(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 May 2022 (12.05.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/096335 A1

(51) International Patent Classification:
A61B 6/03 (2006.01) *A61B 6/00* (2006.01)

(21) International Application Number:
PCT/EP2021/079763

(22) International Filing Date:
27 October 2021 (27.10.2021)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/109,141 03 November 2020 (03.11.2020) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW,

(54) **Title:** SYSTEM AND METHOD FOR NUCLEAR MEDICINE IMAGING WITH ADAPTIVE STOPPING CRITERIA

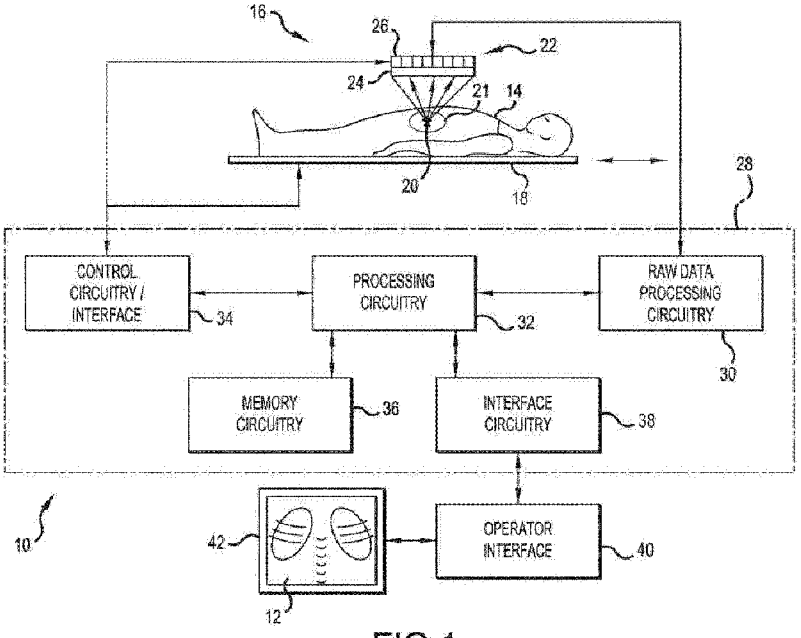

FIG.1

(57) **Abstract:** A system and method employ an imaging apparatus, wherein the imaging apparatus is configured to detect image-related events in a subject using one or more image acquisition parameters, and a processing circuit including a process and associated memory. The processing circuit is configured to: receive an indication of a region of interest in the subject; produce projections, sinograms, or images from the detected image-related events; apply the projections, sinograms, or images to a trained deep neural network implemented by the processing circuit to detect and segment an organ region of interest in the projections, sinograms, or images and to detect and segment a background region of interest in the projections, sinograms, or images; determine statistics for the image-related events in the organ region of interest and in the background region of interest; and select an optimal value for at least one of the image acquisition parameters based on the determined statistics.

WO 2022/096335 A1

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SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

SYSTEM AND METHOD FOR NUCLEAR MEDICINE IMAGING WITH ADAPTIVE STOPPING CRITERIA

TECHNICAL FIELD

This invention pertains to imaging systems, and in particular systems and methods for nuclear medicine imaging.

BACKGROUND AND SUMMARY

Nuclear Medicine (NM) imaging includes e.g., positron emission tomography (PET) imaging and single photon emission computed tomography (SPECT) imaging.

Regardless of the particular technology which is employed, all NM acquisitions include some criteria specifying what detected gamma photon events to include in the acquired images and when to stop collecting detected gamma photon events. The parameters specifying what to collect are part of the acquisition parameters, and the parameters specifying when to stop collecting are knows as stopping rules. Stopping rules typically involve either time, or acquired count statistics.

The user can typically adjust the default total acquisition time prior to starting the acquisition to account for variations in patient size, administered radiopharmaceutical dose, radioisotope decay rate, or the time which has elapsed since measuring the radiopharmaceutical dose. Most NM systems provide an adaptive stopping rule for static and gated acquisitions, such as the total number of detected events, or the number of normal beats or breaths, respectively.

For acquisitions involving a gantry or patient indexing, most systems acquire for the same length of time at each index position. X-ray computed tomography (CT) systems typically implement mechanisms to adjust the photon flux to compensate for variations in the patient's anatomy during the acquisition. Some NM systems provide one of the adaptive criteria mentioned above to use for the first index position, and then all other positions are acquired for the actual time of that first position. Then, depending on the type of scan, post-processing of the acquired data may compensate for radioactive decay and patient attenuation effects.

Technologists select a stopping rule for a scan based on their site's procedures for performing a diagnostic test, in conjunction with the patient schedule and the length of time allocated for the examination. In general, existing NM stopping rules do not provide optimal acquisition results for the organ(s) or disease process of interest in an examination. Either the rules use global statistics, which may not reflect the signal-to-noise ratios within the organ or region of interest, or they do not result in predictable acquisition times to enable a busy imaging department to stay on schedule. Scan protocols typically do not support varying the acquisition time per index / frame, nor do they explicitly implement trade-offs between parameters.

One major difficulty for NM systems in this regard is that typically the radiopharmaceutical dose is administered to the subject or patient prior to positioning the subject with respect to the imaging system, so at the time of the scan the primary optimization parameter which is available is imaging time. In addition, many clinical sites follow ALARA [as low as reasonably achievable] guidelines, resulting in doses toward the lower end of the standard dose range, meaning that acquisition times would have to increase to keep the total detected events or global statistics constant compared to exams using higher doses. In addition, for scans involving a gantry or patient indexing, the impacts of radioactive decay and patient attenuation result in a decrease in the number of detected events, an information deficit that post-processing cannot fully recover.

Also, the state of the art in systems in the field use statistics from the entire image, such as total number of detected events [often called "counts"], total number of contributing events, average number of counts per pixel, or average number of counts per square centimeter, with optimal values derived from information theory and Poisson noise statistics. These statistics do not measure object to background contrast directly, but indirectly optimize the contrast by ensuring the pixel intensity variability due to Poisson noise is below some threshold.

Accordingly, it would be desirable to provide improved systems and methods for establishing stopping criteria for a NM imaging session. In particular, it would be desirable to provide improved systems and methods which can automatically determine the clinically optimal point when the imaging session should be terminated.

In one aspect of the invention, a system comprises: an imaging apparatus, wherein the imaging apparatus is configured to detect image-related events in a subject during an acquisition time period which is constrained by one or more acquisition stopping rule parameters; and a processing circuit which includes a processor and associated memory. The processing circuit is configured to: produce projections, sinograms, or images from the detected image-related events; apply the projections, sinograms, or images to a trained deep neural network implemented by the processing circuit to detect and segment an organ region of interest (ROI) in the projections, sinograms, or images and to detect and segment a background region of interest (ROI) in the projections, sinograms, or images; determine statistics for the image-related events in the organ ROI and in the background ROI; and select an optimal value for at least one of the acquisition stopping rule parameters based on the determined statistics.

In some embodiments, the processing circuit is configured to select the value for at least one of the acquisition stopping rule parameters to optimize at least one of a signal-to-noise ratio in the organ ROI or a contrast ratio between the organ ROI and the background ROI.

In some embodiments, the system further comprises a display device, and the processing circuit is further configured to cause the display device to display an indication of the selected value for at least one of the acquisition stopping rule parameters.

In some embodiments, the system further comprises a user interface, and the processing circuit is further configured to receive from a user via the user interface an indication of approval of the selected

value for at least one of the acquisition stopping rule parameters, and in response to the indication of approval to stop the acquisition based on the approved value of the acquisition stopping rule parameter.

In some embodiments, the processing circuit is further configured to receive additional acquisition parameters and to further optimize at least one of the acquisition stopping rule parameters based on the received additional acquisition parameters, wherein the received additional acquisition parameters include at least one of an examination type, a subject size, a subject weight, a radiopharmaceutical dose administered to the subject, attenuation data for the subject, attenuation data for detected events by the system, and a specified maximum acquisition time.

In some embodiments, the imaging apparatus comprises a single photon emission computed tomography (SPECT) imaging apparatus.

In some embodiments, the imaging apparatus comprises a positron emission tomography (PET) imaging apparatus.

In another aspect of the invention, a method comprises: detecting, with an imaging apparatus, image-related events in a subject which is disposed on a platform, during an acquisition time period which is set by one or more acquisition stopping rule parameters; producing projections, sinograms, or images from the detected image-related events; applying the projections, sinograms, or images to a trained deep neural network implemented by the processing circuit to detect and segment an organ region of interest (ROI) in the projections, sinograms, or images and to detect and segment a background region of interest (ROI) in the projections, sinograms, or images; determining statistics for the image-related events in the organ ROI and in the background ROI; and selecting a value for at least one of the acquisition stopping rule parameters based on the determined statistics.

In some embodiments, the method further comprises selecting the value for at least one of the acquisition stopping rule parameters to optimize at least one of a signal-to-noise ratio in the organ ROI or a contrast ratio between the organ ROI and the background ROI.

In some embodiments, the method further comprises displaying on a display device an indication of the selected value of at least one of the acquisition stopping rule parameters.

In some embodiments, the method further comprises: receiving from a user an indication of approval of the selected value of at least one of the acquisition stopping rule parameters; and in response to the indication of approval, stopping the acquisition based on the approved value.

In some embodiments, the imaging apparatus comprises a single photon emission computed tomography (SPECT) imaging apparatus.

In some embodiments, the imaging apparatus comprises a Positron Emission Tomography (PET) imaging apparatus.

In yet another aspect of the invention, a system comprises: an imaging apparatus, and a processing circuit including a processor and associated memory. The imaging apparatus is configured to detect image-related events in a subject using one or more image acquisition parameters. The processing circuit is configured to: receive an identification of an organ region of interest in the subject, wherein said

region of interest includes an organ and background region of interests; produce projections, sinograms, or images from the detected image-related events; apply the projections, sinograms, or images to a trained deep neural network implemented by the processing circuit to detect and segment the received organ region of interest (ROI) in the projections, sinograms, or images and to detect and segment a background region of interest (ROI) in the projections, sinograms, or images; determine statistics for the image-related events in the received organ ROI and in the background ROI; and select an optimal value for at least one of the image acquisition parameters based on the determined statistics.

In some embodiments, the processing circuit is further configured to select the value for at least one of the image acquisition parameters to optimize at least one of a signal-to-noise ratio in the received organ ROI or a contrast ratio between the received organ ROI and the background ROI.

In some embodiments, the processing circuit further comprises a display device, and the processing circuit is further configured to cause a display device to display an indication of the selected value of at least one of the image acquisition parameters.

In some embodiments, the processing circuit further comprises a user interface, and the processing circuit is further configured to receive from a user via the user interface an indication of approval of the selected value of at least one of the image acquisition parameters, and in response to the indication of approval to adjust the selected image acquisition parameters to have the approved value.

In some embodiments, the image acquisition parameters include at least one acquisition stopping rule parameter.

In some embodiments, the imaging apparatus comprises a single photon emission computed tomography (SPECT) imaging apparatus.

In some embodiments, the imaging apparatus comprises a Positron Emission Tomography (PET) imaging apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a high level functional block diagram of one example of an imaging system, in particular a single photon emission computed tomography (SPECT) imaging system.

FIG. 2 illustrates a block diagram of another example of an imaging system, in particular a combination positron emission tomography (PET) / computed tomography (CT) imaging system.

FIG. 3 illustrates an example of assignments of imaging system components between positron emission tomography (PET) functionality and computed tomography (CT) functionality in a combined PET/CT system.

FIG. 4 illustrates a block diagram of an example embodiment of a processor and associated memory according to embodiments of the disclosure.

FIG. 5 depicts an example of how image data may be applied to a trained deep neural network to perform image segmentation to identify organs of interest and appropriate background regions.

FIG. 6 illustrates a flowchart of an example embodiment of a method of determining one or more image acquisition parameters for acquiring image data from a subject.

DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided as teaching examples of the invention.

In particular, in order to illustrate the principles of the present invention, various systems and methods are described in the context of determining one or more image acquisition parameters, for example acquisition stopping rule parameters, for acquiring image data from a subject. More broadly, however, principles which are utilized in the disclosed systems and methods may also be employed in other contexts, for example image acquisition systems where there are multiple imaging parameters and the best image for a particular application is associated with optimizing the image statistics in a particular object or region, rather than for the image as a whole. Accordingly, the invention is to be understood to be defined by the claims and not limited by details of specific embodiments described herein, unless those details are recited in the claims themselves.

FIGs. 1 and 2 are provided and described in detail to illustrate examples of imaging systems to which some principles of the present invention may be applied. It should be understood that these principles may be applied to a wide variety of types of image acquisition, including but not limited to: Static planar NM / PET with no gantry or patient indexing, no gating, and no time-slicing; Dynamic planar NM / PET with no gantry or patient indexing; Gated planar NM / PET with no gantry or patient indexing; Total body planar NM / indexed PET with no gating and no time-slicing; Single position SPECT with an indexing gantry around the patient, but no gating and no time-slicing; Single position gated SPECT with an indexing gantry around the patient, with gating at each index; Total body SPECT with an indexing gantry around, and indexing along, the patient, but no gating and no time-slicing; and Dynamic SPECT with an indexing gantry around the patient, once per time-slice. It also should be understood that these principles may be applied to a wide variety of types of imaging systems, including but not limited to: large area detector general NM systems, small area detector dedicated organ SPECT systems, SPECT-only systems, PET-only systems, PET/CT systems, PET/MR systems, and other imaging systems based on radioactive emissions from an object of interest, such as a patient to whom a radiopharmaceutical has been administered.

With the foregoing discussion in mind, FIG. 1 illustrates a high level functional block diagram of one example of an imaging system, in particular a SPECT imaging system 10. SPECT imaging system 10 is designed to produce useful images (e.g., three-dimensional images) of an organ region of interest 20

of a patient or subject 14, using suitable detector components (such as pin-hole gamma cameras or collimated scintillating detectors) as described in detail below. The images of region of interest 20 may include a background region of interest 21 which is adjacent to or surrounding organ region of interest 20.

SPECT imaging system 10 includes a scanner 16, a patient support 18, system control and processing circuit 28 and an operator interface 40. Scanner 16 may be one embodiment of an imaging apparatus.

Patient support 18 may also be referred to as a patient bed or a platform, and may be movable with respect to scanner 16 to allow for imaging of different tissues or anatomies in organ region of interest 20 within subject 14. Beneficially, patient support 18 may include a motor or similar device for automatically moving patient support 18 in response to one or more control signals provided by processing circuit 28. Beneficially, patient support 18 may be configured to move in at least two orthogonal directions (e.g., top-to-bottom and left-to-right) under control of processing circuit 28. In some embodiments, patient support 18 may be configured to move in all three orthogonal directions (i.e., including vertically) under control of processing circuit 28. Additionally or alternatively, scanner 16 may be configured to move in response to one or more control signals provided by processing circuit 28.

Prior to image data collection, a radioisotope, such as a radiopharmaceutical substance (sometimes referred to as a radiotracer), is administered to subject 14, and may be bound or taken up by particular tissues or organs in organ region of interest 20. Typical radioisotopes include various radioactive forms of elements that emit gamma radiation during decay. Various additional substances may be selectively combined with such radioisotopes to target specific areas or tissues in organ region of interest 20 of the body of subject 14. SPECT imaging system 10 produces three-dimensional volume images of an image space in response to detection of image-related events by scanner 16. Here, detection of an image-related event may be detection of an individual photon from the decay of an element of the radioisotope which has been administered to subject 14.

Gamma radiation emitted by the radioisotope is detected by a detector component 22, such as a digital detector or gamma cameras. Although illustrated in the figure as a planar device positioned above the patient to simplify illustration, in practice the detector structure(s) 22 may be positioned about subject 14, such as in an arc or ring about subject 14, or may be attached to a positioner (e.g., a C-arm, gantry, or other movable arm) that allows the detector structure(s) 22 to be moved in such an arc or orbit about the patient during data acquisition to produce a three-dimensional image of organ region of interest 20 and background region of interest 21. In general, the detector structure(s) 22 typically include one or more components or elements capable of sensing gamma radiation or otherwise generating a detectable signal in response to such radiation. In the illustrated embodiment, the detector structures comprise one or more collimators and a scintillator, together represented generally as reference numeral 24. The collimator may be formed from parallel or non-parallel elements that allow gamma radiation emitted only in certain directions to impact the detecting components. In detector embodiments employing a scintillator, the

scintillator may be made of a crystalline material, such as sodium iodide (NaI), that converts the received gamma radiation to lower energy light energy (e.g., in an ultraviolet range). Photomultiplier tubes 26 then receive this light and generate event data corresponding to photons impacting specific discrete picture element (pixel) regions. In other embodiments, the detector structure 22 may not be collimated but may instead use other gamma radiation sensing technologies, such as one or more pin-hole gamma cameras, as also discussed herein.

In the depicted embodiment, the detector structure(s) 22 is coupled to system control and processing circuit 28. Control and processing circuit 28 may include a number of physical and/or software components that cooperate to allow the collection and processing of image data to create the desired images. For example, control and processing circuit 28 may include raw data processing circuitry 30 that initially receives the data from the detector structure(s) 22, and that may perform various filtering, value adjustments, and so forth. Processing circuitry 32 allows for the overall control of imaging system 10, and for manipulation and/or reconstruction of image data 12. Processing circuitry 32 may also perform calibration functions, correction functions, and so forth on the data. Processing circuitry 32 may also perform image reconstruction functions, such as based on various algorithms (e.g., back projection, iterative reconstruction, and so forth). Such functions may also be performed in post-processing on local or remote equipment. As will be appreciated, the various image reconstruction and artifact correction algorithms discussed herein may be implemented in part or in their entirety using one or both of raw data processing circuitry 30 and/or processing circuitry 32.

In the depicted embodiment, processing circuitry 32 interacts with control circuitry/interface 34 that allows for control of the scanner and its components, including patient support 18, a camera, and so forth. Moreover, processing circuitry 32 may be supported by various circuits, such as memory circuitry 36 that may be used to store image data, calibration or correction values, routines performed by processing circuitry 32 (such as the motion artifact correction algorithms disclosed herein), and so forth. In some embodiments, as explained in greater detail below, processing circuitry 32 implements a trained deep neural network for segmenting images produced from image data obtained by scanner 16, and identifies organ region of interest 20 and background region of interest 21 in the images, thereby facilitating selection of one or more image acquisition parameters for use by SPECT imaging system 10 to acquire image data, for example one or more acquisition stopping rule parameters for stopping the image acquisition.

Finally, processing circuitry 32 may interact with interface circuitry 38, designed to support operator interface 40. Operator interface 40 allows for imaging sequences to be commanded, scanner and system settings to be viewed and adjusted, images to be viewed, and so forth. In the illustrated embodiment, reconstructed images 12 may be viewed by an operator via display 42.

In an institutional setting, the imaging system 10 may be coupled to one or more networks to allow for the transfer of scheduling data to the imaging system, as well as to permit transmission and storage of image data and processed images. For example, local area networks, wide area networks,

wireless networks, and so forth may allow for storage of image data on radiology department information systems and/or on hospital information systems. Such network connections further allow for transmission of image data to remote post-processing systems, physician offices, and so forth.

With respect to the gamma ray detection components 22 of the SPECT imaging system 10, two arrangements may be employed: parallel and non-parallel. In an example of a parallel arrangement, a detector may be collimated with an arrangement of parallel structures such that the resulting acquisition of gamma rays is not divergent, for example with a collimated detector assembly or collimated camera. In an example of a non-parallel arrangement, the employed collimation is non-parallel such as a pinhole collimator, fan-beam collimator, or cone-beam collimator.

To produce images of organ region of interest 20, SPECT system 10 employs various image acquisition parameters, including acquisition stopping rule parameters for determining when to stop the image acquisition. Accordingly, described below with respect to FIG. 6 is an example of a method of determining one or more image acquisition parameters, for example acquisition stopping rule parameters, for acquiring image data from a subject.

FIG. 2 illustrates a block diagram of another example of an imaging system 2000. Imaging system 2000 includes as an imaging apparatus a positron emission tomography (PET) subsystem in combination with an X-ray computed tomography (CT) subsystem. It should be understood that in general the PET subsystem may share components with the CT subsystem, as will be discussed below with respect to FIG. 3. The imaging apparatus is configured to detect image-related events for a subject 14 in three dimensions. Here, detection of an image-related event may be detection of a photon pair from the decay of an element of the radioisotope which has been administered to subject 14.

Imaging system 2000 includes: gantry 15; patient support or platform 18; gamma ray detector/sensor 2022; first digitization and readout electronics 2030; X-ray source 2120; X- ray detector/sensor 2122; second digitization and readout electronics 2130; processing circuit 2028; user interface 2040 and display 2042. Also illustrated in dashed lines in FIG. 2 is a radiopharm source 2020. Radiopharm source 2020 is not strictly part of PET/CT imaging system 2000 system, but it is essential to create useful images.

Processing circuit 2028 includes: modules 2032 for processing data from first digitization and readout electronics 2030 and second digitization and readout electronics 2130; and application packages 2034 for utilizing reconstructed image data. Processing circuit 2028 may be supported by various electrical circuits, such as memory circuitry that may be used to store image data, calibration or correction values, routines performed by one or more processors, and so forth. In some embodiments, as explained in greater detail below, processing circuit 2028 executes a trained deep neural network for segmenting projections, sinograms and/or reconstructed images produced from image data obtained by detector/sensors 2022 and 2122, and identifies organ region of interest 20 and background region of interest 21 in the images, thereby facilitating selection of one or more image acquisition parameters for use by PET/CT imaging system 2000 system to acquire image data, for example one or more acquisition

stopping rule parameters for stopping the image acquisition.

Beneficially, patient support 18 may include a motor or similar device for automatically moving patient support 18 in response to one or more control signals provided by processing circuit 2028. Beneficially, patient support 18 may be configured to move in at least two orthogonal directions (e.g., top-to-bottom and left-to-right) under control of processing circuit 2028. In some embodiments, patient support 18 may be configured to move in all three orthogonal directions (i.e., including vertically) under control of processing circuit 2028. Additionally or alternatively, gantry 15 may be configured to move in response to one or more control signals provided by processing circuit 2028.

In operation, combined PET/CT imaging system 2000 uses radioactive materials (also known as a tracer or radio-tracer) for imaging, and is generally categorized within the field of nuclear medicine (NM). Subject 14 resides on patient support 18, and one or more detectors 2022 may be provided in gantry 15 for detecting image-related events which can be processed to obtain a three-dimensional volume image of organ region of interest 20 and background region of interest 21 in subject 14. A radioisotope, such as a radiopharmaceutical substance (sometimes referred to as a radiotracer), is administered to subject 14, which gets trapped within the tissues in organ region of interest 20. The unstable nuclei of radioisotopes within subject 14 emit positrons, which combine with neighboring electrons to produce a pair of gamma rays moving at 180 degrees to each other. These gamma rays are detected by detector(s) 2022 disposed within the donut-shaped body of gantry 15. The energy and location of these gamma rays are recorded, preprocessing and sinogram binning is performed and used by processing system 2028 to reconstruct three-dimensional (3D) images of tracer concentration within organ region of interest 20 in the body of subject 14, using algorithms as are known in the art.

As noted above, in combined PET/CT imaging system 2000, the PET subsystem may share components with the CT subsystem.

FIG. 3 illustrates an example of assignments of imaging system components between positron emission tomography (PET) functionality 3200 and computed tomography (CT) functionality 3100 in a combined PET/CT system, such as PET/CT imaging system 2000.

As shown in FIG. 3, CT modality 3100 and PET modality 3200 share patient support 18, gantry 15, a console subsystem 3400 supporting a graphical user interface (GUI) for an operator (e.g., user interface 2040 and display 2042 of FIG. 2), and a service subsystem 3500 supporting software applications used by service personnel for installation, configuration, repair, and maintenance of combined PET/CT imaging system 2000.

CT modality 3100 employs a Data Measurement System (DMS) 3130 (e.g., detector/sensor 2122 and readout/digitization electronics 2130 of FIG. 2) to acquire CT data (e.g., from an X-ray source and corresponding detector), and Common Image Reconstruction System (CIRS) 3132 to reconstruct CT image data. PET modality 3200 includes PET Detector and Acquisition Subsystem to acquire PET data (e.g., detector/sensor 2122, readout/digitization electronics 2130 and the preprocessing and sinogram binning module of FIG. 2), and a Nuclear Medicine Reconstruction System (NMRS) subsystem 3132 to

reconstruct PET image data.

The general operations of a combined PET/CT imaging system are known, and will not be repeated in detail here. Instead, only details related to determining one or more image acquisition parameters, for example acquisition stopping rule parameters, for acquiring image data from a subject will be described in detail below, in particular with respect to FIG. 6.

To produce images of the organ region of interest, 20, PET/CT imaging system 2000 employs various image acquisition parameters, including acquisition stopping rule parameters for determining when to stop the image acquisition. Accordingly, described below with respect to FIG. 6 is an example of a method of determining one or more image acquisition parameters, for example acquisition stopping rule parameters, for acquiring image data from subject 14.

FIG. 4 illustrates a block diagram illustrating an example embodiment of a processing circuit 4000 according to embodiments of the disclosure. Processing circuit 4000 includes processor 400 and associated memory circuit 450.

Processing circuit 4000 may be used to implement one or more processors described herein, for example, system control and processing circuitry 28 in FIG. 1, or processing circuit 2028 in FIG. 2. In some embodiments, processing circuit 28 in FIG. 1, or processing circuit 2028 in FIG. 2 may include more than one processor 400, and/or more than one memory circuit 450.

Processor 400 may be any suitable processor type including, but not limited to, a microprocessor, a microcontroller, a digital signal processor (DSP), a field programmable array (FPGA) where the FPGA has been programmed to form a processor, a graphical processing unit (GPU), an application specific circuit (ASIC) where the ASIC has been designed to form a processor, or a combination thereof.

Processor 400 may include one or more cores 402. Core 402 may include one or more arithmetic logic units (ALU) 404. In some embodiments, core 402 may include a floating point logic unit (FPLU) 406 and/or a digital signal processing unit (DSPU) 408 in addition to or instead of ALU 404.

Processor 400 may include one or more registers 412 communicatively coupled to core 402. Registers 412 may be implemented using dedicated logic gate circuits (e.g., flip-flops) and/or any memory technology. In some embodiments registers 412 may be implemented using static memory. Registers 412 may provide data, instructions and addresses to core 402.

In some embodiments, processor 400 may include one or more levels of cache memory 410 communicatively coupled to core 402. Cache memory 410 may provide computer-readable instructions to core 402 for execution. Cache memory 410 may provide data for processing by core 402. In some embodiments, the computer-readable instructions may have been provided to cache memory 410 by a local memory, for example, local memory attached to the external bus 416. Cache memory 410 may be implemented with any suitable cache memory type, for example, metal-oxide semiconductor (MOS) memory such as static random access memory (SRAM), dynamic random access memory (DRAM), and/or any other suitable memory technology.

Processor 400 may include a controller 414, which may control input to the processor 400 from

other processors and/or components included in a system (e.g., patient support 18, scanner 16, gantry 15, readout and digitization electronics 2030/2130, etc.) and/or outputs from processor 400 to other processors and/or components included in the system (e.g., patient support 18, scanner 16, gantry 15, etc.). Controller 414 may control the data paths in the ALU 404, FPLU 406 and/or DSPU 408. Controller 414 may be implemented as one or more state machines, data paths and/or dedicated control logic. The gates of controller 414 may be implemented as standalone gates, FPGA, ASIC or any other suitable technology.

Registers 412 and cache 410 may communicate with controller 414 and core 402 via internal connections 420A, 420B, 420C and 420D. Internal connections may be implemented as a bus, multiplexor, crossbar switch, and/or any other suitable connection technology.

Inputs and outputs for processor 400 may be provided via bus 416, which may include one or more conductive lines. Bus 416 may be communicatively coupled to one or more components of processor 400, for example controller 414, cache 410, and/or register 412. Bus 416 may be coupled to one or more components of the system, such as patient support 18, scanner 16, gantry 15, etc. mentioned previously.

Bus 416 may be coupled to one or more external memories which may be included in memory circuit 450. The external memories may include Read Only Memory (ROM) 432. ROM 432 may be a masked ROM, Electronically Programmable Read Only Memory (EPROM) or any other suitable technology. The external memory(ies) may include Random Access Memory (RAM) 433. RAM 433 may be a static RAM, battery backed up static RAM, Dynamic RAM (DRAM) or any other suitable technology. The external memory(ies) may include Electrically Erasable Programmable Read Only Memory (EEPROM) 435. The external memory(ies) may include Flash memory 434. The External memory(ies) may include a magnetic storage device such as disc 436, and/or optical storage devices such as compact discs (CDs), digital versatile discs (DVDs), etc.

In some embodiments, processing circuit 4000, and in particular processor 400, may control operations of, and process data obtained by, a SPECT imaging system, such as SPECT imaging system 10 illustrated in FIG. 1. In some embodiments, processing circuit 4000, and in particular processor 400, may control operations of, and process data obtained by, a combination PET/CT system, such as the combination PET/CT imaging system 2000 illustrated in FIG. 2.

Processing circuit 4000, and in particular processor 400, may perform algorithms or operations described below with respect to FIG. 6 to determine one or more image acquisition parameters, for example acquisition stopping rule parameters, for acquiring image data from a subject.

In particular, processing circuit 4000 may be configured to implement a trained deep neural network to detect and segment an organ region of interest (ROI) and a background ROI in the image data. Deep neural networks constitute a technology which may be employed in “deep learning” systems and artificial intelligence (“AI”) systems. Each layer of a neural network implements a non-linear transformation from inputs to outputs, and a deep neural network is one which has many layers. Deep

neural networks are trained using large datasets of examples with known, well-described contents.

Here, a trained deep neural network is a deep neural network which has been trained to recognize one or more organs or regions of interest in a subject based on a set of image data where the region(s) and/or organ(s) of interest are known and identified. This set of image data may be referred to as a training dataset. The trained deep neural network may be trained during the development and/or manufacture of the imaging system using clinical NM projection and/or reconstructed images containing typical organs of interest, such as the heart, brain, kidneys, liver, bladder, bones, lungs, thyroid, parathyroid, etc. It also may be trained on typical background regions, such as air, muscle, parenchyma, etc.

In operation, sinograms, projection images or [real-time] reconstructed images are applied to the neural network prior to, or during, acquisition in an NM imaging session to identify objects or regions of interest and segment the images. The segmentation results are used to identify the physical locations and extent of the organ(s) of interest and the patient's body. In general, system and acquisition planning may be modified to use information from the segmentation results to determine one or more image acquisition parameters, for example acquisition stopping rule parameters, for acquiring image data from a subject.

FIG. 5 depicts an example of how image data may be applied to a trained deep neural network 500 to facilitate determining one or more image acquisition parameters, for example acquisition stopping rule parameters, for acquiring image data from a subject. Here, trained deep neural network 500 receives as one input image data 502, for example projections, sinograms, or images produced from detected image-related events from a subject to whom a radiopharmaceutical dose has been administered. Trained deep neural network 500 also receives one or more parameters 504 for a nuclear medicine imaging session of the subject, including an identification of a region / organ of interest which is desired to be imaged in the nuclear medicine imaging session. As trained deep neural network 500 has been trained using the training dataset to recognize the region / organ of interest and its corresponding background region of interest, its internal parameters are optimized for the recognition of that region / organ of interest and background region of interest in the input image data 502. In response to the detected region / organ of interest and the background region of interest in the input image data 502, trained deep learning neural network 500 may output one or more sets of data or signals 506 which identify the region / organ of interest and background region of interest in the image data. .

For patients that have been given a dose prior to the imaging session, the identification of the organ and background ROIs can be done during the planning / positioning phase of the exam using a short acquisition, or information acquired during patient positioning / scan planning. For dynamic uptake studies, the identification of the organ and background ROIs can be done during the uptake portion of the scan. For organ(s) or regions of interest larger than a single detector field of view, such as the musculo-skeletal system, skin, or entire gastrointestinal (GI) tract, the detection of the organ and background ROIs may be repeated during the acquisition for each position (patient index) of the detector field of view.

FIG. 6 illustrates a flowchart of a method 600 of determining one or more image acquisition

parameters, for example acquisition stopping rule parameters, for an imaging system, such as SPECT imaging system 10 or PET/CT imaging system 2000, to acquire image data from a subject.

In an operation 610, parameters for a nuclear medicine imaging session of a subject are provided. Such parameters may include, among other things, an acquisition type, a patient size, a radiopharmaceutical which is administered to the subject, and an organ / region of interest which is to be imaged.

In an operation 620, a radiopharmaceutical dose is administered to the subject.

In an operation 630, the imaging apparatus performs a pre-scan acquisition imaging on the subject using one or more image acquisition parameters and detects image-related events in the subject produced in response to the radiopharmaceutical dose during an acquisition time period, for example to position the subject and to optimize the clinical imaging parameters. Here, the image acquisition parameters may include one or more acquisition stopping rule parameters which may set the acquisition time period.

In an operation 640, the imaging apparatus produces projections, sinograms, or images from the detected image-related events

In an operation 650, a processing circuit applies the projections, sinograms, or images to a trained deep neural network to segment the projections, sinograms, or images and identify an organ region of interest (ROI) and a background region of interest (ROI) in the subject.

In an operation 660, statistics are determined for the image-related events in the organ region of interest and in the background region of interest. Statistics that might be used once an organ ROI and background ROI have been reliably identified in operation 650 may include the same statistics which have been employed with respect to the entire image, but now are applied just to those regions, e.g.. average counts per pixel and average counts per square centimeter within each region. These statistics can be compared to optimize expected contrast between the regions, such as using an average count ratio between the organ ROI and the background ROI, or a ratio of average count in the organ ROI divided by the standard deviation in the background ROI. Optimal values for these statistics may depend on the organ of interest (for example the heart or brain might have different optimal values than lungs or bones), the radiopharmaceutical used (for example active uptake radiopharmaceuticals, such as for the thyroid, might have a different optimal value than perfusion radiopharmaceuticals), and the type of study (for example static planar studies might have different optimal values than dynamic, uptake studies).

In an operation 670, a value of at least one of the image acquisition parameters is selected based on the determined statistics.

Optimal image acquisition parameters might be selected by using deep neural networks (DNNs), decision trees, disease-specific heuristics, and site-specific rules of thumb. The DNNs and decision trees may be trained using a large number of clinical and phantom studies. The heuristics and rules of thumb may combine clinical expertise with physiological models and phantom studies to derive reasonably good parameter values.

A benefit of using region of interest statistics for optimizing acquisition parameters, including stopping rules, may be to ensure a minimum image quality, especially in the case where the image acquisition could stop at an optimal image quality earlier than the acquisition time recommended by the customer's standard clinical protocol.

For general nuclear medicine imaging systems with calibrated detectors, the image quality in the projection images is a function of pixel count noise, object to background contrast, scatter photon rejection, and system resolution; with better image quality associated with lower noise and scatter, and higher contrast and resolution. Thus, acquisition parameters that impact image quality, besides the stopping rules discussed below (which primarily impact noise and contrast), may include:

- parameters associated with pixel size [number of pixels, image size (cm/image), image zoom factor (mm/pixel)] - the smaller the pixel size the more time / counts needed for optimal image quality;
- parameters associated with reconstruction image quality [number of projection angles, total range of projection angles, pixel size parameters] - the larger the number of projection angles the longer the total acquisition time needed for optimal image quality;
- parameters associated with dynamic image quality [number of frames, clinical rate of change to be imaged] - the larger the number of frames the longer the total acquisition time needed for optimal image quality;
- parameters associated with gamma photon energy acceptance window(s) - with smaller windows needing longer total acquisition time for optimal image quality.

In some embodiments, one or more acquisition stopping rule parameters is selected based on the determined statistics. In various embodiments, the image acquisition parameters which may be adjusted include acquisition time per frame, total number of frames, indexing type and speed, and frame size / image resolution / FOV scaling factors.

In some embodiments, various operations described above may be omitted, performed differently, performed in a different order, and/or repeated, and/or additional operations may be performed.

For example, in some embodiments, method 600 may further include an operation of displaying on a display device an indication of the selected value forat least one of the acquisition stopping rule parameters. In some embodiments, method 600 may further include operations of receiving from a user an indication of approval of the selected value for at least one of the acquisition stopping rule parameters, and in response to the indication of approval, stopping the acquisition based on the approved value.

In some embodiments, the order of operations 610 and 620 may be reversed.

The method 600 of FIG. 6 described above may be more clearly understood from the following explanation.

The method includes the application of deep neural networks to detect and segment the organ

region of interest (ROI) of a subject or patient. For patients that have been given a dose prior to the scan, this identification of the organ ROI can be done during the planning / positioning phase of the exam using a short acquisition, or information acquired during patient positioning / scan planning. For dynamic uptake studies, this identification of the organ ROI can be done during the uptake portion of the scan. For organ(s) of interest larger than a single detector field of view (FOV), such as the musculo-skeletal system, skin, or entire GI tract, the detection of the organ ROI could be repeated during the acquisition for each position (patient index) of the detector FOV.

The method applies the deep neural network to perform the detection / segmentation of the extent of the patient's body and to identify a organ region of interest and a background region of interest in the image data (e.g., projections, sinograms, or images) produced from image-related events which are detected by an imaging apparatus.

The method uses the detected organ / background ROIs to adjust one or more imaging parameters, for example to optimize the organ signal-to-noise ratio (signal-to-noise ratio in the organ region of interest), or the organ-to-background contrast ratio (organ region of interest to background region of interest contrast ratio). Other information that could inform the optimization include scheduled exam, study type, patient size, weight, dose, patient and system attenuation information (when available), and the maximum allowed acquisition time.

In some embodiments, the updated position(s) and/or plans are presented to the user for review and approval prior to moving the patient and/or the start of the acquisition.

The following list describes examples of image acquisition parameters and tradeoffs which may pertain to various different acquisition types:

- Static planar NM / PET [no gantry or patient indexing, no gating, no time-slicing]: the primary trade-off is between time and 2-D resolution / spatial scale factors, with more detected events [counts] enabling higher resolution / more pixels or voxels. The trade-off may be constrained by the intent of the clinical exam and size(s) of the organ(s) or object(s) of interest.
- Dynamic planar NM / PET [no gantry or patient indexing, no gating]: trade-offs can occur along two dimensions: time and resolution. The time dimension has several components: the length of a time slice in a phase, the number of time slices in a phase, the number of phases [a phase is a period of time with constant width time slices, often corresponding to a specific physiologic state or event], and the total acquisition time. Systems that acquire list-mode raw data could perform accurate re-binning, allowing the time slice to be set towards or at the end of the acquisition. The physiology of interest in a particular exam would place constraints on the min and max values for the number of phases and time slices. The total length of [each phase of] the acquisition could be adjusted, enabling the acquisition to complete once a target level of uptake or washout had occurred in the organ(s) of interest. In addition, the trade-off between resolution and time is possible for each phase of the acquisition, although it would be more natural if it was constant for the entire acquisition, as described for static acquisitions.
- Gated planar NM / PET [no gantry or patient indexing]: the trade-offs for this acquisition type

are similar to the dynamic planar type, with the concept of multiple phases replaced by the concept of a summary beat / breath. The type of exam would place constraints on the number of slices per beat or breath. Gated acquisitions frequently include parameters for rejecting bad beats / breaths, thus an additional parameter trade-off might be to adjust these parameters slightly to include more (or fewer) beats / breaths in the final images.

- Total body planar NM / indexed PET [no gating, no time-slicing]: the primary trade-off is length of time at each index position, speed of motion / number of index positions, and the total scan length. Varying the speed of motion / time per index position within the acquisition may be possible, based on the clinical objectives of the exam, but one consequence of this is differing background noise per index position, something already present to a limited extent in most acquisitions due to radioactive decay. As with the static planar type, a trade-off can also be made between resolution / scale factor and total acquisition time.
- Single position SPECT [indexing gantry around the patient, no gating, no time-slicing]: the primary trade-off is between time and 3-D resolution; not only the 2-D resolution in each projection image, but also the reconstruction resolution associated with the number of angles / projections acquired around the patient. The SPECT reconstruction algorithm may impose limitations on the number of projections, as some are limited to having that number be a power of two. Varying the time per index position may result in differing background noise per position, which may result in subtle artifacts in the reconstructed images.
- Single position gated SPECT [indexing gantry around the patient, with gating at each index]: this is the combination of the single position SPECT and the gated planar acquisition types described above.
- Total body SPECT [indexing gantry around, and indexing along, the patient, no gating, no time-slicing]: this is the combination of the single position SPECT and total body planar acquisition types described above.
- Dynamic SPECT [indexing gantry around the patient, once per time-slice]: this is a combination of the single position SPECT and dynamic planar acquisition types described above.

Various embodiments may combine the variations described above.

While preferred embodiments are disclosed in detail herein, many other variations are possible which remain within the concept and scope of the invention. Such variations would become clear to one of ordinary skill in the art after inspection of the specification, drawings and claims herein. The invention therefore is not to be restricted except within the scope of the appended claims.

CLAIMS

1. A system, comprising:

an imaging apparatus, wherein the imaging apparatus is configured to detect image-related events in a subject during an acquisition time period which is set by one or more acquisition stopping rule parameters;

a processing circuit including a processor and associated memory, wherein the processing circuit is configured to:

produce projections, sinograms, or images from the detected image-related events,

apply the projections, sinograms, or images to a trained deep neural network implemented by the processing circuit to detect and segment an organ region of interest in the projections, sinograms, or images and to detect and segment a background region of interest in the projections, sinograms, or images,

determine statistics for the image-related events in the organ region of interest and in the background region of the interest, and

select an optimal value for at least one of the acquisition stopping rule parameters based on the determined statistics.

2. The system of claim 1, wherein the processing circuit is configured to select a value for at least one of the acquisition stopping rule parameters to optimize at least one of a signal-to-noise ratio in the organ region of interest or a contrast ratio between the organ region of interest and the background region of interest.

3. The system of claim 1, further comprising a display device, wherein the processing circuit is further configured to cause the display device to display an indication of the selected value for at least one of the acquisition stopping rule parameters.

4. The system of claim 3, further comprising a user interface, wherein the processing circuit is further configured to receive from a user via the user interface an indication of approval for the selected value for at least one of the acquisition stopping rule parameters, and in response to the indication of approval to stop the acquisition based on the approved selected value for the acquisition stopping rule parameters.

5. The system of claim 1, wherein the processing circuit is further configured to receive additional acquisition parameters and to optimize at least one of the acquisition stopping rule parameters based on the received additional acquisition parameters, wherein the received additional

acquisition parameters include at least one of an examination type, a subject size, a subject weight, a radiopharmaceutical dose administered to the subject, attenuation data for the subject, attenuation data for detected events by the system, and a specified maximum acquisition time.

6. The system of claim 1, wherein the imaging apparatus comprises a single photon emission computed tomography (SPECT) imaging apparatus.

7. The system of claim 1, wherein the imaging apparatus comprises a Positron Emission Tomography (PET) imaging apparatus.

8. A method, comprising:

detecting, with an imaging apparatus, image-related events in a subject which is disposed on a platform, during an acquisition time period which is set by one or more acquisition stopping rule parameters;

producing projections, sinograms, or images from the detected image-related events;

applying the projections, sinograms, or images to a trained deep neural network implemented by the processing circuit to detect and segment an organ region of interest in the projections, sinograms, or images and to detect and segment a background region of interest in the projections, sinograms, or images;

determining statistics for the image-related events in the organ region of interest and in the background region of the interest; and

selecting an optimal value for at least one of the acquisition stopping rule parameters based on the determined statistics.

9. The method of claim 8, further comprising selecting a value for at least one of the acquisition stopping rule parameters to optimize at least one of a signal-to-noise ratio in the organ region of interest or a contrast ratio between the organ region of interest and the background region of interest.

10. The method of claim 8, further comprising displaying on a display device an indication of the selected value for at least one of the acquisition stopping rule parameters.

11. The method of claim 10, further comprising:

receiving from a user an indication of approval of the selected value for at least one of the acquisition stopping rule parameters; and

in response to the indication of approval, stopping the acquisition based on the approved

value.

12. The method of claim 8, wherein the imaging apparatus comprises a single photon emission computed tomography (SPECT) imaging apparatus.

13. The method of claim 8, wherein the imaging apparatus comprises a Positron Emission Tomography (PET) imaging apparatus.

14. A system, comprising:

an imaging apparatus, wherein the imaging apparatus is configured to detect image-related events in a subject using one or more image acquisition parameters; and

a processing circuit including a processor and associated memory, wherein the processing circuit is configured to:

receive an indication of a region of interest in the subject, said region of interest including an organ and background region of interest;

produce projections, sinograms, or images from the detected image-related events;

apply the projections, sinograms, or images to a trained deep neural network implemented by the processing circuit to detect and segment the organ region of interest in the projections, sinograms, or images and to detect and segment the background region of interest in the projections, sinograms, or images;

determine statistics for the image-related events in the organ region of interest and in the background region of the interest; and

select an optimal value for at least one of the image acquisition parameters based on the determined statistics.

15. The system of claim 14, wherein the processing circuit is configured to select a value for at least one of the image acquisition parameters to optimize at least one of a signal-to-noise ratio in the organ region of interest or a contrast ratio between the organ region of interest and the background region of interest.

16. The system of claim 14, further comprising a display device, wherein the processing circuit is further configured to cause a display device to display an indication of the selected value for at least one of the image acquisition parameters.

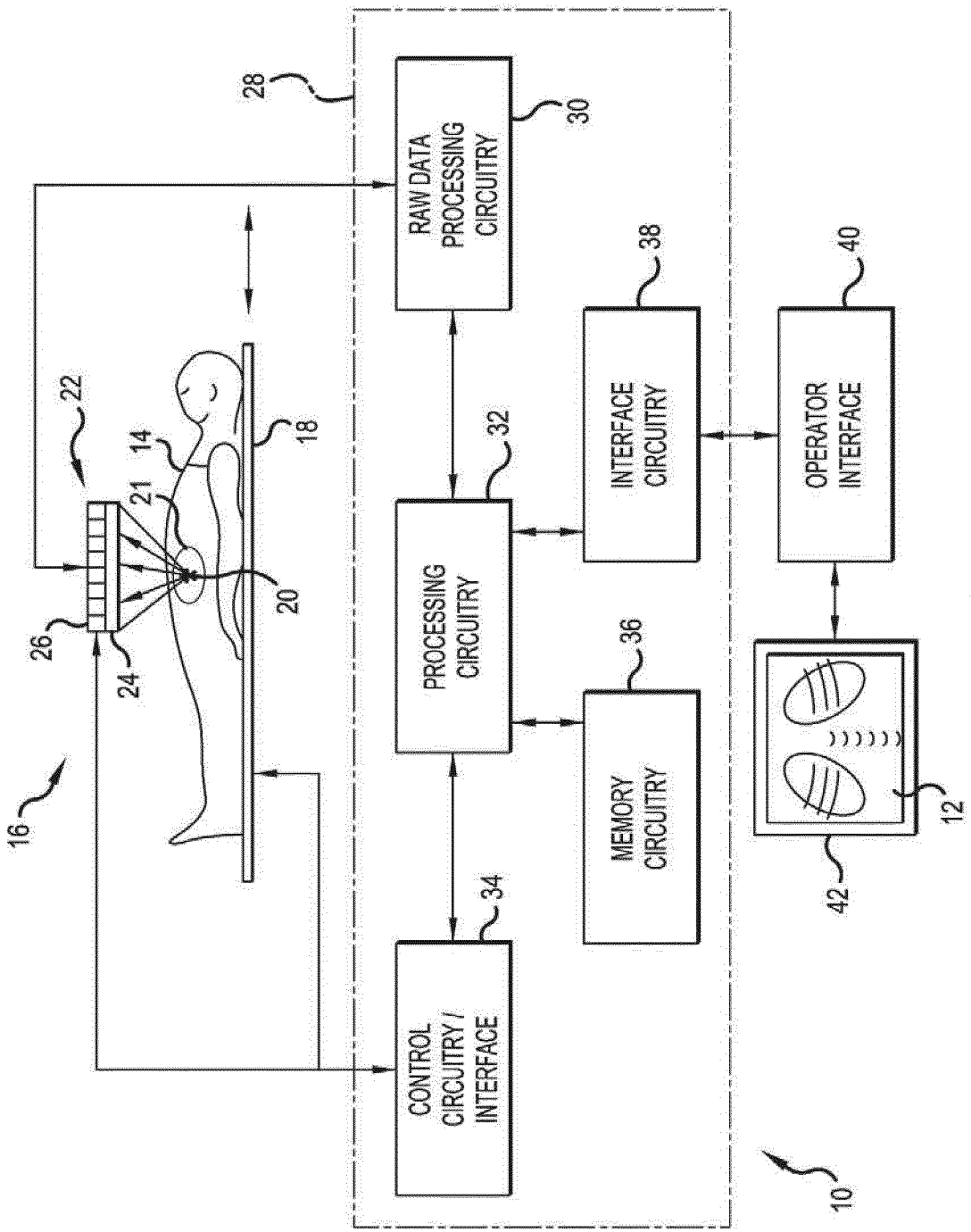
17. The system of claim 16, further comprising a user interface, wherein the processing circuit is further configured to receive from a user via the user interface an indication of approval of

the selected value for at least one of the image acquisition parameters, and in response to the indication of approval to adjust the image acquisition parameters to have the approved value.

18. The system of claim 15, wherein the image acquisition parameters include at least one acquisition stopping rule parameter.

19. The system of claim 14, wherein the imaging apparatus comprises a single photon emission computed tomography (SPECT) imaging apparatus.

20. The system of claim 14, wherein the imaging apparatus comprises a Positron Emission Tomography (PET) imaging apparatus.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CONTROL CIRCUITRY / INTERFACE
INTERFACE CIRCUITRY
MEMORY CIRCUITRY
OPERATOR INTERFACE
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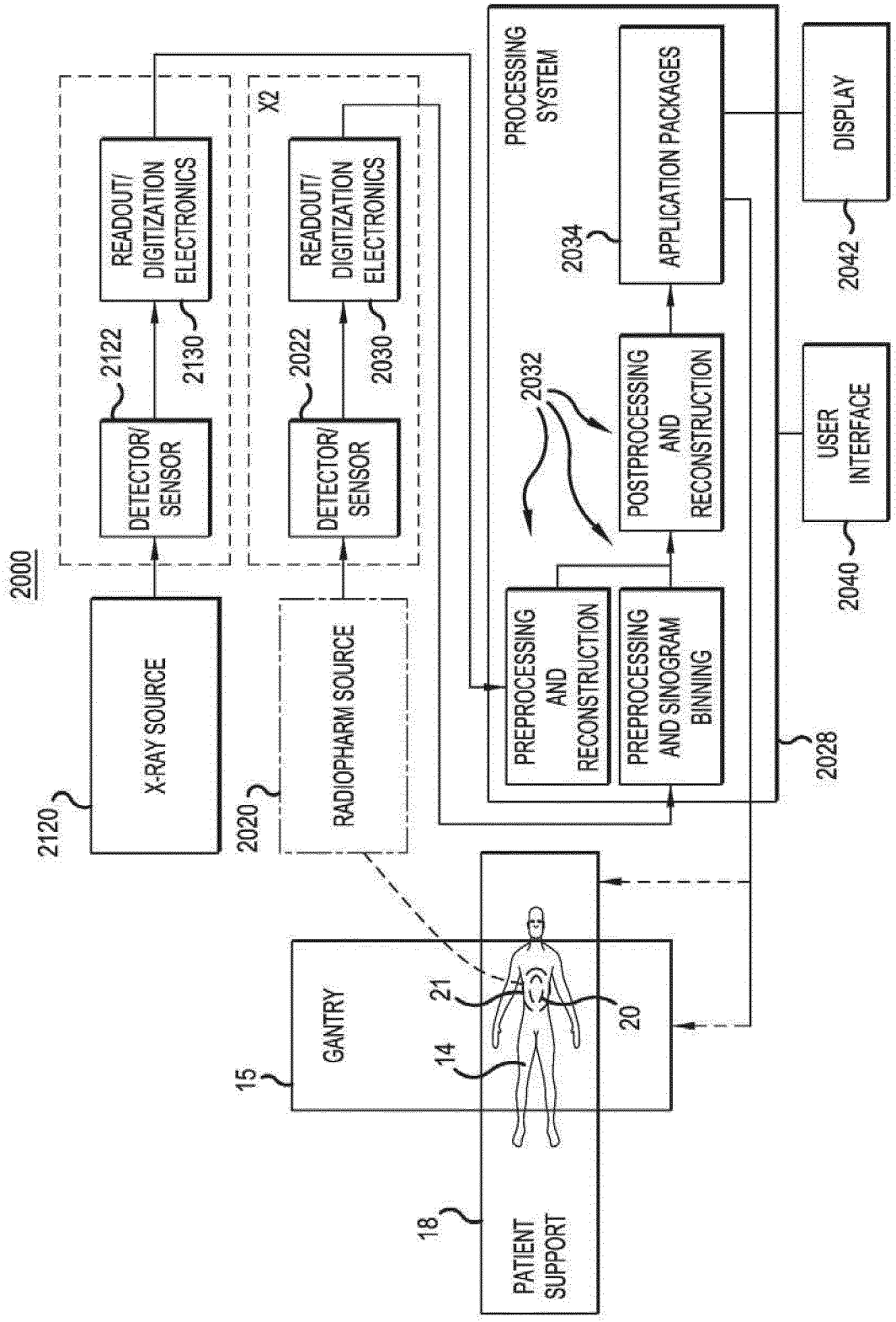
42

FIG.1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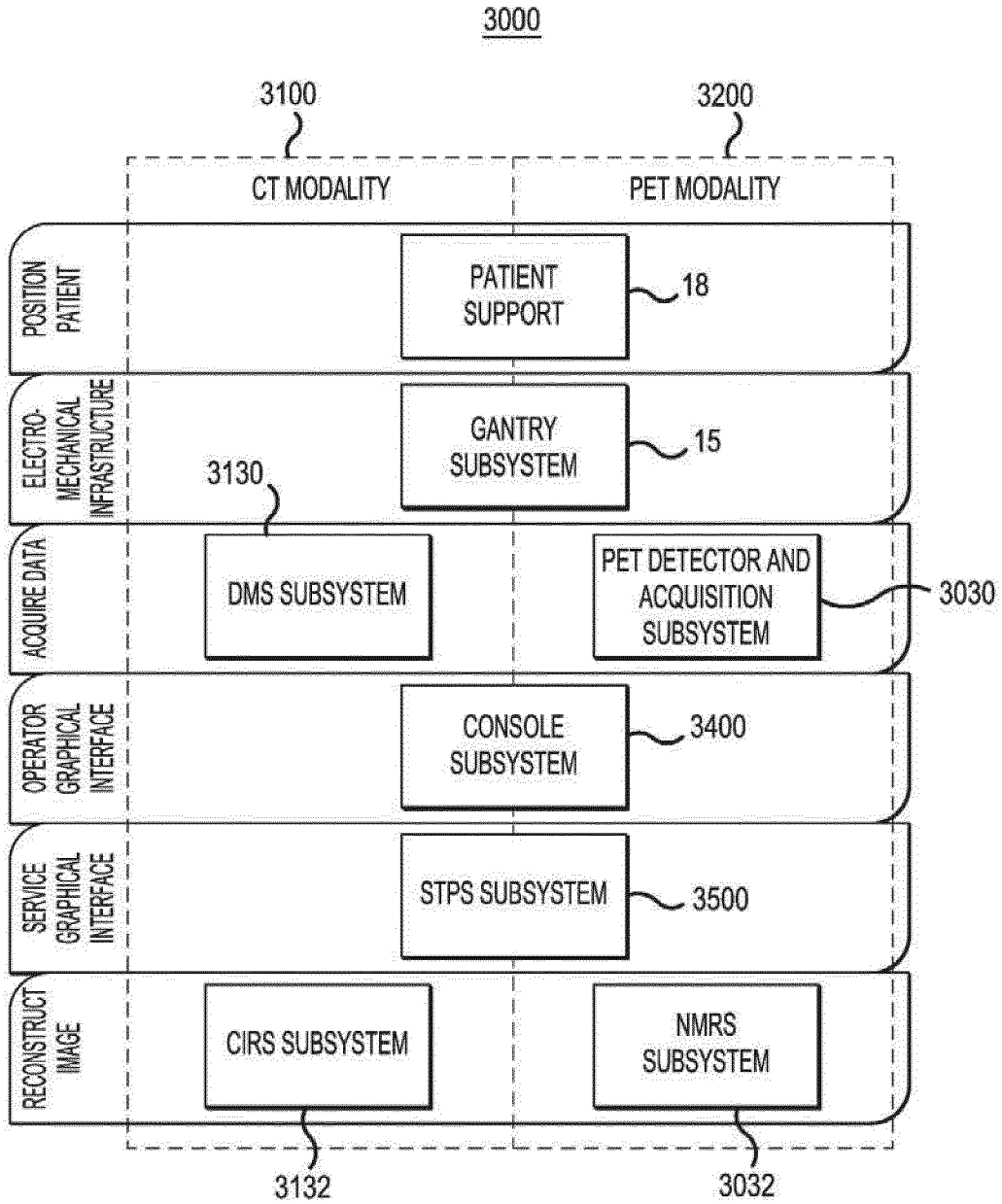
PATIENT SUPPORT

FIG.2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PET DETECTOR AND ACQUISITION SUBSYSTEM
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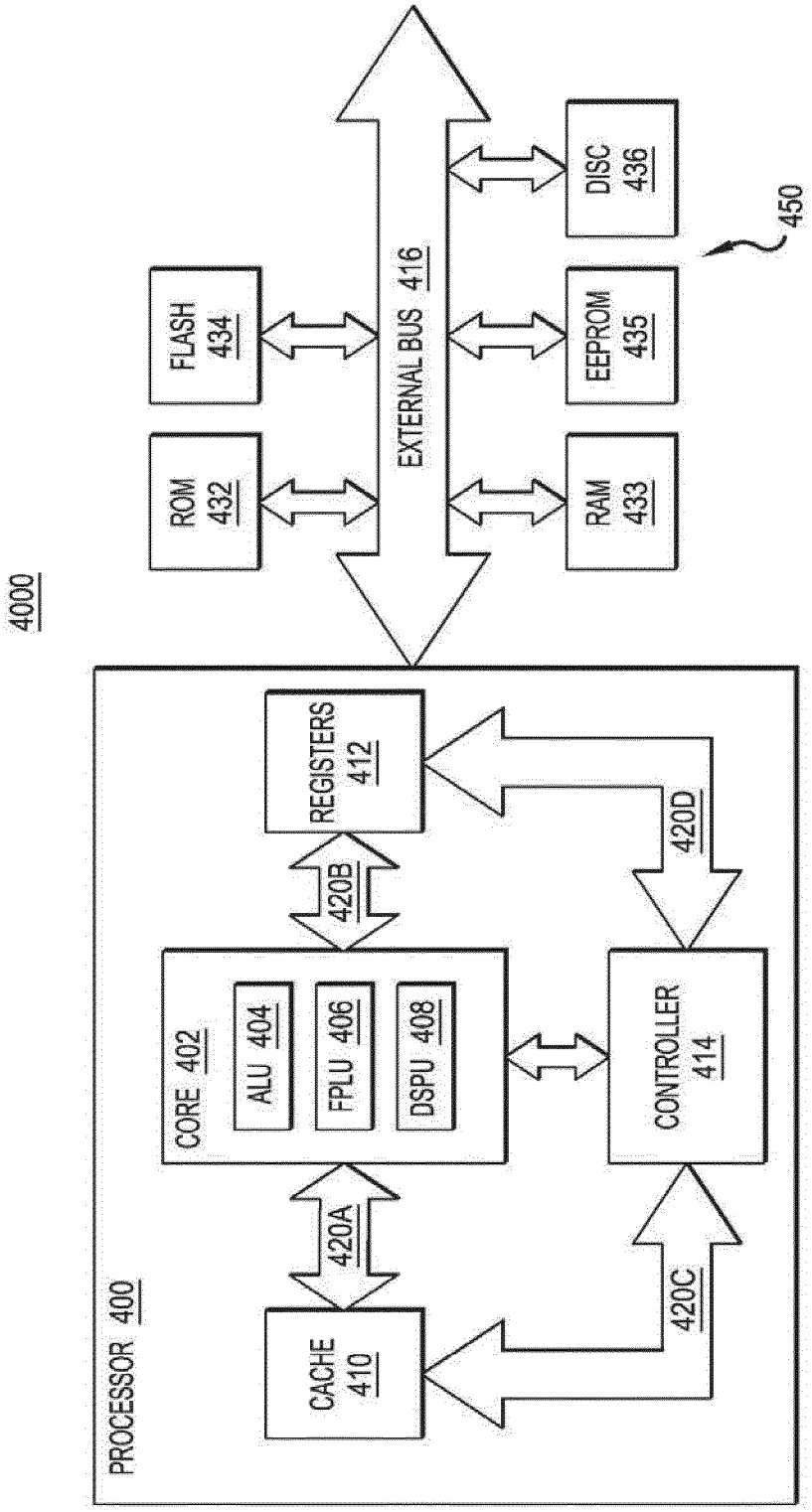
FIG.3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REGISTERS 412
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EEPROM 435
DISC 436
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FIG.4

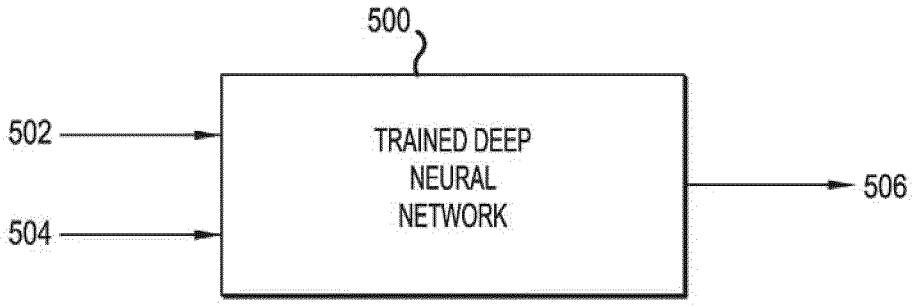

FIG.5

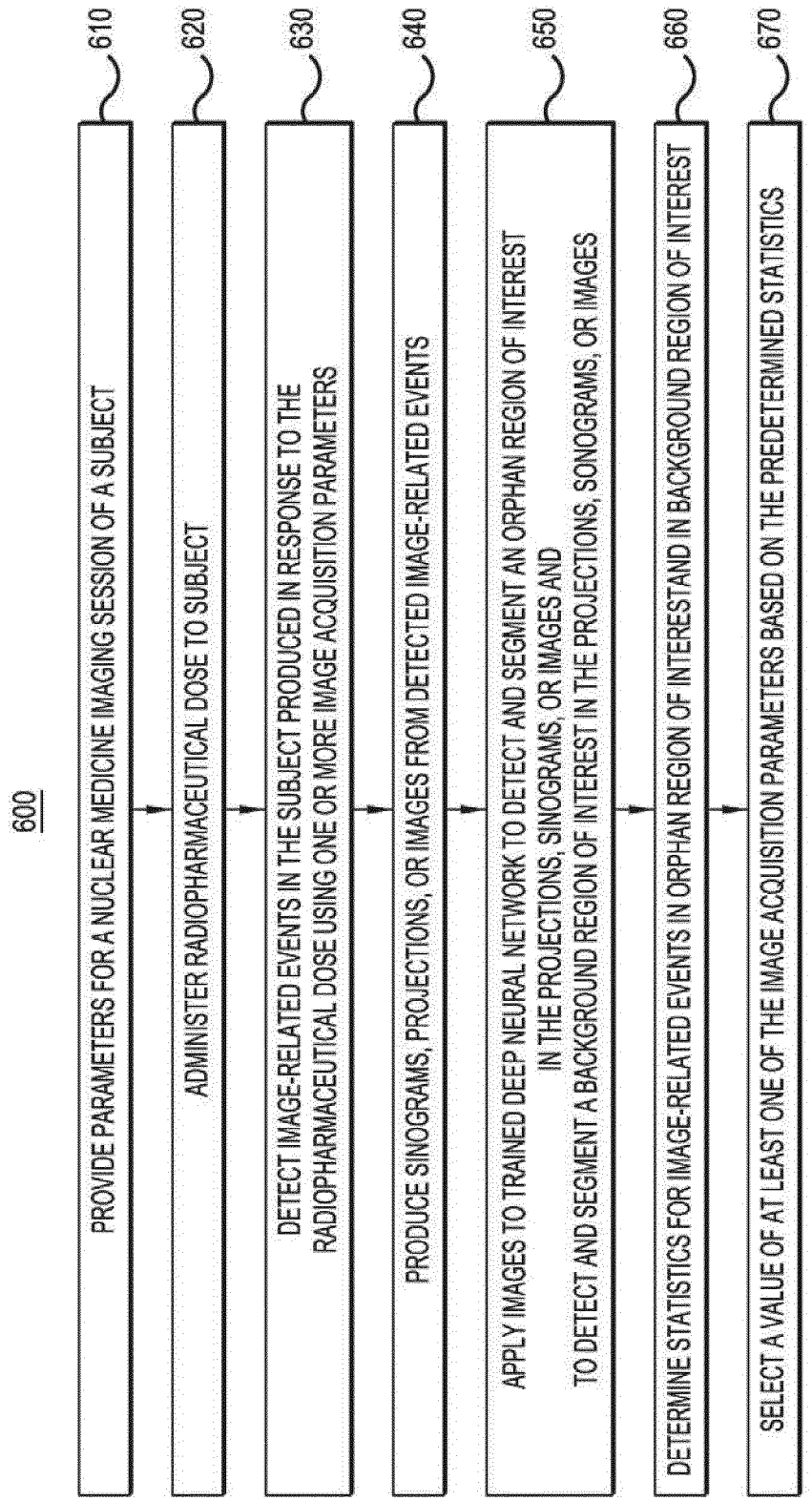
600
610
PROVIDE PARAMETERS FOR A NUCLEAR MEDICINE IMAGING SESSION OF A SUBJECT
620
ADMINISTER RADIOPHARMACEUTICAL DOSE TO SUBJECT
630
DETECT IMAGE-RELATED EVENTS IN THE SUBJECT PRODUCED IN RESPONSE TO THE RADIOPHARMACEUTICAL DOSE USING ONE OR MORE IMAGE ACQUISITION PARAMETERS
640
PRODUCE SINOGRAMS, PROJECTIONS, OR IMAGES FROM DETECTED IMAGE-RELATED EVENTS
650
APPLY IMAGES TO TRAINED DEEP NEURAL NETWORK TO DETECT AND SEGMENT AN ORPHAN REGION OF INTEREST IN THE PROJECTIONS, SINOGRAMS, OR IMAGES AND TO DETECT AND SEGMENT A BACKGROUND REGION OF INTEREST IN THE PROJECTIONS, SONOGRAMS, OR IMAGES
660
DETERMINE STATISTICS FOR IMAGE-RELATED EVENTS IN ORPHAN REGION OF INTERESTAND IN BACKGROUND REGION OF INTEREST
670
SELECT A VALUE OF AT LEAST ONE OF THE IMAGE ACQUISITION PARAMETERS BASED ON THE PREDETERMINED STATISTICS

FIG.6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/079763

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/03 A61B6/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/171183 A1 (NARAYANAN MANOJ [US] ET AL) 2 July 2009 (2009-07-02) abstract figures 1,2 paragraph [0001] - paragraph [0030] -----	1-20
A	GONG KUANG ET AL: "PET Image Reconstruction Using Deep Image Prior", IEEE TRANSACTIONS ON MEDICAL IMAGING, IEEE, USA, vol. 38, no. 7, 2 July 2019 (2019-07-02), pages 1655-1665, XP011732645, ISSN: 0278-0062, DOI: 10.1109/TMI.2018.2888491 [retrieved on 2019-06-28] abstract figures 1-8 Sections I - VII -----	1-20

-/--

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

[X] See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 January 2022	09/02/2022

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

1

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/079763

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/136328 A1 (JANSEN FLORIBERTUS HEUKENSFELDT [US] ET AL) 30 May 2013 (2013-05-30) abstract figures 1-5 paragraph [0005] - paragraph [0065] -----	1-20
A	SAIPRASAD RAVISHANKAR ET AL: "Image Reconstruction: From Sparsity to Data-adaptive Methods and Machine Learning", ARXIV.ORG, CORNELL UNIVERSITY LIBRARY, 201 OLIN LIBRARY CORNELL UNIVERSITY ITHACA, NY 14853, 5 April 2019 (2019-04-05), XP081463843, DOI: 10.1109/JPROC.2019.2936204 abstract figures 1-10 Sections I - VIII -----	1-20

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2021/079763

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2009171183 A1	02-07-2009
		WO 2007046013 A2	26-04-2007
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