



- (51) **International Patent Classification:**
G01T 1/164 (2006.01) *G01T 1/29* (2006.01)
- (21) **International Application Number:**
PCT/IB2015/051925
- (22) **International Filing Date:**
17 March 2015 (17.03.2015)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
61/971,769 28 March 2014 (28.03.2014) US
- (71) **Applicant:** KONINKLIJKE PHILIPS N.V. [NL/NL];
High Tech Campus 5, NL-5656 AE Eindhoven (NL).
- (72) **Inventors:** LAURENCE, Thomas Leroy; c/o High Tech
Campus, Building 5, NL-5656 AE Eindhoven (NL).
WANG, Sharon Xiaorong; c/o High Tech Campus, Build-
ing 5, NL-5656 AE Eindhoven (NL).
- (74) **Agents:** STEFFEN, Thomas et al.; High Tech Campus
Building 5, NL-5656 AE Eindhoven (NL).
- (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, DK, DM,

DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
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, SA, SC,
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, 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))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))

- (54) **Title:** DEAD PIXEL COMPENSATION IN POSITRON EMISSION TOMOGRAPHY (PET)

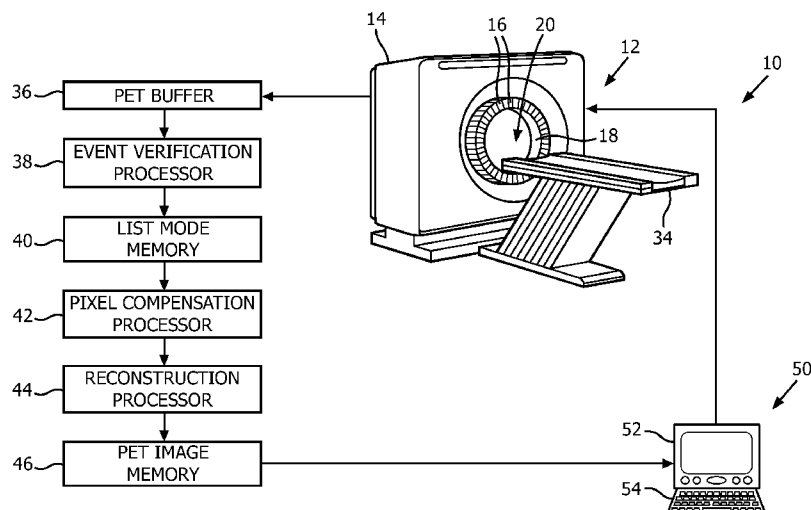


FIG. 2

- (57) **Abstract:** A system (10) and a method (100) compensate for one or more dead pixels in positron emission tomography (PET) imaging. A pixel compensation processor receives PET data describing a target volume of a subject. The PET data is missing data for one or more dead pixels. The pixel compensation estimates PET data for the dead pixels from the received PET data.

DEAD PIXEL COMPENSATION IN POSITRON EMISSION TOMOGRAPHY (PET)

The present application relates generally to positron emission tomography (PET). It finds particular application in conjunction with compensating for dead pixels, and will be described with particular reference thereto. However, it is to be understood that it also finds application in other usage scenarios, and is not necessarily limited to the aforementioned application.

In the past, PET systems have typically employed photomultiplier tubes (PMTs), such as 1.5 inch PMTs, for light detection. A typical PMT based PET system contains anywhere from about 12,000 to 33,000 individual scintillators, but uses only 200 to 800 PMTs. As such, a typical PMT based PET system is fairly intolerant of a non-functioning PMT. Because of the size of PMTs, a non-functioning PMT renders a large part of the detector inoperable. Further, Anger logic does not support calculating the location of scintillation events that occur in an inoperable part of the detector.

More recently, PET systems have been transitioning to SiPMs, such as 3x3 or 4x4 millimeter (mm) SiPMs, for light detection. In SiPM based PET system, there is a high probability that some of the SiPMs may not function properly. In contrast with PMT based PET system, the SiPM channel count of SiPM based PET system approaches the scintillator count. Since the impacted area of a non-functioning SiPM is fairly small, a SiPM based PET system can tolerate non-functioning SiPMs. This applies to a one-to-one coupling of scintillators to SiPMs, and a many-to-one coupling of scintillators to SiPMs where micro-Anger calculations are performed to determine event positions.

While SiPM based PET systems can tolerate non-functioning SiPMs, the quality of reconstructed images is degraded. Non-functioning SiPMs result in dead pixels. A pixel is the smallest area to which a scintillation event can be localized. A dead pixel is a pixel missing valid data. Dead pixels may also arise due to problems in one or more of scintillator performance, optical coupling between SiPMs and scintillators, and processing electronics. Dead pixels result in imaging artifacts during reconstruction. Artifacts during reconstruction are

more pronounced for higher statistic scans with a fairly uniform activity in the scanned target volume.

With reference to FIGURE 1, a sinogram generated using a PET scanner with three dead pixels is provided. The sinogram describes spatial information and does not contain time-of-flight (TOF) information. The PET scanner includes a one-to-one coupling between scintillators and SiPMs, and the smallest area to which a scintillation event can be localized is a SiPM/scintillator pair. As can be seen, dead pixels cause dark lines of missing data, emphasized by the arrows. The gap between the detectors generates the periodic mesh pattern.

The present application provides a new and improved system and method which overcome these problems and others.

In accordance with one aspect, a system for compensating for one or more dead pixels in positron emission tomography (PET) imaging is provided. The system includes a pixel compensation processor which receives PET data describing a target volume of a subject. The PET data is missing data for one or more dead pixels. The pixel compensation processor further estimates PET data for the dead pixels from the received PET data.

In accordance with another aspect, a method for compensating for one or more dead pixels in positron emission tomography (PET) imaging is provided. PET data describing a target volume of a subject is received. The PET data is missing data for one or more dead pixel. PET data for the dead pixels is estimated from the received PET data.

In accordance with another aspect, a system for compensating for one or more dead pixels in positron emission tomography (PET) imaging is provided. The system includes a plurality of silicon photomultipliers (SiPMs) which generate PET data describing a target volume of a subject. The system further includes a pixel compensation processor which receives PET data describing a target volume of a subject from the SiPMs. The PET data is missing data for a dead pixel associated with a non-functioning SiPM. The pixel compensation processor further generates PET data for the dead pixel from the received PET data.

One advantage resides in reduced imaging artifacts.

Another advantage resides in increased image quality.

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

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

FIGURE 1 illustrates a prior art sinogram generated using a positron emission tomography (PET) imaging system with dead pixels.

10 FIGURE 2 illustrates a PET imaging system with a pixel compensation processor according to the present application.

FIGURE 3 illustrates a detector of the PET imaging system of FIGURE 2.

FIGURE 4 illustrates a sinogram generated from the same data as the sinogram of FIGURE 1 and using pixel compensation according to the present application.

15 FIGURE 5 illustrates a method of compensating for dead pixels in PET imaging.

PET scanners employing silicon photomultipliers (SiPMs) for light detection have a high likelihood of dead pixels. A pixel is the smallest area to which a scintillation event can be
20 localized. A dead pixel is a pixel missing valid data. Dead pixels may arise due to problems in one or more of scintillator performance, optical coupling between SiPMs and scintillators, SiPMs, and processing electronics. The present application describes an approach for compensating for dead pixels by filling in the missing data with data from other pixels. This eliminates missing lines-of-response (LOR) and yields an image better representing the scanned
25 target volume.

A number of approaches are described hereafter for filling the missing data of dead pixels. In one instance, a first order approximation is employed. According to this approach, the event data of pixels neighboring a dead pixel is duplicated and the duplicate data is augmented by replacing the locations of the neighboring pixels with the location of the dead
30 pixel. In another instance, sinogram space interpolation is employed. According to this

approach, each position in the sinogram space associated with a dead pixel is interpolated from neighboring positions.

With reference to FIGURE 2, a PET imaging system **10** includes a PET scanner **12**. The PET scanner **12** generates raw scan data and includes a stationary gantry **14** housing a plurality of gamma detectors **16** arranged around a bore **18** of the scanner **12**. The bore **18** defines an examination volume **20** for receiving a target volume of a subject to be imaged, such as a brain, torso, or the like. The detectors **16** are typically arranged in one or more stationery rings which extend the length of the examination volume **20**. However, rotatable heads are also contemplated. The detectors **16** detect gamma photons from the examination volume **20** and generate the raw scan data.

With reference to FIGURE 3, each of the detectors **16** includes one or more scintillators **22** arranged in a grid. The scintillators **22** scintillate and generate visible light pulses in response to energy depositions by gamma photons. As illustrated, a gamma photon **24** deposits energy in a scintillator **26**, thereby resulting in a visible light pulse **28**. The magnitude of a visible light pulse is proportional to the magnitude of the corresponding energy deposition. Examples of scintillators **22** include sodium iodide doped with thallium (NaI(Tl)), cerium-doped lutetium yttrium orthosilicate (LYSO) and cerium doped lutetium oxyorthosilicate (LSO).

In addition to the scintillators **22**, the detectors **16** each includes a sensor **30** detecting the visible light pulses in the scintillators **22**. The sensor **30** includes a plurality of light sensitive elements **32**. The light sensitive elements **32** are arranged in a grid of like size as the grid of scintillators **22** and optically coupled to corresponding scintillators **22**. The light sensitive elements **32** can be coupled to the scintillators **22** in a one-to-one arrangement, a one-to-many arrangement, a many-to-one arrangement, or any other arrangement. Typically, as illustrated, the light sensitive elements **32** are silicon photomultipliers (SiPMs), but photomultiplier tubes (PMTs) are also contemplated.

Where the light sensitive elements **32** are SiPMs, there is typically a one-to-one correspondence between the scintillators **22** and the light sensitive elements **32**, as illustrated, but other correspondences are contemplated. Each of the SiPMs includes a photodiode array (e.g., Geiger-mode avalanche photodiode arrays), each photodiode corresponding to a cell of the photodiode array. Suitably, the SiPMs **32** are configured to operate in a Geiger mode to produce a series of unit pulses to operate in a digital mode. Alternatively, the SiPMs can be configured to

operate in an analog mode. Where the light sensitive elements **32** are PMTs, there is often a many-to-one correspondence between the scintillators **22**, but other correspondences are contemplated.

Referring back to FIGURE 2, during a scan of a subject using the scanner **12**, a target volume of the subject is injected with a radiopharmaceutical or radionuclide. The radiopharmaceutical or radionuclide causes gamma photons to be emitted from the target volume. The target volume is then positioned in the examination volume **20** using a subject support **34** corresponding to the scanner **12**. Once the target volume is positioned within the examination volume **20**, the scanner **12** is controlled to perform a scan of the target volume and event data is acquired. The acquired event data describes the time, location and energy of each scintillation event detected by the detectors **16** and is suitably stored in a PET data buffer **36**.

The location of a scintillation event corresponds to a pixel of the scanner **12**. A pixel is the smallest area to which a scintillation event can be localized. For example, suppose the light sensitive elements **32** are SiPMs and there is a one-to-one coupling between scintillators **22** and light sensitive elements **32**. In such instances, the smallest area to which a scintillation event can be localized is typically a scintillator/SiPM pair, whereby a pixel typically corresponds to a scintillator/SiPM pair. As another example, suppose the light sensitive elements **32** are PMTs or SiPMs and there is a many-to-one coupling between scintillators **22** and light sensitive elements **32**. In such instances, Anger logic is typically used to localize scintillation events to individual scintillators **22**, whereby a pixel typically corresponds to a scintillator **22**, but not a light sensitive element **32**.

Subsequent to acquisition, or concurrently therewith, an event verification processor **38** filters the buffered event data. The filtering includes comparing energy (cell counts in the digital mode) of each scintillation event to an energy window, which defines the acceptable energy range for scintillation events. Those scintillation events falling outside the energy window are filtered out. Typically, the energy window is centered on the known energy of the gamma photons to be received from the examination volume **20** (e.g., 511 kiloelectron volt (keV)) and determined using the full width half max (FWHM) of an energy spectrum generated from a calibration phantom. The event verification processor **38** further generates lines of response (LORs) from the filtered event data. A LOR is defined by a pair of gamma photons striking the detectors **16** within a specified time difference of each other (i.e., a

coincident event). The specified time difference is small enough to ensure the gammas are from the same annihilation event. Hence, assuming that there is a one-to-one correspondence between scintillation events and gamma photons striking the detectors **16**, a LOR can be defined by a pair of scintillation events.

5 The foregoing filtering of event data and determining of LORs assumed that there was a one-to-one correspondence between scintillation events and gamma photons striking the detectors **16**. However, those skilled in the art will appreciate that in practice, a gamma photon can yield multiple scintillation events. In some instances, before the event data is passed to the event verification processor **38**, the scintillation events of the event data are combined based on
10 gamma photon. For example, the energy of scintillation events belonging to a common gamma photon can be summed and the location with which the gamma photon struck the detectors **16** can be approximated. The event verification processor **38** then filters and determines LORs from the updated event data.

 Data describing the coincident events, as or once determined by the event
15 verification processor **38**, is stored within a list mode memory **40** as a list, where each list item corresponds to a coincident event. The data for each of the list items describes the corresponding LOR by the spatial data (e.g., by the X and Z locations) for the two pixels to which the pair of gamma photons of the LOR are localized. Further, the data for each of the list items can optionally describe the energy of the two gamma photons of the corresponding
20 coincident event, and/or either the times stamps of the two gamma photons or the difference between the times stamps of the two gamma photons.

 A pixel compensation processor **42** receives the list mode data, as it is being generated or once it's generated, and fills in missing event data for dead pixels by using event data from other pixels. A dead pixel is a pixel missing valid data. Dead pixels may arise due to
25 problems in one or more of scintillator performance, optical coupling between light sensitive elements **32** and scintillators **22**, light sensitive elements **32**, and processing electronics. Because PET scanners acquire three-dimensional (3D) data, a simple flood and/or uniformity correction cannot be performed at the detectors **16**, as is done in single-photon emission computed tomography (SPECT) and computed tomography (CT). PET requires the missing pixel pair to
30 be generated. Any approach can be employed to fill in data missing for dead pixels, but two approaches use first order approximation and sinogram space interpolation, respectively.

According to the first order approximation approach, the list mode data is directly used. As noted above, the list mode data contains a list item for each detected coincident event. Compensation for each dead pixel is performed by, for each list item corresponding to a neighboring pixel, determining whether the list item meets selection criteria and, if so, both
5 duplicating the list item and replacing the location of the neighboring pixel with the location of the dead pixel in the duplicate list item. A neighboring pixel is typically any pixel immediately adjacent to the dead pixel, but different criteria can be employed to define what a neighboring pixel is. For example, a neighboring pixel can be any pixel sharing a detector ring with the dead pixel, and/or being immediately adjacent to the dead pixel or within a predetermined number of
10 pixels (e.g., 2 pixels) of the dead pixel.

As noted above, a list item is processed only if selection criteria are met. No specific selection criteria need to be employed. In a simple case, all list items are selected. In more complicated cases, a list item is probabilistically selected. For example, each neighboring pixel is associated with a probability of an event being relevant to the dead pixel. The
15 probability can be based on the distance of the neighboring pixel to the dead pixel and/or whether the neighboring pixel is on the same detector ring as the dead pixel. For example, the probability can be lower the farther away the neighboring pixel is from the dead pixel and/or lower when the neighboring pixel is on a different detector ring as the dead pixel. When a list item corresponding to a neighboring pixel is encountered, a random number is determined. If
20 the probability of the determined random number is less than or equal to the probability of the neighboring pixel, the list item is selected.

According to the sinogram space interpolation approach, the list mode data is converted to sinograms, one for each slice. This conversion can alternatively be performed by another component of the system **10**, whereby the pixel compensation processor **42** receives
25 sinogram data instead of list mode data. Typically, the sinograms are generated from true, scatter and random coincident events (collectively referred to as prompt coincident events), but the sinograms can be generated from any combination of true, scatter and random coincident events. For example, the sinograms can be generated from true and random coincident events.

The sinogram space is sometimes referred to as the LOR space since each
30 position signifies the pair of pixels that measured a coincident event. While sinograms typically only provide the spatial connectivity data for pixels, sinograms can be extended to include time-

of-flight (ToF) data describing the ToF values for each coincident data. The ToF value for a coincident event is the difference in time measurements between the pair of pixels detecting the coincident event. To extend sinograms to include ToF data, each sinogram (corresponding to a slice) is divided into frames, one for each of a plurality of ToF bins. The ToF bins collectively span the range of possible ToF values for the scanner **12**, with each individual ToF bin spanning a sub-range corresponding to the ToF precision of the scanner **12**. For example, a typical scanner has a ToF precision of about 25 picoseconds (ps), whereby each of the ToF bins typically spans a 25 ps range. Further, a typical scanner has +/- 2.5 nanosecond (ns) range of ToF values, where a typical sinogram includes 201 frames.

Using the sinograms, values for each discrete location (i.e., positions) in the sinograms that are associated with dead pixels are interpolated (i.e., estimated) from neighboring positions. Where the sinograms include ToF data, a position is specific to a frame. As those skilled in the art will appreciate, a dead pixel manifests as a diagonal line of missing data in a sinogram. A neighboring position is typically any position immediately adjacent to the position being estimated, but different criteria can be employed to define what a neighboring position. Neighboring positions of a position being estimated can span across sinograms and/or, where ToF data is included, frames. Alternatively, neighboring positions of a position being estimated can be limited to the same sinogram or, where ToF data is included, the same frame.

Advantageously, by using sinograms, the interpolation can include data modeling to fit the known data and to estimate missing pixel data. The interpolation can be performed using any suitable interpolation technique. For example, the interpolation can be performed using the well-known nearest neighbor interpolation technique. As another example, more complicated techniques, such as the well-known bilinear interpolation technique or pattern matching techniques, can be employed. The bilinear interpolation technique performs a weighting of neighbor values, and pattern matching techniques examines the shape of the sine waves within the sinograms. Asymmetrical weighting may be performed for edge pixels of detectors that generally have lower collection efficiency due to Compton (i.e., scatter) events not being collected as efficiently as center pixels of detectors.

As should be appreciated, the sinogram space interpolation approach is much more computationally intensive than the first order approximation approach. Whereas the first order approximation approach can be performed while the list mode data is being generated, the

sinogram space interpolation approach can only be performed once the list mode data is generated. The sinogram space interpolation approach uses the final values for neighboring pixels to estimate the value for dead pixels.

Referring to FIGURE 4, a sinogram compensated for three dead pixels is provided. The sinogram was generated from the same data used to generate the sinogram of FIGURE 1. The data for the dead pixels was approximated using the sinogram space interpolation approach. As can be seen, through comparison with the sinogram of FIGURE 1, the compensated sinogram provides cleaner data for reconstruction that eliminates artifacts in the reconstructed image. Notably, the areas of missing data, demarcated by the arrows of FIGURE 1, have been filled with data.

Referring back to FIGURE 2, a PET reconstruction processor **44** reconstructs the corrected list mode data and/or sinogram data from the pixel compensation processor **42** into a final, reconstructed image of the target volume. The reconstructed image is typically stored in a PET image memory **46**. To generate the reconstructed image, any suitable reconstruction algorithm can be employed. For example, an iterative-based reconstruction algorithm can be employed.

A control system **48**, such as a computer, provides a graphical user interface (GUI) to users of the system. The GUI makes use of a display device **50** and a user input device **52** to allow the users to interact with the control system **48**. By way of the GUI, the control system **48** can be employed to control the scanner **12** to image a subject. For example, the user can coordinate a PET image of a target volume of the subject. Further, by way of the GUI, the control system **48** can be employed to view and, optionally, manipulate images stored in the image memory **46**. For example, an image of the image memory can be displayed on the display device **50**.

In some instances, one or more of the data buffer **36**, the event verification processor **38**, the list mode memory **40**, the pixel compensation processor **42**, the reconstruction processor **44**, and the image memory **46** are integrated with the control system **48**. For example, the reconstruction processor **44**, the pixel compensation processor **42**, and the event verification processor **38** can share a common processor of the control system **48**. In such instances, the reconstruction processor **44**, the pixel compensation processor **42**, and the event verification

processor **38** are typically implemented as software modules. The software modules are stored on a memory of the control system and executed by a processor of the control system.

With reference to FIGURE 5, a method **100** for compensating for dead pixels in a PET imaging is provided. The method **100** is suitably performed by one or more processors **42**,
5 **44**. In that regard, the method **100** is typically embodied by processor executable instructions stored on a memory and executed by the processors **42**, **44**.

According to the method **100**, PET data describing a target volume of a subject and generated by a PET scanner **12** is received **102**. The PET data is missing data for one or more pixels of the scanner **12**. These so called dead pixels may arise due to problems in one or
10 more of scintillator performance, optical coupling between light sensitive elements and scintillators, light sensitive elements, and processing electronics. Examples of the light sensitive elements include SiPMs and PMTs. Using the received PET data, PET data is estimated **104** for the dead pixels. In contrast with SPECT, PET data is three dimensional (3D). Hence, the process of estimating PET data is more involved than in SPECT.

In some instances, the received PET data is list mode data, each list item corresponding to a coincident event. In such instances, one approach to estimating the PET data for the dead pixel includes duplicating list items associated with neighboring pixels. The locations of the neighboring pixels in the duplicate PET data are then replaced with the location of the dead pixel. While all the list items associated with neighboring pixels can be employed,
20 the list items can also be intelligently selected. For example, list items associated with neighboring pixels can be probabilistically selected. In some instances, the received PET data is sinogram data, optionally including ToF data. In such instances, one approach to estimating the PET data for a dead pixel includes interpolating a value for each discrete location in the sinogram domain that is associated with the dead pixel from the values of neighboring locations.
25 For example, nearest neighbor interpolation can be performed.

Once data is estimated for the dead pixels, the combination of the received data and the estimated data is reconstructed **106** into an image representing the target volume. To generate the reconstructed image, any suitable reconstruction algorithm can be employed. For example, an iterative-based reconstruction algorithm can be employed.

30 As used herein, a memory includes any device or system storing data, such as a random access memory (RAM) or a read-only memory (ROM). Further, as used herein, a

processor includes any device or system processing input device to produce output data, such as a microprocessor, a microcontroller, a graphic processing unit (GPU), an application-specific integrated circuit (ASIC), an field-programmable gate array (FPGA), and the like; a controller includes any device or system controlling another device or system, and typically includes at
5 least one processor; a user input device includes any device, such as a mouse or keyboard, allowing a user of the user input device to provide input to another device or system; and a display device includes any device for displaying data, such as a liquid crystal display (LCD) or a light emitting diode (LED) display.

The invention has been described with reference to the preferred embodiments.

10 Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A system **(10)** for compensating for one or more dead pixels in positron emission tomography (PET) imaging, said system **(10)** comprising:
a pixel compensation processor **(42)** which:
receives PET data describing a target volume of a subject, the PET data missing data for one or more dead pixels; and
estimates PET data for the dead pixels from the received PET data.
2. The system **(10)** according to claim 1, wherein a pixel is the smallest area to which a scintillation event can be localized.
3. The system **(10)** according to either one of claims 1 and 2, wherein the pixel compensation processor **(42)** estimates the PET data for one of the dead pixels by:
duplicating PET data of a neighboring pixel; and
replacing a location of the neighboring pixel with a location of the dead pixel in the duplicate PET data.
4. The system **(10)** according to claim 3, wherein the received PET data is list mode data describing a coincident event at each list item, and wherein the duplicate PET data is a list item of the received PET data.
5. The system **(10)** according to any one of claims 1-4, wherein the pixel compensation processor **(42)** estimates the PET data for one of the dead pixels by:
probabilistically selecting subsets of PET data of pixels neighboring the dead pixel and included in the received PET data;
duplicating or weightedly combining the selected subsets of PET data; and
replacing locations of the neighboring pixels with a location of the dead pixel in the duplicate or weightedly combined PET data.

6. The system **(10)** according to any one of claims 1-5, wherein the received PET data is sinogram data, and wherein the pixel compensation processor **(42)** estimates the PET data for the dead pixels in the sinogram domain.

7. The system **(10)** according to claim 6, wherein the sinogram domain includes a dimension for time-of-flight (ToF).

8. The system **(10)** according to any one of claims 1-7, wherein the pixel compensation processor **(42)** estimates the PET data for one of the dead pixels by:

interpolating a value for each discrete location in the sinogram domain that is associated with the dead pixel from the values of neighboring locations.

9. The system **(10)** according to any one of claims 1-8, further including:
a reconstruction processor **(44)** which reconstructs the received PET data and the generated PET data into an image representation of the target volume.

10. A method **(100)** for compensating for one or more dead pixels in positron emission tomography (PET) imaging, said method **(100)** comprising:

receiving **(102)** PET data describing a target volume of a subject, the PET data missing data for one or more dead pixel; and

estimating **(104)** PET data for the dead pixels from the received PET data.

11. The method **(100)** according to claim 10, wherein a pixel is the smallest area to which a scintillation event can be localized.

12. The method **(100)** according to either one of claims 10 and 11, wherein the estimating **(104)** includes:

duplicating PET data of a neighboring pixel of one of the dead pixels; and

replacing a location of the neighboring pixel with a location of the dead pixel in the duplicate PET data.

13. The method **(100)** according to claim 12, wherein the received PET data is list mode data describing a coincident event at each list item, and wherein the duplicate PET data is a list item of the received PET data.

14. The method **(100)** according to any one of claims 10-13, wherein the estimating **(104)** includes:

probabilistically selecting subsets of PET data of pixels neighboring one of the dead pixels and included in the received PET data;

duplicating or weightedly combining the selected subsets of PET data; and

replacing locations of the neighboring pixels with a location of the dead pixel in the duplicate PET data.

15. The method **(100)** according to any one of claims 10-14, wherein the received PET data is sinogram data, and wherein the method **(100)** further includes:

estimating **(104)** the PET data for the dead pixels in the sinogram domain.

16. The method **(100)** according to claim 15, where the sinogram domain includes a dimension for time-of-flight (ToF).

17. The method **(100)** according to any one of claims 10-16, wherein the estimating **(104)** includes:

interpolating a value for each discrete location in the sinogram domain that is associated with the dead pixels from the values of neighboring locations.

18. The method **(100)** according to any one of claims 10-17, further including:

reconstructing **(106)** the received PET data and the generated PET data into an image representation of the target volume.

19. At least one processor **(42, 44)** programmed to perform the method **(100)** according to any one of claims 10-18.

20. A system **(10)** for compensating for one or more dead pixels in positron emission tomography (PET) imaging, said system **(10)** comprising:

a plurality of silicon photomultipliers (SiPMs) **(32)** which generate PET data describing a target volume of a subject;

a pixel compensation processor **(42)** which:

receives PET data describing a target volume of a subject from the SiPMs **(32)**, the PET data missing data for a dead pixel associated with a non-functioning SiPM **(32)**; and

generates PET data for the dead pixel from the received PET data.

1/3

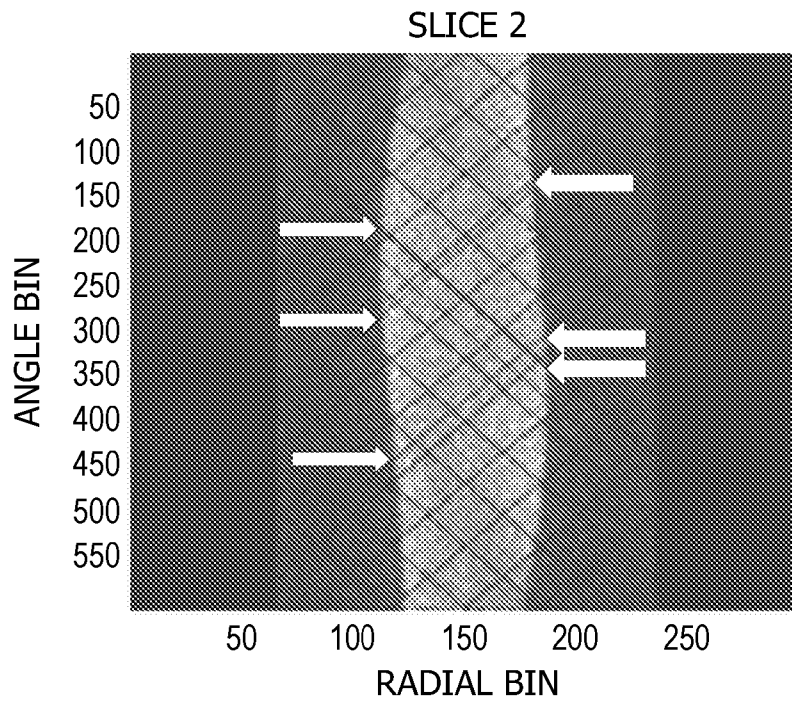


FIG. 1
(PRIOR ART)

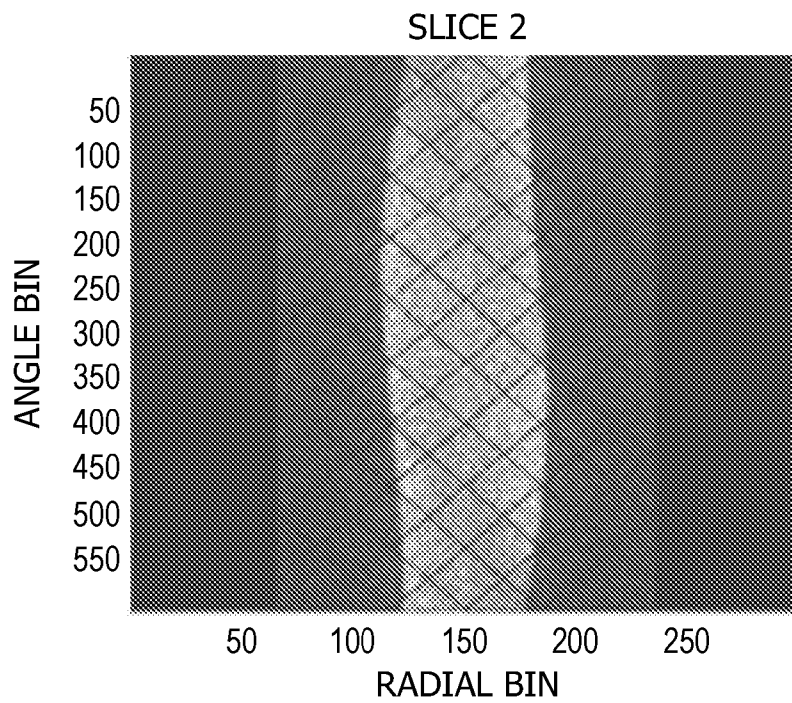


FIG. 4

2/3

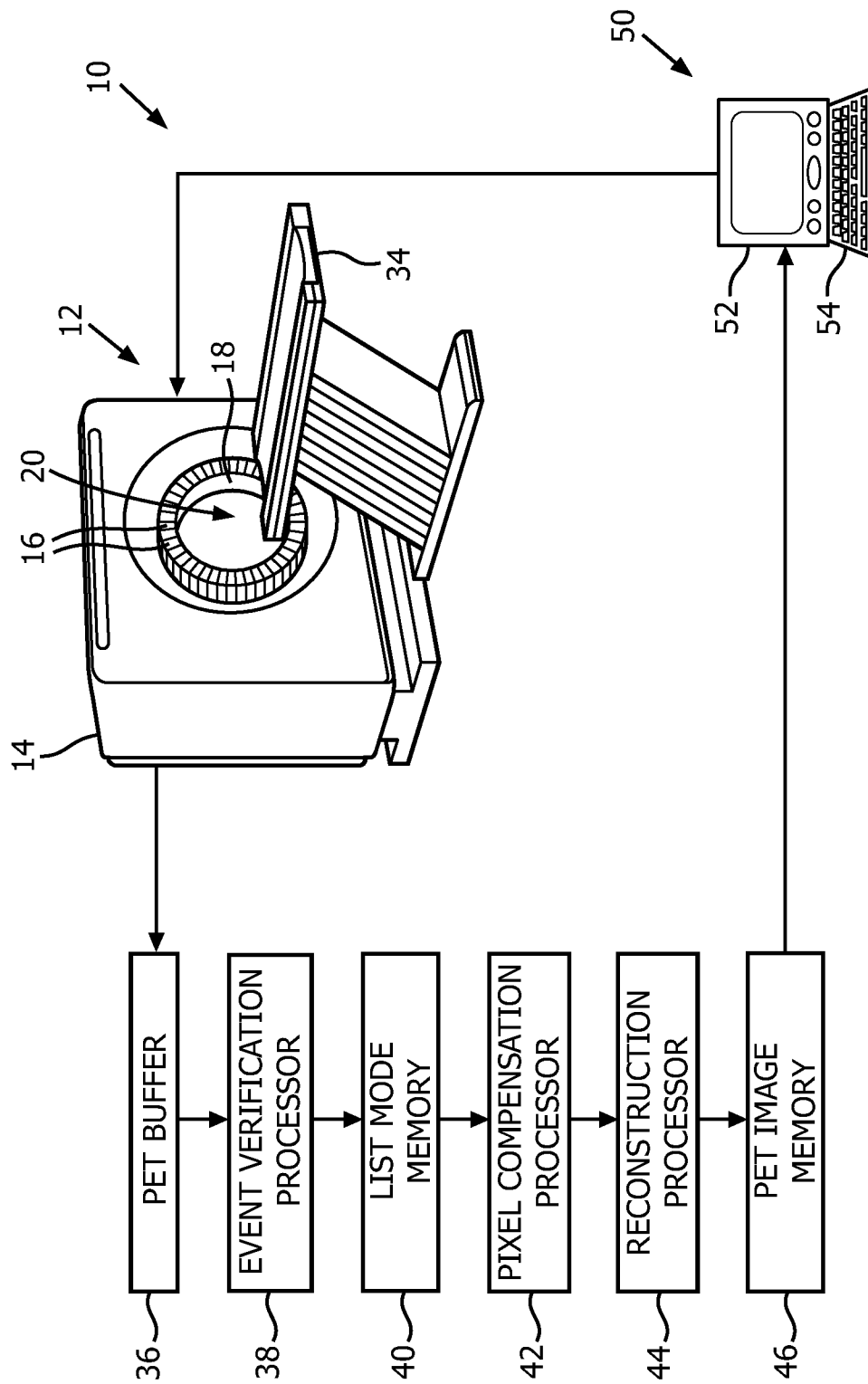


FIG. 2

3/3

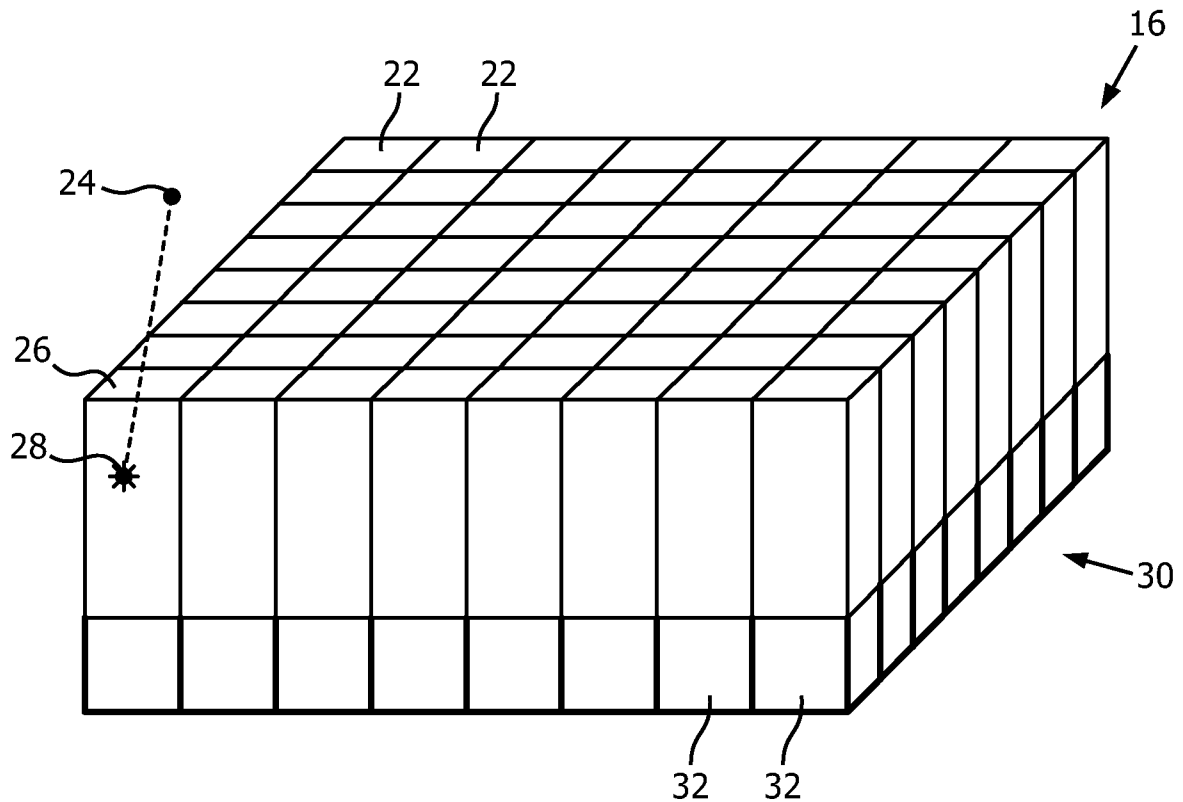


FIG. 3

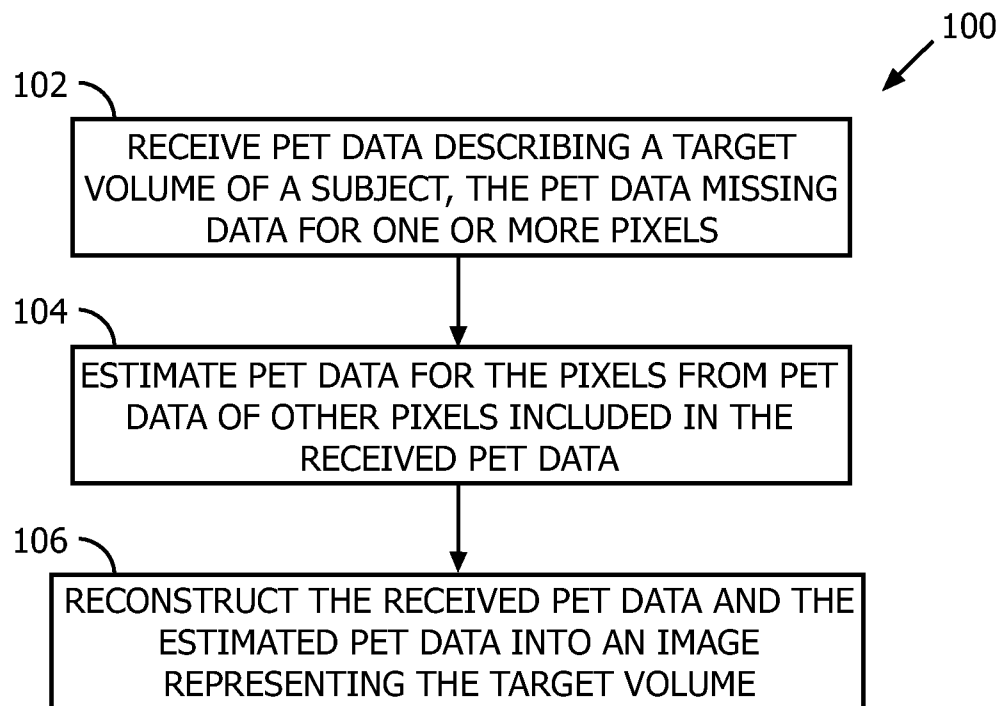


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/051925

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01T1/164 G01T1/29
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)

G01T G06T 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, BIOSIS, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/226032 A1 (LI BAOJUN [US] ET AL) 18 September 2008 (2008-09-18)	1,2,6, 8-11,15, 17-19
Y	figures 1, 2, 5-8 paragraphs [0010], [0018], [0025], [0032] - [0040], [0043], [0045] -----	3-5,7, 12-14, 16,20
X	US 2011/235940 A1 (PAVKOVICH JOHN [US]) 29 September 2011 (2011-09-29) figure 2 paragraphs [0043], [0045] -----	1,2, 8-11, 17-19
Y	WO 03/001243 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS MED SYST INC [US]) 3 January 2003 (2003-01-03) page 2, line 33 - line 34 ----- -/-	3-5, 12-14

☒ Further documents are listed in the continuation of Box C.

☒ 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

4 June 2015

Date of mailing of the international search report

16/06/2015

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Johnstone, John

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/051925

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/097175 A1 (GANIN ALEXANDER [US] ET AL) 11 May 2006 (2006-05-11)	7,16
A	paragraphs [0015], [0018] -----	4,13
Y	US 2012/068076 A1 (DAGHIGHIAN FARHAD [US]) 22 March 2012 (2012-03-22) figure 8a/b paragraph [0056] -----	20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2015/051925

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008226032 A1	18-09-2008	US 2008226032 A1	18-09-2008
		US 2011116700 A1	19-05-2011
-----		-----	
US 2011235940 A1	29-09-2011	US 2011235940 A1	29-09-2011
		WO 201119478 A2	29-09-2011
-----		-----	
WO 03001243 A2	03-01-2003	EP 1402286 A2	31-03-2004
		JP 4401166 B2	20-01-2010
		JP 2004532998 A	28-10-2004
		US 6694172 B1	17-02-2004
		WO 03001243 A2	03-01-2003
-----		-----	
US 2006097175 A1	11-05-2006	NONE	
-----		-----	
US 2012068076 A1	22-03-2012	NONE	
-----		-----	