(19) NL Octrooicentrum

(11) **2005892**

(12) C OCTROOI

(21) Aanvraagnummer: **2005892**

(22) Aanvraag ingediend: **22.12.2010**

(51) Int.Cl.:
A61B 6/03 (2006.01) ***G06T 11/00*** (2006.01)

(30) Voorrang:
23.12.2009 US 61/289822
08.12.2010 US 12/962972

(43) Aanvraag gepubliceerd:
06.07.2011

(47) Octrooi verleend:
18.12.2012

(45) Octrooischrift uitgegeven:
28.12.2012

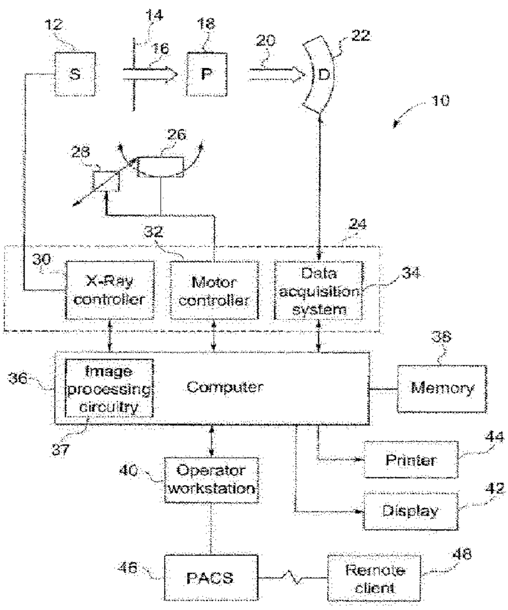
(73) Octrooihouder(s):
General Electric Company
te Schenectady, New York,
Verenigde Staten van Amerika (US).

(72) Uitvinder(s):
Xiaoye Wu te NISKAYUNA, NEW YORK (US).
David Allen Langan
te NISKAYUNA, NEW YORK (US).
Jiang Hsieh te Waukesha, Wisconsin (US).
Robert Franklin Senzig
te Waukesha, Wisconsin (US).
Dan Xu te NISKAYUNA, NEW YORK (US).
Thomas Matthew Benson
te NISKAYUNA, NEW YORK (US).
Hao Lai te Niskayuna, New York (US).

(74) Gemachtigde:
Ir. H.V. Mertens c.s. te Rijswijk.

(54) Dual-energy imaging at reduced sample rates.

(57) The present disclosure relates to the generation of dual-energy X-ray data (62, 64) using a data sampling rate comparable to the rate utilized for single-energy imaging. In accordance with the present technique a reduced kVp switching rate is employed compared to conventional dual-energy imaging. Full angular resolution is achieved in the generated images.



Dit octrooi is verleend ongeacht het bijgevoegde resultaat van het onderzoek naar de stand van de techniek en schriftelijke opinie. Het octrooischrift wijkt af van de oorspronkelijk ingediende stukken. Alle ingediende stukken kunnen bij NL Octrooicentrum worden ingezien.

NL C 2005892

DUAL-ENERGY IMAGING AT REDUCED SAMPLE RATES

BACKGROUND OF THE INVENTION

The subject matter disclosed herein relates to non-invasive imaging and, in particular, to dual-energy imaging.

In the fields of medical imaging and security screening, non-invasive imaging techniques have gained importance due to benefits that include unobtrusiveness, convenience, and speed. In medical and research contexts, non-invasive imaging techniques are used to image organs or tissues beneath the surface of the skin. Similarly, in industrial or quality control (QC) contexts, non-invasive imaging techniques are used to examine parts or items for hidden defects that may not be evident from an external examination. In security screening, non-invasive imaging techniques are typically used to examine the contents of containers (e.g., packages, bags, or luggage) without opening the containers and/or to screen individuals entering or leaving a secure location.

A number of non-invasive imaging modalities exist today. One such technique, dual-energy (DE) radiography, involves the acquisition of X-ray attenuation data at different energies within a relatively small time interval. The attenuation data at the different energy levels may then be used to decompose the imaged anatomy and create a first image of a first material (e.g., water or bone) and a second image of a second material (e.g., iodine, or other contrast agents). Because of the need to acquire sufficient attenuation data at multiple X-ray energies, the data or imaging sampling rate may be significantly increased (e.g., doubled) relative to scans where data is acquired at only a single energy. Such increased sampling rates may be difficult to obtain because of the physical, electrical, and/or mechanical constraints imposed by the imaging system hardware. Further, the smaller view times associated with the faster sampling rate may result in increased noise relative to the useful signal in such sampling schemes. Accordingly, techniques are needed to overcome the problems associated with dual energy image acquisition and reconstruction. The techniques described herein are intended to address one or more of these problems associated with dual energy imaging systems.

BRIEF DESCRIPTION OF THE INVENTION

In one embodiment, a method for acquiring dual-energy projection data is provided. The method includes the act of alternately emitting X-rays corresponding to a low kVp and a high kVp such that a corresponding set of low kVp projection data is acquired for each low kVp emission and a corresponding set of high kVp projection data is acquired for each high kVp emission. The aggregate sets of low kVp projection data or high kVp projection data, when taken alone, do not provide full angular resolution. But the combined sets of low kVp projection data and high kVp projection data provide full angular resolution. A mixed kVp image is generated using the combined low kVp projection data and high kVp projection data. A seed image is generated based upon the mixed kVp image. The seed image is updated to generate an updated image. The updated image is reprojected to generate density projections at full angular resolution. One or more of high kVp images, low kVp images, material decomposition images, or monochromatic images are generated based at least in part on the generated density projections.

In another embodiment, a method for acquiring dual-energy projection data is provided. The method includes the act of alternately generating X-rays corresponding to a low kVp and a high kVp such that a corresponding set of low kVp projection data is acquired for each low kVp emission and a corresponding set of high kVp projection data is acquired for each high kVp emission. A mixed kVp image is generated using the combined low kVp projection data and high kVp projection data. A seed image approximating one basis material is generated based upon the mixed kVp image. The seed image is updated to generate an updated image. The updated image is reprojected to generate density projections at full angular resolution. The generated density projections are used to compute missing angular views for the set of low kVp projection data or the set of high kVp projection data. One or more of high kVp images, low kVp images, material decomposition images, or monochromatic images are generated based at least in part on the one or more computed missing angular views for the set of low kVp projection data or the set of high kVp projection data.

In a further embodiment, a multi-energy imaging system is provided. In one such embodiment, the multi-energy imaging system includes an X-ray source capable of emitting X-rays at a low kVp and a high kVp and a detector assembly capable of generating signals in response to the emitted X-rays. The imaging system also includes a data acquisition system configured to acquire the signals generated by the detector assembly such that a corresponding set of low kVp projection data is acquired for each low kVp emission and a corresponding set of high kVp projection data is acquired for each high kVp emission, wherein the aggregate sets of low kVp projection data or high kVp projection data, when taken alone, do not provide full angular resolution but the combined sets of low kVp projection data and high kVp projection data provide full angular resolution. In addition, the imaging system includes image processing circuitry configured to execute one or more algorithms. When executed by the image processing circuitry, the one or more algorithms: generate a mixed kVp image using the combined low kVp projection data and high kVp projection data; extract a seed image based upon the mixed kVp image; update the seed image to generate an updated image; reproject the updated image to generate density projections at full angular resolution; and generate one or more of high kVp images, low kVp images, material decomposition images, or monochromatic images based at least in part on the generated density projections.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. 1 is a perspective view of a dual-energy (DE) X-ray imaging system in accordance with an embodiment of the present technique; and

FIG. 2 is a flowchart depicting steps of a dual-energy imaging algorithm in accordance with an embodiment of the present technique.

DETAILED DESCRIPTION OF THE INVENTION

As described in detail below, embodiments of a dual-energy (DE) imaging system and techniques are provided for producing materially decomposed (MD) and/or monochromatic images with little or no increase in the sampling rate as compared to the acquisition of image data at a single-energy. This approach utilizes a basis material decomposition algorithm that allows the kVp (kilivolts peak) switching rate (associated with switching between the two X-ray energies used for dual-energy data acquisition) to be reduced by half compared to conventional dual-energy approaches. In one embodiment of the present approach, a mixed kVp image is obtained at full angular resolution. A seed image corresponding to one basis material is extracted and updated. The updated basis material image is then used to generate full angular resolution low- or high-energy images, basis material images, or monochromatic images. Although the embodiments illustrated herein are described in a medical imaging context, it should be noted that the presently contemplated techniques may also be applicable in security or quality control contexts.

With the foregoing in mind and turning now to the drawings, FIG. 1 illustrates a multi-energy X-ray imaging system 10 that may be used in accordance with the present techniques. In the illustrated embodiment, the multi-energy X-ray imaging system 10 is a digital X-ray system that is designed to both acquire and process image data for display. The system 10 is capable of acquiring X-ray attenuation image data at two or more X-ray energy levels. For example, in one embodiment, the system 10 is capable of acquiring projection data of a region of interest using X-rays at a first energy level (e.g., high energy) as well as using X-rays at a second, different energy level (e.g., low energy). Further, the depicted system 10 may acquire projection data at a variety of angular positions. For the different angular positions, image data may be acquired at both X-ray energy levels or at only one of the X-ray energy levels. The multi-energy X-ray imaging system 10 (e.g., a dual-energy imaging system) may be used to produce images based on the data acquired at the different X-ray energy levels (i.e., high energy and low energy images), based on different basis materials (e.g., bone images, water images, contrast images, and so forth), or based on a specified wavelength (i.e., a monochromatic image).

For example, with respect to basis material images, a first basis material and a second basis material will have different absorption characteristics for the low energy X-rays and the high energy X-rays generated by the system 10, enabling the system

10 to distinguish the absorption of X-rays caused by the first basis material and the absorption caused by the second basis material. Such differential absorption allows the system 10 to be operable to produce both high energy projections and low energy projections that may be materially decomposed (based on these differential absorption characteristics) to produce basis material images (e.g., water images, bone images, iodine images, calcium images, etc.) for further analysis of the desired anatomy. Though the illustrated imaging system 10 is discussed in the context of medical imaging, the techniques and configurations discussed herein are applicable in other non-invasive imaging contexts, such as security screening or industrial nondestructive evaluation of manufactured parts.

In the embodiment illustrated in FIG. 1, the multi-energy imaging system 10 is depicted as a computed tomography (CT) imaging system that includes an X-ray source 12. The X-ray source is configured to generate X-ray at different energy levels, as discussed herein. The source 12 may be positioned proximate to a collimator 14. The collimator 14 may consist of one or more collimating regions, such as lead or tungsten shutters, for each emission point of the source 12. The collimator 14 typically defines the size and shape of the one or more X-ray beams 16 that pass into a region in which a subject 18, such as a human patient, is positioned. Each X-ray beam 16 may be generally fan-shaped or cone-shaped, depending on the configuration of the detector array and/or the desired method of data acquisition, as discussed below. An attenuated portion 20 of each X-ray beam 16 passes through the subject 18 and impacts a detector array, represented generally at reference numeral 22.

The illustrated system 10 may include one or more collimators 14 or filters that shape or limit an emitted stream of radiation directed toward a region in which the subject 18 is positioned. However, in some embodiments, the system 10 may not include a collimator, and images may be obtained using the full field of view of the system 10. Alternatively, in certain embodiments, the field of view of the system 10 may be reduced by using the collimator 14 to reduce the spread of X-rays produced by the X-ray source 12. The collimator 14 can be selectively placed over the X-ray source 12 when desired or the collimator 14 may be kept disposed over the X-ray source 12.

Additionally, the collimator 14 may be adjustable so that full (or wide) field of view and reduced (or narrow) field of view images may be obtained with the collimator disposed over the X-ray source 12. It should be noted that the present techniques may be used in an imaging system having a standard collimator, a slit collimator, any other suitable collimator, or no collimator at all.

The detector 22 is generally formed by a plurality of detector elements that detect the X-ray beams 16 after they pass through or around the subject 18. Each detector element produces an electrical signal that represents the intensity of the X-ray beam 16 incident at the position of the detector element when the beam strikes the detector 22. Alternatively, each element of detector 22 may count incident photons in the X-ray beam 16 and may also determine their energy. Typically, the X-ray beam 16 is generated and the corresponding electrical signals are acquired at a variety of angular positions around the subject of interest so that a plurality of radiographic projection views can be collected. The electrical signals are acquired and processed to reconstruct an image that is indicative of the features within the subject 18, as discussed in further detail below.

It should be noted that the digital X-ray detector 22 may be any detector that is operable to perform dual-energy X-ray imaging. For instance, the digital X-ray detector 22 may be an amorphous silicon flat panel that has the ability to acquire two images in rapid succession. Additionally, the detector 22 may include energy discriminative detector materials that are capable of separating X-ray photons from one acquisition into two energy bins. Such detectors may be useful in acquiring data via energy discrimination or photon counting approaches. That is, the digital detector 22 may be capable of facilitating image acquisition speeds that enable the acquisition of high and low energy images with large energy separation (mean energy separations in spectra as high as approximately 90keV), which may translate to improved image subtraction. In one embodiment, the X-ray detector 22 converts the X-ray photons received on its surface to lower energy photons, and subsequently to electric signals, which are acquired and processed to reconstruct one or more images of the features within the subject.

A system controller 24 commands operation of the imaging system 10 to execute examination protocols and to process the acquired data. The source 12 is typically controlled by the system controller 24. Generally, the system controller 24 furnishes power, focal spot location, control signals and so forth, for the multi-energy examination sequences. The detector 22 is coupled to the system controller 24, which commands acquisition of the signals generated by the detector 22. The system controller 24 may also execute various signal processing and filtration functions, such as initial adjustment of dynamic ranges, interleaving of digital image data, and so forth. In the present context, system controller 24 may also include signal-processing circuitry and associated memory circuitry. As discussed in greater detail below, the associated memory circuitry may store programs and/or routines executed by the system controller 24 or a processor-based system in communication with the system controller 24, such as programs or routines for implementing the presently disclosed techniques. Further, the memory circuitry of the system controller 24 may also store configuration parameters, image data, and so forth. In one embodiment, the system controller 24 may be implemented as all or part of a processor-based system such as a general purpose or application-specific computer system.

In the illustrated embodiment of FIG. 1, the system controller 24 may control the movement of a linear positioning subsystem 28 and a rotational subsystem 26 via a motor controller 32. In an embodiment where the imaging system 10 includes rotation of the source 12 and/or the detector 22, the rotational subsystem 26 may rotate the source 12, the collimator 14, and/or the detector 22 about the subject 18. It should be noted that the rotational subsystem 26 might include a gantry comprising both stationary components (stator) and rotating components (rotor). The linear positioning subsystem 28 may enable the subject 18, or more specifically a patient table that supports the subject 18, to be displaced linearly. Thus, the patient table may be linearly moved within the gantry or within an imaging volume (e.g., the volume located between the source 12 and the detector 22) and enable the acquisition of data from particular areas of the subject 18 and, thus the generation of images associated with those particular areas. Additionally, the linear positioning subsystem 28 may displace the one or more components of the collimator 14, so as to adjust the shape and/or direction of the X-ray beam 16. In embodiments comprising a stationary source 12 and a stationary detector 22, a mechanical rotational subsystem may be absent, with emitters spaced at different angular locations about the subject instead being activated at different times to allow acquisition of projections at different angles. Similarly, in embodiments in which the source 12 and the detector 22 are configured to provide extended or sufficient coverage along the z-axis (i.e., the axis associated with the main length of the subject 18) and/or linear motion of the subject is not required, the linear positioning subsystem 28 may be absent.

The source 12 may be controlled by an X-ray controller 30 disposed within the system controller 24. The X-ray controller 30 may be configured to provide power and timing signals to the source 12. In addition, the X-ray controller may operate to control the energy level of the X-rays emitted by the source 12 at any given time. In addition, in some embodiments the X-ray controller 30 may be configured to selectively activate the source 12 such that tubes or emitters at different locations within the system 10 may be operated in synchrony with one another or independent of one another.

Further, the system controller 24 may comprise a data acquisition system 34. In such an embodiment, the detector 22 is coupled to the system controller 24, and more particularly to the data acquisition system 34. The data acquisition system 34 receives data collected by readout electronics of the detector 22. The data acquisition system 34 typically receives sampled analog signals from the detector 22 and converts the data to digital signals for subsequent processing by a processor-based system, such as a computer 36. Alternatively, in other embodiments, the detector 22 may convert the sampled analog signals to digital signals prior to transmission to the data acquisition system 34.

In the depicted embodiment, a computer 36 is coupled to the system controller 24. The data collected by the data acquisition system 34 may be transmitted to the computer 36 for subsequent processing and reconstruction. For example, the data collected from the detector 22 may undergo pre-processing and calibration at the data acquisition system 34 and/or the computer 36 to produce representations of the line integrals of the attenuation coefficients of the subject 18 and the scanned objects. In one embodiment, the computer 36 contains image-processing circuitry 37 for processing and filtering the data collected from the detector 22. The processed data, commonly called projections, may then be reconstructed by the image processing circuitry 37 to form an image of the subject 18 and/or the scanned area.

In one implementation, the projections are reconstructed into high- and/or low energy images, materially decomposed (MD) images, and/or monochromatic images, in accordance with the techniques discussed herein. For example, the image processing circuitry 37 may include instructions for receiving acquired image data, generating high- or low- energy images, materially decomposed images, or monochromatic images in accordance with the techniques described in detail below, and outputting the generated images via an output device, such as the display 42, a printer 44, or the like. Once reconstructed, the images produced by the system 10 of FIG. 1 may reveal an internal region of interest of the subject 18 which can be used for diagnosis, evaluation, and so forth.

The computer 36 may comprise or communicate with a memory 38 that can store data processed by the computer 36, data to be processed by the computer 36, or routines and/or algorithms to be executed by the computer 36, such as for processing image data in accordance with the present techniques. It should be understood that any type of computer accessible memory device capable of storing the desired amount of data and/or code may be utilized by such a system 10. Moreover, the memory 38 may comprise one or more memory devices, such as magnetic, solid-state, or optical devices, of similar or different types, which may be local and/or remote to the system 10. The memory 38 may store data, processing parameters, and/or computer programs comprising one or more routines or algorithms for performing the image processing and reconstruction techniques described herein.

The computer 36 may also be adapted to control features enabled by the system controller 24 (i.e., scanning operations and data acquisition). Furthermore, the computer 36 may be configured to receive commands and scanning parameters from an operator via an operator workstation 40 which may be equipped with a keyboard and/or other input devices. An operator may, thereby, control the system 10 via the operator workstation 40. Thus, the operator may observe from the computer 36 the reconstructed image and other data relevant to the system 10, initiate imaging, select and apply image filters, and so forth. Further, the operator may manually identify and/or review features and regions of interest from the reconstructed image. Automated detection algorithms may be applied to aid in identifying and/or manipulating the features or regions of interest.

As illustrated, the system 10 may also include a display 42 coupled to the operator workstation 40. The display 42 may be utilized to observe the reconstructed images, for instance. Additionally, the system 10 may include a printer 44 coupled to the operator workstation 40 and configured to print a copy of the one or more reconstructed images. The display 42 and the printer 44 may also be connected to the computer 36 directly or via the operator workstation 40. Further, the operator workstation 40 may include or be coupled to a picture archiving and communications system (PACS) 46. It should be noted that PACS 46 might be coupled to a remote system 48, radiology department information system (RIS), hospital information system (HIS) or to an internal or external network, so that others at different locations can gain access to the image data.

Although only one operator workstation is depicted, one or more operator workstations 40 may be linked in the system 10 for outputting system parameters, requesting examinations, viewing images, and so forth. In general, displays 42, printers 44, workstations 40, and similar devices supplied within the system 10 may be local to the data acquisition components, or may be remote from these components, such as elsewhere within an institution or hospital, or in an entirely different location, linked to the image acquisition system 10 via one or more configurable networks, such as the Internet, virtual private networks, and so forth. Furthermore, although the previous discussion discloses typical embodiments of the imaging system 10, any other suitable system configuration may be employed to acquire image data and process such data via the techniques described herein.
With the foregoing system discussion in mind, an imaging system 10 as described above may be used in multi, e.g., dual, energy imaging protocols. In conventional approaches, the kVp associated with the X-ray source might be modulated rapidly between a low and high kVp setting to achieve the desired X-ray energy profile for a data acquisition. In such a conventional, approach, the number of views at low or high kVp has to be sufficient enough individually such that each of the kVp projections can form an image without view starvation artifacts. As a result, during a scan, the sampling rate has to be doubled compared to that of a single kVp scan. Such an increased sampling scheme reduces the effective photon energy separation between the low and high kVp due to the finite high voltage ramp up and ramp down slope. In addition, the signal to electronic noise ratio is increased as a result of the reduced view time. In accordance with the present disclosure, a basis material

decomposition approach is described in which the sampling rate is not doubled while sufficient angular resolution is maintained.

In conventional basis material decomposition (BMD), measurements of low and high kVp projection rays fully aligned in space are acquired. These high- and low kVp projections are transformed to a new set of projections, each representing the density line integration of corresponding basis material along the ray path, as mathematically described in the following:

(1) $$m_1 = F_1(p_{low}, p_{high})$$

(2) $$m_2 = F_2(p_{low}, p_{high})$$

where, m_1 and m_2 are the density integral of materials 1 and 2, respectively, p_{low} and p_{high} are the measured and processed projections at low and high kVp, and F() functions are derived from system calibration.

In this conventional approach, for decomposition to be performed, p_{low} and p_{high} are projections at the same ray path. In a fast kVp switching implementation, p_{low} in the p_{high} ray path is obtained by interpolating among low kVp projections in the vicinity around p_{high} ray path to the precise p_{high} ray path, or vice versa. To avoid the loss of angular resolution, high view numbers of low and high kVp projections are employed, resulting in the use of a fast switching mode. The rapid switching decreases the time duration of low and high kVp states, relatively increasing the portion of the kVp transition time in both low and high views. As a result, the effective energy separation between the two projections narrows. In addition, the signal to electronic noise ratio decreases. The energy narrowing effect leads to elevated noise in the decomposed projections m_1 and m_2 due to the nature of the BMD process. In general, the more energy separation between low and high kVp states, the better noise characteristic in the decomposed material density images.

In accordance with the present approach, the same angular resolution for the basis material decomposed images is maintained despite a relatively slow kVp switching rate being employed in the scan. For example, referring now to FIG. 2, in one implementation low and high kVp X-ray emissions are alternated sequentially (block 60), with the total number of angular views of low and high kVp projections 62, 64 sufficient to satisfy the required angular resolution. In accordance with one such implementation, the sampling rate is approximately half that of a direct basis material decomposition. In the depicted embodiment, the low and high kVp projections 62, 64 are not separated to form individual images, but are instead combined (block 66) together to form a mixed kVp image volume 68. The mixed kVp image volume 68, $Img_{mix}(x, y, z)$, is equivalent to a middle or intermediate kVp image. That is, in one implementation the mixed kVp image volume 68 approximates an image volume obtained at 120kVp when the low-energy and high-energy X-ray emissions are obtained at 80 kVp and 140 kVp respectively. No additional artifacts are typically observed in the mixed kVp image volume 68 compared to images reconstructed using the respective low or high kVp with full angular views, i.e., conventional high-energy images and low-energy images.

Image data related to material decomposition pairs of interest 74, 76 may be approximately extracted (block 72) from the mixed kVp image volume 68 and/or image data not related to such basis materials of interest may be excluded or removed from the mixed kVp image volume 68. For example, in one implementation bone and iodine data points are individually extracted from the mixed kVp image volume 68 and non-contrast enhanced soft tissue is eliminated. Such an example may pertain to an implementation in which iodine (i.e., contrast) and bone (e.g., calcium) material decomposition images are to be generated. In one implementation, intensity value thresholds (such as based upon threshold values of Hounsfield units (HU)) may be employed to perform the extraction. In another implementation, bone may be segmented from iodine, such as by employing a bone location-contour and HU differences.

The extracted image data 74, 76 may be used to generate (block 80) a seed image 82 for use in subsequent processing. As may be appreciated, the seed image 82 has the full angular resolution since it is extracted from the mixed kVp image volume 68 which posses full angular resolution. For example, in the above implementation the segmented bone HU image data points and contrast solution HU image data points are separately transformed to pure iodine density representations based on a pre-knowledge of high and low kVp spectra, the bone composition and the difference between pure iodine and the iodine solution set. In this example, the new image volume serves as a seeding non-water object image, e.g. seed image 82. The more accurate the seed image 82 when generated, the less intensity modification is needed in the later stages. In the present example, in the seed image 82, small vessels and lesions with insufficient iodine contrast may be missed and there may be a difference between the transformed iodine density image and the true iodine density.

Such a difference may be reduced or eliminated by updating (block 86) the seed iodine image using sparsely sampled projections from direct projection based basis material decomposition to generate an updated or true density image 88. For instance, in keeping with the previous example, to update the seed iodine image, sparsely sampled (half the view number, or less) projections m_1 and m_2 (92, 94) from a direct basis material decomposition (block 90) are obtained from angularly aligned low and high kVp projections p_{low} and p_{high} by interpolation in the angular direction. In such an example, where m_2 is the iodine projection, the difference projection p_{update} of m_2 and reprojected rays from the seed iodine p_i at the same angular direction is computed.

(3) $$p_{update} = R(m_2) - p_i$$

where operator R() matches the spatial resolution of the iodine projections from direct basis material decomposition to that from the reprojected rays p_i based on the seed image 82.

A difference image can be reconstructed from difference projection p_{update} of m_2 and added to the seed iodine image to form the updated iodine image 88. If the seed iodine image is very close to the true iodine image, the difference image is small in magnitude, adding limited noise contamination to the seed image 82. The difference image may contain image data representing the small vessels and/or other small features that are missing in the seed image 82, and it may also correct for inaccurate density values of the iodine in the seed image 82 to the true iodine density representation. Both of these features in the updating process help provide an accurate iodine density image, on which generation of subsequent images discussed herein rely. The update is physically accurate due to the fact that in material decomposition space, the beam hardening effect is greatly minimized.

The updated density or material image 88 is reprojected (block 100) to obtain iodine density projections 102 at full angular resolution. For example, let p_{id} be the reprojected iodine density projection 102 in the angular direction corresponding to the initially sampled low and high kVp projections 62, 64. The low kVp and high kVp projections 62, 64 can be inter-transformed (block 104) with the help of p_{id}. The transformation may take the following functional forms in one embodiment, which can be captured during system calibration.

(4) $$p_{low\_transformed} = T_{low2high}(p_{high}, p_{id})$$

(5) $$p_{high\_transformed} = T_{high2low}(p_{low}, p_{id})$$

After the transformation, the missing angular views in the initial low or high kVp projections are patched and full angular resolution kVp images 112, 114 may be generated (block 110) using the transformed and original kVp projection sets. In addition, upon generation of the full angular resolution low and high kVp projections, the corresponding material decomposition images 118, 120, such as a water and iodine image pair, can be effectively computed (block 116). Further, monochromatic images 124 may be generated (block 122) using the transformed and original sets of kVp projections. This process may be performed after obtaining the material decomposition images 118, 120, by proper weighting of the two material decomposition images 118, 120, as the following,

(6) $$\mathrm{Im}_{mono} = \mathrm{Im}_{m1}\,\mu_{m1}(E) + \mathrm{Im}_{m2}\,\mu_{m2}(E)$$

where, Im_{m1} and Im_{m2} are the two material decomposition images 118, 120 (in the example above the water and iodine images respectively) with corresponding mass attenuation coefficients $\mu_{m1}(E)$ and $\mu_{m2}(E)$ at energy E.

Thus, by using the basis material decomposition algorithm disclosed herein, fast kVp switching rate can be effectively reduced by a factor of 2. This reduction in switching frequency can significantly increase the energy separation between the low and high kVp projections, thus providing reduced noise in the materially decomposed images.

Further, the typical images associated with dual energy scanning can be deduced without loss of angular resolution and without view starvation artifacts. This algorithm may be useful in dual energy cardiac imaging where fast sampling rates are needed due to the temporal resolution requirements imposed by the beating heart. Thus, the present algorithm offers an alternative to effectively reduce the sample-rate typically associated with dual energy scanning. Further, in accordance with this algorithm, the sampling does not have to follow a one-low and one-high kVp pattern. For example, the low kVp samples can be further reduced as long as they do not create view starvation artifact in the iodine density image updating process.

Technical effects of the invention include generation of high and/or low kVp images, materially decomposed images, and/or monochromatic images at a reduced kVp switching rate. Other technical effects include generating materially decomposed (or other) images associated with dual-energy scanning that have the same angular resolution as when generated by conventional techniques but at a kVp switching rate that is essentially half the switching rate used in the conventional techniques.
Further, a technical effect of the present disclosure is a multi- or dual-energy imaging system that executes multi- or dual-energy imaging protocols in which the sampling rate is not doubled but where angular resolution is maintained.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

Part list:

10	X-ray Imaging System
12	X-ray Source
14	Collimator
16	X-Rays
18	Subject
20	Attenuated X-rays
22	Detector Array
24	System Controller
26	Rotational Subsystem
28	Linear Positioning Subsystem
30	X-Ray Controller
32	Motor Controller
34	Data Acquisition System
36	Computer
37	Image Processing Circuitry
38	Memory
40	Operator Workstation
42	Display
44	Printer
46	PACS
48	Remote Client
60	Acquire high and low kVp projection data
62	High kVp Projections
64	Low kVp Projections
66	Reconstruct Combined Projections
68	Mixed kVp Image Volume
72	Extract M1 and M2 data sets
74	M1 Image Data
76	M2 Image Data
80	Generate Seed Image
82	Seed Image
86	Update Seed Image
88	Updated Density Image
90	Basis Material Decomposition
92	Sparse Sampled M1 Projections
94	Sparse Sampled M2 Projections
100	Reproject Updated Density Iamge
102	Density Projections
104	Transform Low and High kVp Projections
106	Transformed Low kVp Projections
108	Transformed High kVp Projections
110	Reconstruct Low and/or High kVp Images
112	Low kVp Image Volume
114	High kVp Image Volume

116	Reconstruct Material Decomposition Images
118	M1 Image
120	M2 Image
122	Generate Monochromatic Image
124	Monochromatic Image

CONCLUSIES

1. Werkwijze voor het verwerven van tweevoudige-energie projectiegegevens (62, 64), omvattende:

het afwisselend emitteren van röntgenstralen, die corresponderen met een lage kVp en een hoge kVp, zodanig dat een corresponderende verzameling van lage kVp projectie-gegevens (64) wordt verworven voor elke lage kVp emissie en een corresponderende verzameling van hoge kVp projectiegegevens (62) wordt verworven voor elke hoge kVp emissie, waarbij de totale verzamelingen van lage kVp projectiegegevens (64) of hoge kVp projectiegegevens (62), wanneer deze afzonderlijk worden genomen, geen volle hoek-resolutie verschaffen, doch de gecombineerde verzamelingen van lage kVp projectie-gegevens (64) en hoge kVp projectiegegevens (62) een volle hoekresolutie verschaffen;

het genereren (66) van een gemengde kVp afbeelding (68) onder gebruikmaking van de gecombineerde lage kVp projectiegegevens (64) en hoge kVp projectiegegevens (62);

het onttrekken (80) van een kiemafbeelding (82) die een basismateriaal benadert, gebaseerd op de gemengde kVp afbeelding (68);

het bijwerken (86) van de kiemafbeelding (82) om een bijgewerkte dichtheidsafbeelding (88) te genereren, waarbij het bijwerken (86) van de kiemafbeelding (82) het gebruik van spaarzaam bemonsterde projecties (92,94) omvat die zijn gegenereerd door een een basismateriaalontbindingsproces (90), en waarbij het bijwerken (86) van de kiemafbeelding (82) het genereren van een verschilafbeelding omvat van een van de spaarzaam bemonsterde projecties (92, 94) die overeenstemmen met de kiemafbeelding en het toevoegen van de verschilafbeelding aan de kiemafbeelding (82) omvat om de bijgewerkte afbeelding (88) te genereren.

het herprojecteren (100) van de bijgewerkte dichtheidsafbeelding (88) om dichtheidsprojecties (102) bij volle hoekresolutie te genereren;

het genereren van een of meer hoge kVp afbeeldingen (114), lage kVp afbeeldingen (112), materiaalontbindingsafbeeldingen (118, 120) of monochromatische afbeeldingen (124) tenminste gedeeltelijk gebaseerd op de gegenereerde dichtheidsprojecties (102).

2. Werkwijze volgens conclusie 1, waarbij het genereren van een of meer hoge kVp afbeeldingen (114), lage kVp afbeeldingen (112), materiaalontbindingsafbeeldingen (118, 120) of monochromatische afbeeldingen (124), tenminste gedeeltelijk gebaseerd op de

gegenereerde dichtheidsprojecties (102), het berekenen van een of meer ontbrekende hoekaanzichten voor de verzameling van lage kVp projectiegegevens (64) of de verzameling van hoge kVp projectiegegevens (62) omvat.

3. Werkwijze voor het verwerven van tweevoudige-energie projectiegegevens, omvattende:

het afwisselend emitteren van röntgenstralen, die corresponderen met een lage kVp en een hoge kVp, zodanig dat een corresponderende verzameling van lage kVp projectie-gegevens (64) wordt verworven voor elke lage kVp emissie en een corresponderende verzameling van hoge kVp projectiegegevens (62) wordt verworven voor elke hoge kVp emissie;

het genereren (66) van een gemengde kVp afbeelding (68) onder gebruikmaking van de gecombineerde lage kVp projectiegegevens (64) en hoge kVp projectiegegevens (62);

het onttrekken (80) van een kiemafbeelding (82), die een basismateriaal benadert, op basis van de gemengde kVp afbeelding (68);

het bijwerken (86) van de kiemafbeelding (82) om een bijgewerkte dichtheidsafbeelding (88) te genereren, waarbij het bijwerken (86) van de kiemafbeelding (82) het gebruik van spaarzaam bemonsterde projecties (92,94) omvat die zijn gegenereerd door een een basismateriaalontbindingsproces (90), en waarbij het bijwerken (86) van de kiemafbeelding (82) het genereren van een verschilafbeelding omvat van een van de spaarzaam bemonsterde projecties (92, 94) die overeenstemmen met de kiemafbeelding en het toevoegen van de verschilafbeelding aan de kiemafbeelding (82) omvat om de bijgewerkte dichtheidsafbeelding (88) te genereren

het herprojecteren (100) van de bijgewerkte dichtheidsafbeelding (88) om dichtheidsprojecties (102) bij volle hoekresolutie te genereren;

het gebruiken van de gegenereerde dichtheidsprojecties (102) om ontbrekende hoekaanzichten voor de verzameling van lage kVp projectiegegevens (64) of de verzameling van hoge kVp projectiegegevens (62) te berekenen;

het genereren van een of meer hoge kVp afbeeldingen (114), lage kVp afbeeldingen (112), materiaalontbindingsafbeeldingen (118, 120) of monochromatische afbeeldingen (124), tenminste gedeeltelijk gebaseerd op de een of meer berekende ontbrekende hoekaanzichten voor de verzameling van lage kVp projectiegegevens (64) of de verzameling van hoge kVp projectiegegevens (62).

4. Werkwijze volgens conclusie 3, waarbij de ene of beide van de verzameling van lage kVp projectiegegevens (64) en de verzameling van hoge kVp projectiegegevens (62) minder dan een vol hoekbereik verschaffen.

5. Werkwijze volgens conclusie 3, waarbij de gemengde kVp afbeelding (68) equivalent is aan een afbeelding, die zou zijn gegenereerd bij een kVp tussen de lage kVp en de hoge kVp.

6. Werkwijze volgens conclusie 3, waarbij het onttrekken (80) van de kiemafbeelding (82) het toepassen van een Hounsfield eenheid (HU) drempel of een segmentatiebenadering omvat.

7. Werkwijze volgens conclusie 3, waarbij de kiemafbeelding (82) volle hoekresolutie heeft.

8. Meervoudige-energie afbeeldingssysteem (10), omvattende:

een röntgenbron (12), die in staat is röntgenstralen (16) met een lage kVp en een hoge kVp te emitteren;

een detectorsamenstel (22), dat in staat is signalen in reactie op de geëmitteerde röntgenstralen (16) te genereren;

een gegevensverwervingssysteem (34), dat is ingericht om de door het detector-samenstel gegenereerde signalen te verwerven, zodanig dat een corresponderende verzameling van lage kVp projectiegegevens (64) wordt verworven voor elke lage kVp emissie en een corresponderende verzameling van hoge kVp projectiegegevens (62) wordt verworven voor elke hoge kVp emissie, waarbij de totale verzamelingen van lage kVp projectiegegevens (64) of hoge kVp projectiegegevens (62), wanneer deze afzonderlijk worden genomen, geen volle hoekresolutie verschaffen, doch de gecombineerde verzamelingen van lage kVp projectiegegevens (64) en hoge kVp projectiegegevens (62) een volle hoekresolutie verschaffen;

afbeeldingbewerkingsschakelingen (37), die zijn ingericht om een of meer algoritmen uit te voeren, die bij uitvoering door de afbeeldingbewerkingsschakelingen (37):

een gemengde kVp-afbeelding (68) onder gebruikmaking van de gecombineerde lage kVp projectiegegevens (64) en hoge kVp projectiegegevens (62) genereren;

een kiemafbeelding (82) onttrekken die een basismateriaal benadert, gebaseerd op de gemengde kVp afbeelding (69);

de kiemafbeelding (82) bijwerken om een bijgewerkte dichtheidsafbeelding (88) te genereren, waarbij het bijwerken (86) van de kiemafbeelding (82) het gebruik van spaarzaam bemonsterde projecties (92,94) omvat die zijn gegenereerd door een een basismateriaalontbindingsproces (90), en waarbij het bijwerken (86) van de kiemafbeelding (82) het genereren van een verschilafbeelding omvat van een van de spaarzaam bemonsterde projecties (92, 94) die overeenstemmen met de kiemafbeelding en het toevoegen van de verschilafbeelding aan de kiemafbeelding (82) omvat om de bijgewerkte afbeelding (88) te genereren;

de bijgewerkte dichtheidsafbeelding (88) herprojecteren om dichtheidsprojecties (102) bij volle hoekresolutie te genereren;

een of meer van hoge kVp afbeeldingen (114), lage kVp afbeeldingen (112), materiaalontbindingsafbeeldingen (118, 120) of monochromatische afbeeldingen (124), tenminste gedeeltelijk gebaseerd op de gegenereerde dichtheidsprojecties (102), te genereren.

9. Meervoudige-energie afbeeldingssysteem (10) volgens conclusie 8, waarbij de ene of meer hoge kVp afbeeldingen (114), lage kVp afbeeldingen (112), materiaal-ontbindingsafbeeldingen (118, 120) of monochromatische afbeeldingen (124) worden gegeneerd door het berekenen van een of meer ontbrekende hoekaanzichten voor de verzameling van lage kVp projectiegegevens (64) of de verzameling van hoge kVp projectiegegevens (62).

10. Meervoudige-energie afbeeldingssysteem (10) volgens conclusie 8, waarbij de gemengde kVp afbeelding (68) equivalent is aan een afbeelding, die zou zijn gegenereerd bij een kVp tussen de lage kVp en de hoge kVp.

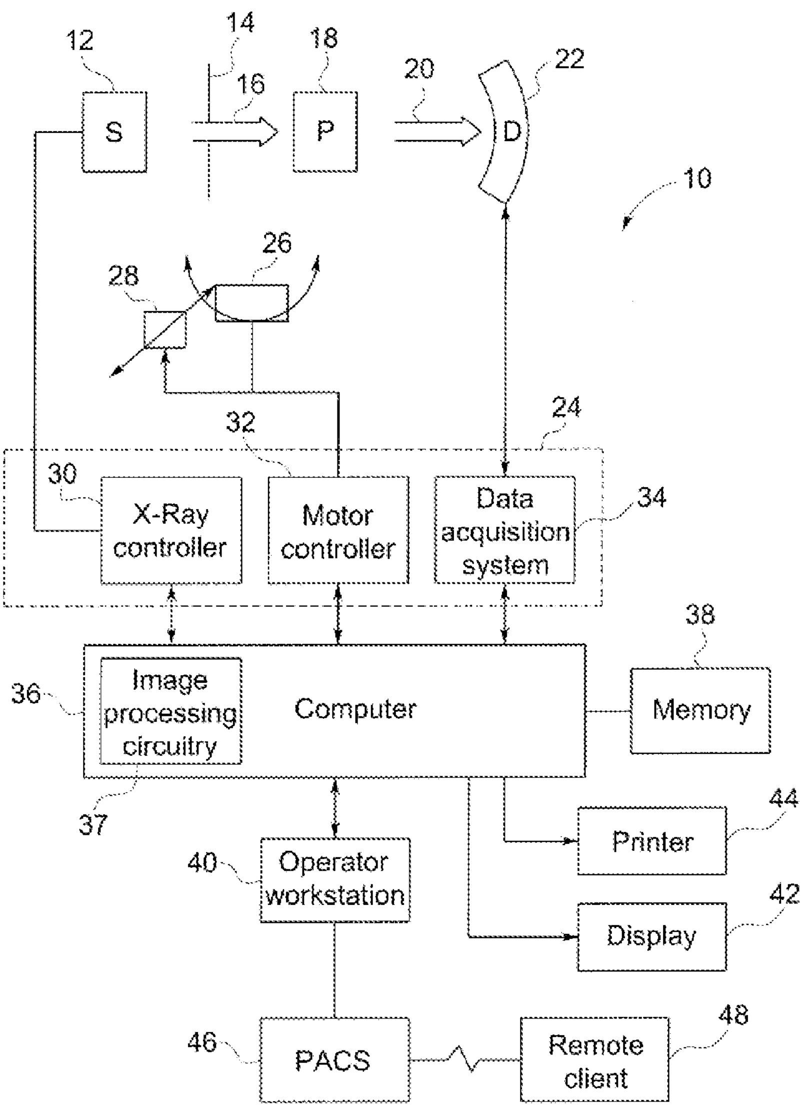
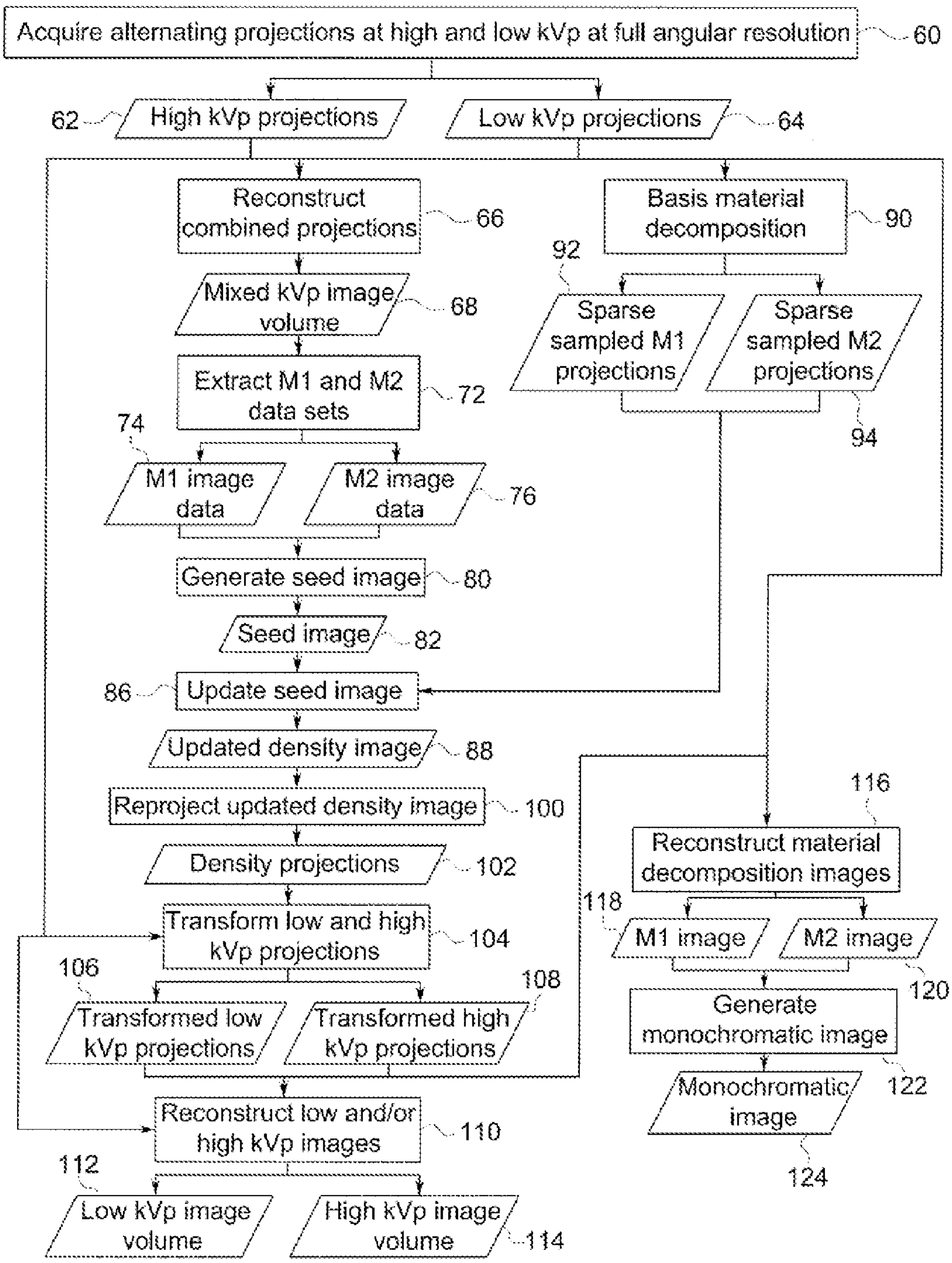

12
S
14
16
18
P
20
22
D
10
26
28
32
24
30
X-Ray controller
Motor controller
Data acquisition system
34
38
36
Image processing circuitry
Computer
Memory
37
44
Printer
40
Operator workstation
42
Display
46
PACS
Remote client
48

FIG. 1



Acquire alternating projections at high and low kVp at full angular resolution
60
High kVp projections
62
Low kVp projections
64
Reconstruct combined projections
66
Basis material decomposition
90
92
Mixed kVp image volume
68
Sparse sampled M1 projections
Sparse sampled M2 projections
94
Extract M1 and M2 data sets
72
74
M1 image data
M2 image data
76
Generate seed image
80
Seed image
82
Update seed image
86
Updated density image
88
Reproject updated density image
100
116
Reconstruct material decomposition images
Density projections
102
118
Transform low and high kVp projections
104
M1 image
M2 image
120
106
Transformed low kVp projections
108
Transformed high kVp projections
Generate monochromatic image
122
Monochromatic image
Reconstruct low and/or high kVp images
110
124
112
Low kVp image volume
High kVp image volume
114

FIG. 2

Agentschap NL
Ministerie van Economische Zaken, Landbouw en Innovatie

OCTROOIAANVRAAG NR.:
NO 137646
NL 2005892

ONDERZOEKSRAPPORT

BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK

RELEVANTE LITERATUUR

Categorie[1]	Literatuur met, voor zover nodig, aanduiding van speciaal van belang zijnde tekstgedeelten of figuren.	Van belang voor conclusie(s) nr:	Classificatie (IPC)
X	US 2009/097611 A1 (NISHIDE AKIHIKO [JP] ET AL) 16 april 2009 (2009-04-16) * (D1) to (D7); alineas [0048], [0061], [0062], [0065], [0066] * -----	1-15	INV. A61B6/03 G06T11/00
X,P	TIMOTHY P SZCZYKUTOWICZ ET AL: "Dual energy CT using slow kVp switching acquisition and prior image constrained compressed sensing;Dual energy CT using slow kVp switching acquisition and PICCS", PHYSICS IN MEDICINE AND BIOLOGY,, deel 55, nr. 21, 12 oktober 2010 (2010-10-12), bladzijden 6411-6429, XP020199465, ISSN: 0031-9155, DOI: 10.1088/0031-9155/55/21/005 * het gehele document * -----	1-15	
X,P	TIMOTHY P. SZCZYKUTOWICZ ET AL: "The dependence of image quality on the number of high and low kVp projections in dual energy CT using the prior image constrained compressed sensing (PICCS) algorithm", PROCEEDINGS OF SPIE, 1 januari 2010 (2010-01-01), bladzijden 762221-762221-10, XP55024426, ISSN: 0277-786X, DOI: 10.1117/12.844471 * het gehele document * ----- -/--	1-15	Onderzochte gebieden van de techniek A61B G06T

Indien gewijzigde conclusies zijn ingediend, heeft dit rapport betrekking op de conclusies ingediend op:

Plaats van onderzoek:	Datum waarop het onderzoek werd voltooid:	Bevoegd ambtenaar:
München	2 oktober 2012	Anscombe, Marcel

[1] CATEGORIE VAN DE VERMELDE LITERATUUR

X: de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur
Y: de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht
A: niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft
O: niet-schriftelijke stand van de techniek
P: tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur

T: na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvraag, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding
E: eerdere octrooi(aanvrage), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven
D: in de octrooiaanvrage vermeld
L: om andere redenen vermelde literatuur
&: lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

3

EOB FORM 02.83 (P0414B)

RELEVANTE LITERATUUR

Categorie[1]	Literatuur met, voor zover nodig, aanduiding van speciaal van belang zijnde tekstgedeelten of figuren.	Van belang voor conclusie(s) nr:
X	WONSEOK HUH ET AL: "Fast kVp-switching dual energy CT for PET attenuation correction", 2009 IEEE NUCLEAR SCIENCE SYMPOSIUM AND MEDICAL IMAGING CONFERENCE (NSS/MIC 2009), ORLANDO, FL, USA, IEEE, PISCATAWAY, NJ, USA, 24 oktober 2009 (2009-10-24), bladzijden 2510-2515, XP031826659, DOI: 10.1109/NSSMIC.2009.5402036 ISBN: 978-1-4244-3961-4 * final paragraph of introduction * -----	1,5,11
X L	JOONKI NOH ET AL: "Statistical Sinogram Restoration in Dual-Energy CT for PET Attenuation Correction", IEEE TRANSACTIONS ON MEDICAL IMAGING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, deel 28, nr. 11, 1 november 2009 (2009-11-01), bladzijden 1688-1702, XP011280942, ISSN: 0278-0062, DOI: 10.1109/TMI.2009.2018283 * completes disclosure of final paragraph of introduction of XP031826659, reference [4]; bladzijde 2511 * * het gehele document * -----	1,5,11
X L	PATRICK J LA RIVIERE ET AL: "Penalized-likelihood sinogram decomposition for dual-energy computed tomography", NUCLEAR SCIENCE SYMPOSIUM CONFERENCE RECORD, 2008. NSS '08. IEEE (19-25 OCT. 2008), IEEE, PISCATAWAY, NJ, USA, 19 oktober 2008 (2008-10-19), bladzijden 5166-5169, XP031418668, ISBN: 978-1-4244-2714-7 * completes disclosure of final paragraph of introduction of XP031826659, reference [11] * * het gehele document * -----	1,5,11

3

[1] CATEGORIE VAN DE VERMELDE LITERATUUR

X: de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur
Y: de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht
A: niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft
O: niet-schriftelijke stand van de techniek
P: tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur
T: na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvrage, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding
E: eerdere octrooi(aanvrage), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven
D: in de octrooiaanvrage vermeld
L: om andere redenen vermelde literatuur
&: lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

AANHANGSEL BEHORENDE BIJ HET RAPPORT BETREFFENDE HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK, UITGEVOERD IN DE OCTROOIAANVRAGE NR.

NO 137646
NL 2005892

Het aanhangsel bevat een opgave van elders gepubliceerde octrooiaanvragen of octrooien (zogenaamde leden van dezelfde octrooifamilie), die overeenkomen met octrooischriften genoemd in het rapport.
De opgave is samengesteld aan de hand van gegevens uit het computerbestand van het Europees Octrooibureau per
De juistheid en volledigheid van deze opgave wordt noch door het Europees Octrooibureau, noch door het Bureau voor de Industriële eigendom gegarandeerd; de gegevens worden verstrekt voor informatiedoeleinden.

02-10-2012

In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
US 2009097611 A1	16-04-2009	JP 2009095405 A	07-05-2009
		US 2009097611 A1	16-04-2009

Agentschap NL
Ministerie van Economische Zaken, Landbouw en Innovatie

SCHRIFTELIJKE OPINIE

DOSSIER NUMMER	INDIENINGSDATUM	VOORRANGSDATUM	AANVRAAGNUMMER
NO137646	22.12.2010	23.12.2009	NL2005892
CLASSIFICATIE INV. A61B6/03 G06T11/00			
AANVRAGER General Electric Company			

Deze schriftelijke opinie bevat een toelichting op de volgende onderdelen:

- ☒ Onderdeel I Basis van de schriftelijke opinie
- ☒ Onderdeel II Voorrang
- ☐ Onderdeel III Vaststelling nieuwheid, inventiviteit en industriële toepasbaarheid niet mogelijk
- ☐ Onderdeel IV De aanvraag heeft betrekking op meer dan één uitvinding
- ☒ Onderdeel V Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid
- ☒ Onderdeel VI Andere geciteerde documenten
- ☐ Onderdeel VII Overige gebreken
- ☐ Onderdeel VIII Overige opmerkingen

	DE BEVOEGDE AMBTENAAR
	Anscombe, Marcel

Aanvraag nr.:

SCHRIFTELIJKE OPINIE

NL2005892

Onderdeel I Basis van de Schriftelijke Opinie

1. Deze schriftelijke opinie is opgesteld op basis van de meest recente conclusies ingediend voor aanvang van het onderzoek.

2. Met betrekking tot **nucleotide en/of aminozuur sequenties** die genoemd worden in de aanvraag en relevant zijn voor de uitvinding zoals beschreven in de conclusies, is dit onderzoek gedaan op basis van:

   a. type materiaal:

   ☐ sequentie opsomming

   ☐ tabel met betrekking tot de sequentie lijst

   b. vorm van het materiaal:

   ☐ op papier

   ☐ in elektronische vorm

   c. moment van indiening/aanlevering:

   ☐ opgenomen in de aanvraag zoals ingediend

   ☐ samen met de aanvraag elektronisch ingediend

   ☐ later aangeleverd voor het onderzoek

3. ☐ In geval er meer dan één versie of kopie van een sequentie opsomming of tabel met betrekking op een sequentie is ingediend of aangeleverd, zijn de benodigde verklaringen ingediend dat de informatie in de latere of additionele kopieën identiek is aan de aanvraag zoals ingediend of niet meer informatie bevatten dan de aanvraag zoals oorspronkelijk werd ingediend.

4. Overige opmerkingen:

Onderdeel II Voorrang

Deze schriftelijke opinie is opgesteld onder de aanname dat eventueel ingeroepen voorrang geldig is, tenzij hieronder anders is aangegeven. Controleren van de voorrang maakt geen deel uit van het reguliere onderzoek naar de stand van de techniek.

Zie aparte bladzijde

Aanvraag nr.:

SCHRIFTELIJKE OPINIE

NL2005892

Onderdeel V Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid

1. Verklaring

Nieuwheid	Ja:	Conclusies	3, 4, 6-10, 13-15
	Nee:	Conclusies	1, 2, 5, 11, 12
Inventiviteit	Ja:	Conclusies	
	Nee:	Conclusies	1-15
Industriële toepasbaarheid	Ja:	Conclusies	1-15
	Nee:	Conclusies	

2. Citaties en toelichting:

Zie aparte bladzijde

Onderdeel VI Andere geciteerde documenten

☒ Andere geciteerde openbaarmakingen

Zie aparte bladzijde

☐ Niet schriftelijke openbaarmakingen

Reference is made to the following documents:

D1 US 2009/097611 A1

D2 TIMOTHY P SZCZYKUTOWICZ ET AL: "Dual energy CT using slow kVp switching acquisition and prior image constrained compressed sensing;Dual energy CT using slow kVp switching acquisition and PICCS", PHYSICS IN MEDICINE AND BIOLOGY,, deel 55, nr. 21, 12 oktober 2010, bladzijden 6411-6429, XP020199465, ISSN: 0031-9155, DOI: 10.1088/0031-9155/55/21/005

D3 TIMOTHY P. SZCZYKUTOWICZ ET AL: "The dependence of image quality on the number of high and low kVp projections in dual energy CT using the prior image constrained compressed sensing (PICCS) algorithm", PROCEEDINGS OF SPIE, 1 januari 2010, bladzijden 762221-762221-10, XP55024426, ISSN: 0277-786X, DOI: 10.1117/12.844471

D4 WONSEOK HUH ET AL: "Fast kVp-switching dual energy CT for PET attenuation correction", 2009 IEEE NUCLEAR SCIENCE SYMPOSIUM AND MEDICAL IMAGING CONFERENCE (NSS/MIC 2009), ORLANDO, FL, USA, IEEE, PISCATAWAY, NJ, USA, 24 oktober 2009, bladzijden 2510-2515, XP031826659, DOI: 10.1109/NSSMIC.2009.5402036 ISBN: 978-1-4244-3961-4

D5 JOONKI NOH ET AL: "Statistical Sinogram Restoration in Dual-Energy CT for PET Attenuation Correction", IEEE TRANSACTIONS ON MEDICAL IMAGING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, deel 28, nr. 11, 1 november 2009, bladzijden 1688-1702, XP011280942, ISSN: 0278-0062, DOI: 10.1109/TMI.2009.2018283

D6 PATRICK J LA RIVIERE ET AL: "Penalized-likelihood sinogram decomposition for dual-energy computed tomography", NUCLEAR SCIENCE SYMPOSIUM CONFERENCE RECORD, 2008. NSS '08. IEEE (19-25 OCT. 2008), IEEE, PISCATAWAY, NJ, USA, 19 oktober 2008, bladzijden 5166-5169, XP031418668, ISBN: 978-1-4244-2714-7

Re Item II

Documents D2 and D3 published before the filing date and appear to disclose the subject-matter of **claims 1-15**. It is assumed however that the priority is valid because the priority documents are not available at the time of writing.

Re Item V

1 Clarity and support by the description.

1.1 **Claim 1** & **11** does not comply with the requirements of clarity and support by the description. The description (fig. 2) appears to make the use of a mixed kVp image, seed extraction, seed updating and reprojection optional in the case of where the kVp images generated are material decomposition images or monochromatic images. This is because the figure indicates by and arrow in the flow-chart that these steps are not part of the route leading to boxes labeled (116) and (122/124). This makes **claim 1** lack support by the description and makes the essential features of the invention unclear.

1.2 **Claim 1, 5 & 11** do not indicate any technical details of the nature of the updating step. This means that essential features are missing. A look at the description indicates that the updating step only has support from a single example, and that therefore the omission of the details leads to a lack of support over the whole breadth of meaning of "update".

1.3 The definition of the seed image should be in **claims 1 & 11** to yield a clear claim and one supported over the breadth of its meaning sufficiently to comply the requirements of support by the description.

1.4 **Claim 3 & 13** do not give any details of what the difference image represents and therefore lacks essential features to solve the problem posed by the application.

2 Novelty

2.1 The subject-matter of **claims 1, 5 & 11** is not new. The reasons are as follows.
Document D1 discloses:
a method for acquiring dual-energy projection data, comprising:
alternately emitting X-rays corresponding to a low kVp and a high kVp such that a corresponding set of low kVp projection data is acquired for each low kVp emission and a corresponding set of high kVp projection data is acquired for each high kVp emission ("D1". This is not document D1, but the reference sign "D1" in document D1. Same applies in the following.), wherein the

aggregate sets of low kVp projection data or high kVp projection data, when taken alone, do not provide full angular resolution (§48) but the combined sets of low kVp projection data and high kVp projection data provide full angular resolution (implicit from §61);
generating a mixed kVp image using the combined low kVp projection data and high kVp projection data ("D2");extracting an seed(*) image ("D3", §62 "....a water equivalent image, a fat equivalent image, a contrast agent equivalent image and a bone equivalent image".) based upon the mixed kVp image (§65, weighting);
updating the seed(*) image to generate an updated image (the updating is the setting of a pixel value to zero, §66);
reprojecting the updated image to generate density projections at full angular resolution ("D4");
generating one or more of high kVp images, low kVp images, material decomposition images, or monochromatic images based at least in part on the generated density projections (D7).

2.2 (*)The seed image in document D1 serves to provide the starting point of the step "D5" & "D6 "which corrects the image to also include the information derived from transient effects (§21 & 24); so this image is a seed of the process, because the final image grows from it, and hence is able to be denoted a seed. It is not clear from the claim what a seed image is. This term appears be be a place-holder for an image in which a single material is chosen to form the image. This is also what is done in document D1 (§62) in any case.

2.3 The same reasoning as in item 2.1 and 2.2 applies *mutatis mutandis* to device **claim 11**.

2.4 The reasoning above in item 2.1 and 2.2 also applies to dependent **claim 2 & 12** and independent **claim 5**, which specify the seed as approximating one basis material (see document D1, §62 and item 2.2)

2.5 Document D4 (final paragraph of introduction, page 2511) discloses the use of undersampled sinograms to obtain density images, and cites in this regard document D5 and D6. Document D5 completes the disclosure regarding the creation of the density images, and appears to disclose (Section III C.) an iterative method according to **claims 1 & 5** and *mutatis mutandis* a device according to **claim 11**. Similarly for document D6 (equation 7, page 5167). The subject-matter of **claims 1, 11 & 5** appears therefore not to be new over document D4.

2.6 The additional subject-matter of the remaining claims appear to refer to subject-matter routine in the art and seem therefore not to be inventive.

Re Item VI

see search report and item II