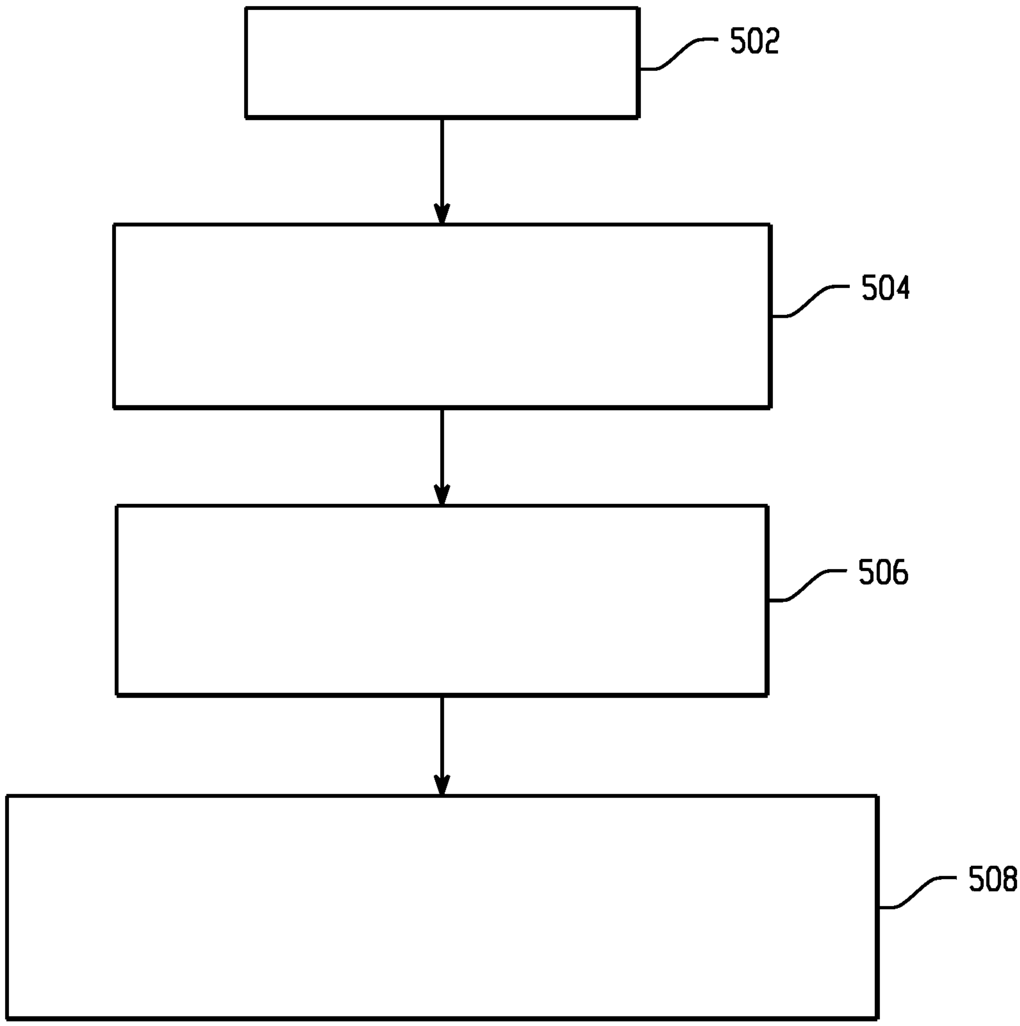

Fig. 5

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 20080137803 A1 **[0002]**
- WO 2008078255 A2 **[0003]**
- WO 2006084382 A1 **[0004]**
- EP IB2007055105 W **[0036]**
- EP 06126653 A **[0036]**

Non-patent literature cited in the description

- **E. ROESSL ; R. PROKSA.** K-edge imaging in x-ray computed tomography using multi-bin photon counting detectors. *Phys. Med. Biol.,* 2007, vol. 52, 4679-7696 **[0034]**

patsnap

专利名称(译)	K边缘成像		
公开(公告)号	EP2296550B1	公开(公告)日	2018-03-28
申请号	EP2009786437	申请日	2009-06-22
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V. 飞利浦知识产权及标准部GMBH		
当前申请(专利权)人(译)	皇家飞利浦N.V. 飞利浦知识产权及标准部GMBH		
[标]发明人	ROESSL EWALD PROKSA ROLAND SCHLOMKA JENS PETER		
发明人	ROESSL, EWALD PROKSA, ROLAND SCHLOMKA, JENS-PETER		
IPC分类号	G01N23/087 A61B6/03 A61B5/00 A61B6/00		
CPC分类号	A61B5/4869 A61B6/032 A61B6/4241 A61B6/481 A61B6/482 G01N23/087		
优先权	61/078575 2008-07-07 US		
其他公开文献	EP2296550A1		
外部链接	Espacenet		

摘要(译)

一种成像系统，包括发射穿过检查区域的多色辐射的辐射源（110）和检测穿过检查区域的辐射并产生指示检测到的光子的能量的信号的检测器（116）。该系统还包括能量鉴别器（122），其基于多个不同的能量阈值来解析信号，其中至少两个能量阈值具有对应于a中两个不同元素的至少两个不同K边缘能量的值。混合物置于检查区域。该系统还包括信号分解器（132），其将能量分解信号分解成至少表示至少两个不同K边缘能量的多K边缘分量。在一个例子中，造影剂中两种不同元素的化学计量比是已知的并且基本上是恒定的。

Equation 1:

$$d_n = \int dE\, T(E)\, D_n(E) \exp(-(\rho P(E) + c\, C(E) + k\, K(E))).$$