



(51) International Patent Classification:

G01R 33/48 (2006.01) A61B 6/00 (2006.01)
A61B 6/03 (2006.01) A61B 5/055 (2006.01)

(21) International Application Number:

PCT/IB2013/050981

(22) International Filing Date:

6 February 2013 (06.02.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

61/596,778 9 February 2012 (09.02.2012) US

(71) Applicant (for all designated States except DE):

KONINKLIJKE PHILIPS N.V. [NL/NL]; High Tech
Campus 5, NL-5656 AE Eindhoven (NL).

(71) Applicant (for DE only): PHILIPS INTELLECTUAL

PROPERTY & STANDARDS GMBH [DE/DE];
Lübeckertordamm 5, 20099 Hamburg (DE).

(72) Inventors: WEISSLER, Bjoern; c/o High Tech Campus,

Building 44, NL-5656 AE Eindhoven (NL). ZINKE,
Manfred Bruno; c/o High Tech Campus, Building 44,
NL-5656 AE Eindhoven (NL).

(74) Agents: STEFFEN, Thomas et al.; High Tech Campus

Building 44, 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, IS, JP, KE, KG, KM, KN, KP,
KR, KZ, LA, LC, LK, LR, LS, LT, 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, 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, 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,
ML, MR, NE, SN, TD, TG).

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments (Rule 48.2(h))

(54) Title: DATA DETECTION DEVICE FOR USE IN COMBINATION WITH AN MRI APPARATUS

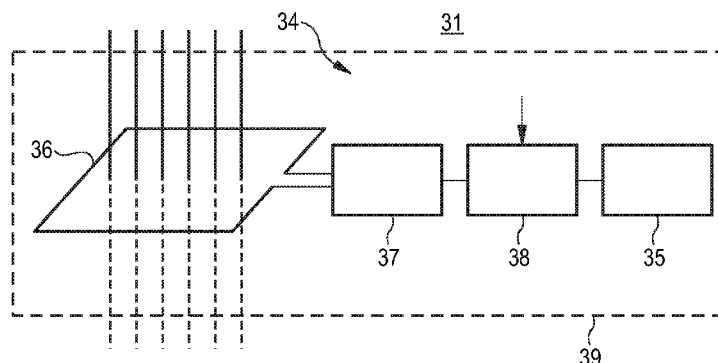


FIG. 2

(57) **Abstract:** The invention relates to a data detection device for use in combination with a magnetic resonance imaging (MRI) apparatus. A magnetic field detection unit (34) serves to detect a temporally varying magnetic field generated by the MRI apparatus, and a timestamping unit (35) generates magnetic field detection timestamps in dependence of the detected temporally varying magnetic field. This allows determining a temporal relation to acquired MRI data.

Data detection device for use in combination with an MRI apparatus

FIELD OF THE INVENTION

The invention relates to a data detection device for use in combination with a magnetic resonance imaging (MRI) apparatus as well as to a corresponding data detection method and data detection computer program. The invention relates further to an imaging apparatus as well as to a corresponding imaging method and imaging computer program.

BACKGROUND OF THE INVENTION

In recent years, there has been a trend towards the combination of different medical imaging modalities for improved diagnosis. For example, the integration of biochemical or metabolic imaging provided by positron emission tomography (PET) and anatomical imaging provided by computed tomography (CT) has proven itself as a standard clinical tool. However, the use of CT in combination with PET has its limitations, such as notable irradiation (X-ray) dose and reduced soft tissue contrast compared to magnetic resonance imaging (MRI). For this reason, MRI is now considered to be an improved alternative to CT. Moreover, the combination of PET and MRI has the potential to offer truly simultaneous acquisition of PET and MRI data. This allows for simultaneous dynamic studies of different parameters, such as diffusion and perfusion, to gain new diagnostic information. In addition, it also enables an enhanced PET image reconstruction, for example, by correcting the acquired PET data for the effects of patient movements, because global and local motion of a body can be tracked efficiently by means of MRI. However, in order to benefit from the combination of two different medical imaging modalities, such as PET and MRI, one must be able to temporally relate the acquired data to each other.

SUMMARY OF THE INVENTION

It is regarded as being an object of the present invention to provide a data detection device for use in combination with a magnetic resonance imaging (MRI) apparatus, which allows determining a temporal relation to acquired MRI data, as well as a corresponding data detection method and data detection computer program. It is regarded as

being a further object of the present invention to provide an imaging apparatus as well as a corresponding imaging method and imaging computer program.

In a first aspect of the present invention, a data detection device for use in combination with a magnetic resonance imaging (MRI) apparatus is presented, wherein the data detection device comprises:

- a magnetic field detection unit for detecting a temporally varying magnetic field generated by the MRI apparatus, and
- a timestamping unit for generating magnetic field detection timestamps in dependence of the detected temporally varying magnetic field.

As will be described in more detail with reference to the embodiments, magnetic resonance imaging (MRI) is based on the use of three kinds of magnetic fields with completely different frequencies: (i) a strong, uniform, static magnetic field B_0 ; (ii) switched magnetic field gradients of low frequencies (which typically vary in the kHz-range), and; (iii) a pulse RF magnetic field B_1 (with a typical frequency in the range of about 100 Mhz). The temporal variations of the two latter magnetic fields inherently provide information about the times at which the MRI apparatus acquires MRI data (in the following also called "MRI acquisition timing"). By detecting such a temporally varying magnetic field generated by the MRI apparatus and by generating magnetic field detection timestamps in dependence of the detected temporally varying magnetic field, the data detection device can therefore determine, in a relatively simple manner, and, in particular, without the need for a special, dedicated interface between the data detection device and the MRI apparatus, a temporal relation to the acquired MRI data.

It is preferred that the magnetic field detection unit comprises at least one coil for providing electric currents induced by temporal variations of the temporally varying magnetic field, and a signal providing unit for providing signals in dependence of the provided electric currents, wherein the timestamping unit is adapted to generate the magnetic field detection timestamps in dependence of the provided signals.

Using the principle of electromagnetic induction, the temporally varying magnetic field generated by the MRI apparatus can be easily and efficiently detected. This also requires only very few additional electronic components to be added to the data detection device, and, therefore, provides a comparably cheap solution. Moreover, because the data detection device and the MRI apparatus can be galvanically separated, such a solution is also particularly safe. In addition, since the provided electric currents are induced by temporal variations of the temporally varying magnetic field, and since the MRI

acquisition timing is manifested, in particular, in the temporal variations of the temporally varying magnetic field, the generated magnetic field detection timestamps can provide a meaningful temporal relation to the acquired MRI data.

In a preferred embodiment, the magnetic field detection unit further comprises
5 a signal comparison unit for comparing the provided signals to a specified signal threshold, wherein the timestamping unit is adapted to generate the magnetic field detection timestamps when the provided signals cross the specified signal threshold.

By comparing the provided signals, which depend on the provided electric currents induced by the temporal variations of the temporally varying magnetic field, to a
10 specified signal threshold, and by generating the magnetic field detection timestamps when the provided signals cross the specified signal threshold, the temporal variations of the temporally varying magnetic field can be easily determined.

It is preferred that the magnetic field detection unit is adapted to enable an adjustment of the sensitivity of detecting the temporally varying magnetic field.

As will be described in more detail with reference to the embodiments, the
15 temporally varying magnetic field generated by the MRI apparatus varies not only with time but may also vary with position in space. For a reliable detection, it is therefore preferred that the sensitivity of detecting the temporally varying magnetic field can be adapted to fit the respective circumstances, e.g., the position and/or orientation of the data detection device
20 relative to the temporally varying magnetic field. In a preferred embodiment, this may be realized by the signal comparison unit being adapted to enable an adjustment of the specified signal threshold.

It is also preferred that the data detection device further comprises a printed circuit board (PCB), wherein the at least one coil is made substantially from PCB traces or
25 comprises an air-core inductor.

In particular by making the at least one coil substantially from PCB traces on a printed circuit board, the at least one coil can be manufactured in a particularly cheap and simple manner.

It is preferred that the magnetic field detection unit comprises three coils that
30 are arranged to be perpendicular to each other.

By using information provided by the three perpendicularly arranged coils, the position and/or orientation of the data detection device relative to the temporally varying magnetic field may be determined.

It is also preferred that the temporally varying magnetic field to be detected is a switched magnetic field gradient generated by the MRI apparatus.

It is preferred that the data detection device further comprises a radio frequency shield for shielding the magnetic field detection unit from a pulse radio frequency (RF) magnetic field B_1 generated by the MRI apparatus.

This configuration ensures that the magnetic field detection unit is not influenced or disturbed by the pulse RF magnetic field B_1 .

It is further preferred that the timestamping unit is adapted to generate the magnetic field detection timestamps in accordance with a common time base that is also utilized for generating data timestamps for data detected by the data detection device.

It is preferred that the data detection device is a nuclear data detection device, in particular, a positron emission tomography (PET) data detection device or a single photon emission computed tomography (SPECT) data detection device.

In a further aspect of the present invention, an imaging apparatus is presented, wherein the imaging apparatus comprises:

- a magnetic resonance imaging (MRI) apparatus, and
- a data detection device as defined in claim 1.

In a further aspect of the present invention, a data detection method for use in combination with a magnetic resonance imaging (MRI) method is presented, wherein the data detection method comprises:

- detecting a temporally varying magnetic field generated by the MRI method, by a magnetic field detection unit, and
- generating magnetic field detection timestamps in dependence of the detected temporally varying magnetic field, by a timestamping unit.

In a further aspect of the present invention, an imaging method is presented, wherein the imaging method comprises:

- magnetic resonance imaging (MRI), and
- data detection as defined in claim 12.

In a further aspect of the present invention, a data detection computer program is presented, wherein the data detection computer program comprises program code means for causing a data detection device as defined in claim 1 to carry out the steps of the data detection method as defined in claim 12, when the data detection computer program is run on a computer controlling the data detection device.

In a further aspect of the present invention, an imaging computer program is presented, wherein the imaging computer program comprises program code means for causing an imaging apparatus as defined in claim 11 to carry out the steps of the imaging method as defined in claim 13, when the imaging computer program is run on a computer controlling the imaging apparatus.

It shall be understood that the data detection device of claim 1, the imaging apparatus of claim 11, the data detection method of claim 12, the imaging method of claim 13, the data detection computer program of claim 14, and the imaging computer program of claim 15 have similar and/or identical preferred embodiments, in particular, as defined in the dependent claims.

It shall be understood that a preferred embodiment of the invention can also be any combination of the dependent claims with the respective independent claim.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following drawings:

Fig. 1 shows schematically and exemplarily an embodiment of an imaging apparatus,

Fig. 2 shows schematically and exemplarily components of a PET data detection device,

Fig. 3 shows schematically and exemplarily a radio frequency shield housing the electronics of a PET data detection device,

Fig. 4 shows schematically and exemplarily a printed circuit board (PCB) comprised by a PET data detection device, and

Fig. 5 shows a flowchart exemplarily illustrating an embodiment of an imaging method.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows schematically and exemplarily an embodiment of an imaging apparatus 10 comprising a magnetic resonance imaging (MRI) apparatus 20 and a positron emission tomography (PET) apparatus 30. The imaging apparatus 10 is capable of acquiring both MRI data and PET data, for example, from spatial areas of an imaging region 11 that are at least partially overlapping or spatially adjacent.

The MRI apparatus 20 comprises a main magnet 21 that serves to generate a strong, uniform, static magnetic field B_0 through the imaging region 11 (along the z direction, by convention). The main magnet 21 may be an annular magnet or a bore-type magnet. Moreover, the main magnet 21 may be superconducting or resistive in nature; in the former case, it is typically disposed in a cryogenic devar or other cooling system (not shown). The MRI apparatus 20 also comprises magnetic field gradient coils 22 that serve to superimpose switched magnetic field gradients in the x, y, and z directions on the static magnetic field B_0 . In addition, the MRI apparatus 20 comprises a radio frequency excitation and reception system. The radio frequency excitation and reception system includes at least one component, such as an illustrated RF coil 23, that can be energized at a suitable radio frequency to generate a pulse RF magnetic field B_1 that excites magnetic resonance (MR) in an imaging subject 12, for example, a human patient, disposed on a table 13 in the imaging region 11. The RF coil 23 can also operate as an RF receiver to receive or detect the MR signals emanating from the imaging region 11 after RF excitation. In some embodiments, different coils are used for the excitation and reception operations. For example, the built-in RF coil 23 may be used to excite magnetic resonance and a different, local coil or dedicated receive coil (not shown) may be positioned over, on, or close to the imaging subject 12 in the imaging region 11 to detect magnetic resonance. It is possible that the MRI apparatus 20 is configurable in different ways using different combinations of built-in coils, local coils, or both.

In MRI, the nuclear spins of the tissue of the imaging subject 12 are aligned by the static magnetic field B_0 generated by the main magnet 21 and are excited by the pulse RF magnetic field B_1 generated, for example, by the RF coil 23. The resulting MR signals are exposed to the switched magnetic field gradients generated by the magnetic field gradient coils 22 to "spatially encode" the MR signals by creating a signature resonance frequency at each location in the imaging subject 12. The relative order and the specific temporal variations of the pulse RF magnetic field B_1 and of the switched magnetic field gradients are typically selectable according to need from a number of predefined "MR pulse sequences" that each show different effects on the characteristics of the resulting MRI images. The spatially encoded MR signals acquired, for example, by the RF coil 23 are temporarily stored in an MRI data storage unit (not shown) for later use, for example, in MRI image reconstruction. To this end, the MRI apparatus 20 comprises an MRI image reconstruction unit 24 that reconstructs the MRI data into a reconstructed MRI image using an image reconstruction algorithm that is suitably adapted to the spatial encoding used in acquiring the

MRI data. For example, a Fourier Transform reconstruction algorithm may be suitably used for reconstructing Cartesian encoded MRI data. The reconstructed MRI image is suitably displayed on a display unit 14, for example, by means of a suitable two- or three-dimensional rendering method, or may be otherwise processed.

5 The PET apparatus 30 comprises a number of positron emission tomography (PET) data detection devices 31 that encircle the imaging region 11. Here, twelve PET data detection devices 31, illustrated as densely shaded boxes, are positioned on a circle between the magnetic field gradient coils 22 and the RF coil 23. In some embodiments, the PET data detection devices 31 can also be positioned in corresponding recesses in the magnetic field
10 gradient coils 22 or they can be otherwise positioned in a most suitable manner.

 In PET imaging, a radiopharmaceutical is administered to the imaging subject 12, in which the radioactive decay events of the radiopharmaceutical produce positrons. Each positron interacts with an electron to produce a positron-electron annihilation event that emits two oppositely directed 511 keV gamma rays. The PET data detection devices 31 are adapted
15 to detect the 511 keV gamma rays that are emitted by the positron-electron annihilation events. Two substantially simultaneous 511 keV gamma ray detection events are thereby presumed to have originated from the same positron-electron annihilation event, which is located somewhere along a "line of response" (LOR) connecting the two substantially simultaneous 511 keV gamma ray detection events. This line of response is sometimes also
20 called a projection or a ray, and the acquired PET data are referred to as projection data.

 The constitution of the PET data detection devices 31 is not shown in detail in Fig. 1. However, in an embodiment, these devices may each include a pixelated array of scintillation crystals optically coupled to a light guide which propagates photons emitted by the scintillation crystals upon incidence of gamma rays to an array of sensor tiles. Each
25 sensor tile typically includes an array of silicon photomultipliers (SiPMs) which, in turn, each include an array of Geiger mode avalanche photodiodes (APDs). The sensor tiles are electronically connected to application specific integrated circuitry (ASICs) that is responsible for digitizing and pre-processing photon detection events. The circuitry may support functions such as pixel identification, timestamping, photon counting, digital biasing, digital triggering, readout, and other functions used in PET imaging with or without time-of-
30 flight or depth-of-interaction information (cf. below). The scintillator crystals are selected to provide high stopping power for the incident gamma radiation with a rapid temporal decay of the scintillation burst. Some suitable materials include LSO, LYSO, MLS, LGSO, LaBr, CsI(Tl), and mixtures thereof. However, it is noted that also other scintillator materials may

be used. The sensor tiles are selected to have high gain and stability and to be low cost and to require a low operating voltage. Suitable sensor tiles include both analog and digital SiPMs.

In conventional PET imaging, substantially simultaneous 511 keV gamma ray detection events are defined as two 511 keV gamma ray detection events occurring within a selected short time window, such as within four nanoseconds, of each other. This short time window takes into account that any positron-electron annihilation event that does not occur at the center of the imaging region 11 will result in a small difference in time of arrival, proportional to the travel times of the two emitted 511 keV gamma rays, at the opposing PET data detection devices 31. A related technique, called time-of-flight PET (TOF-PET) imaging, takes advantage of this small time difference to further localize the positron-electron annihilation event along the LOR with sub-nanosecond precision. Another related technique, called depth-of-interaction PET (DOI-PET) imaging, makes use of multi-layered PET data detector devices to be able to determine the depth of a scintillation event within a scintillation crystal.

The PET data detection devices 31 of the PET apparatus 30 are used to acquire PET data (in the following, the term "PET data" may also include TOF-PET data and/or DOI-PET data). A coincidence detection unit 32 employs temporal windowing to identify 511 keV gamma ray detection events that occurred substantially simultaneously, and, hence, are likely to correspond to the same positron-electron annihilation event, and, hence, define a projection line or line of response (LOR). For TOF processing, the small time difference between the identified substantially simultaneous 511 keV gamma ray detection events is used to spatially estimate the positron-electron annihilation event along the LOR. Likewise, for DOI processing, the necessary depth of interaction information is retrieved. A PET image reconstruction unit 33 then reconstructs the PET data into a reconstructed PET image using a suitable image reconstruction algorithm. For example, a maximum-likelihood expectation maximization (ML-EM) algorithm, a filtered backprojection (FB) algorithm, or an iterative image reconstruction algorithm other than ML-EM may be employed. The reconstructed PET image is suitably displayed on the display unit 14, for example, by means of a suitable two- or three-dimensional rendering method, or may be otherwise processed.

In the imaging apparatus 10 of this embodiment, the PET data detection devices 31 do not continuously encircle the imaging region 11. Such incomplete encirclement can lead to imaging artifacts due to "missing" projections or lines of response (LORs). For example, certain projections can be missed, such that information ordinarily provided by such projections about related positions is unavailable. Advantageously, if TOF-PET data are

acquired and reconstructed, then the time-of-flight localization provides additional information that can be used to compensate for lost information even in the presence of an incomplete encirclement. In addition, other ways of compensating for an incomplete encirclement are known to those skilled in the art in practicing the claimed invention. In other
5 embodiments, the imaging region 11 can also be continuously encircled by the PET data detection devices 31, for example, by providing a larger number of these devices, by making use of devices having a larger spatial extend, or by positioning the devices closer to the imaging region 11.

The acquisition of the MRI and PET data may be performed sequentially (e.g.,
10 MRI first, followed by PET, or vice versa) or may be interleaved. Preferentially, however, the MRI and PET data are acquired simultaneously. This allows for simultaneous dynamic studies of different parameters, such as diffusion and perfusion, to gain new diagnostic information. In addition, it also enables an enhanced PET image reconstruction, for example, by correcting the acquired PET data for the effects of movements of the imaging subject 12,
15 for example, a human patient, because global and local motion of a body can be tracked efficiently by means of MRI. However, in order to realize these benefits, one must be able to temporally relate the data acquired by the two different imaging modalities.

To this end, at least one of the PET data detection devices 31 comprises a magnetic field detection unit that serves to detect a temporally varying magnetic field that is
20 generated by the MRI apparatus 20, and a timestamping unit that generates magnetic field detection timestamps in dependence of the detected temporally varying magnetic field (cf. Fig. 2). Since the temporal variations of the switched magnetic field gradients and of the pulse RF magnetic field B_1 inherently provide information about the times at which the MRI apparatus 20 acquires MRI data (i.e., the "MRI acquisition timing"), it is possible for the PET
25 data detection device 31, by means of the above configuration, to determine, in a relatively simple manner, and, in particular, without the need for a special, dedicated interface between the PET data detection device 31 and the MRI apparatus 20, a temporal relation to the acquired MRI data.

A suitable magnetic field detection unit 34 and a timestamping unit 35 are
30 described in more detail with reference to Fig. 2, which shows schematically and exemplarily a PET data detection device 31 comprising *inter alia* these two components.

The magnetic field detection unit 34, in this embodiment, comprises a coil 36 that serves to provide electric currents that are induced by temporal variations of the temporally varying magnetic field. (The temporally varying magnetic field is illustrated by

the vertical lines that pass through the coil 36.) As described above, the temporally varying magnetic field that is to be detected by the magnetic field detection unit 34 can be the pulse RF magnetic field B_1 generated, for example, by the RF coil 23 of the MRI apparatus 20, or it can be a switched magnetic field gradient generated by the magnetic field gradient coils 22 of the MRI apparatus 20. Here, the later option is realized and the PET data detection device 31 further comprises a radio frequency shield 39 that serves to shield the magnetic field detection unit 34 from the pulse RF magnetic field B_1 generated by the MRI apparatus 20 (for example, by the RF coil 23). In this embodiment, the radio frequency shield 39 is made from a material with suitable RF shielding characteristics, such as copper or carbon, and also houses the electronics of the PET data detection device 31, as is shown schematically and exemplarily in Fig. 3. This configuration ensures, on the one hand, that the PET electronics, including the magnetic field detection unit 34, are not influenced or disturbed by the pulse RF magnetic field B_1 and, on the other hand, that electronic noise from the PET electronics also does not influence or disturb the electronics of the MRI apparatus 20. While the radio frequency shield 39 is substantially impenetrable for the high frequencies of the pulse RF magnetic field B_1 (which typically are in the range of about 100 MHz), the switched magnetic field gradients (which typically vary in the kHz-range) penetrate the radio frequency shield 39 due to their lower frequencies and, because their frequencies are not too low, induce electric currents in the PET electronics. (By way of comparison, the static magnetic field B_0 also penetrates the radio frequency shield 39, but, because of its temporally uniform nature, does not induce electric currents in the PET electronics.)

The electric currents that are induced by the switched magnetic field gradients in the PET electronics are normally regarded as a problem in combined PET/MRI imaging apparatuses and various measures, such as shortening transmission lines as much as possible or utilizing twisted differential pair lines, are typically performed to reduce and/or compensate their influence on the acquisition and processing of the PET data. On the other hand, by providing a coil 36 in a magnetic field detection unit 34 – as described above –, the electric currents that are induced in the coil 36 by a switched magnetic field gradient can also be used advantageously as a basis for generating the magnetic field detection timestamps. To this end, the magnetic field detection unit 34 comprises a signal providing unit 37 that serves to provide signals in dependence of the provided electric currents, wherein the timestamping unit 35 is adapted to generate the magnetic field detection timestamps in dependence of the provided signals. In this embodiment, the magnetic field detection unit 34 further comprises a signal comparison unit 38 that serves to compare the provided signals to a specified signal

threshold, and the timestamping unit 35 is adapted to generate the magnetic field detection timestamps when the provided signals cross the specified signal threshold. It is noted that the term "cross" as used herein is intended to be interpreted broadly, wherein its meaning depends on the characteristic of the provided signals, i.e., on the relationship between the induced electric currents resulting from the temporal variations of the temporally varying magnetic field and the provided signals. For example, if a default "base" signal is provided by the signal providing unit 37 in the case where no induced electric currents are provided by the coil 36 and if the induced electric currents result in a reduction of the provided default "base" signal, the meaning of the term "cross" also includes the case that the provided signals fall below a specified signal threshold that is smaller than the default "base" signal.

The magnetic field detection unit 34 may be realized, for example, by utilizing suitable analog and/or digital comparator electronics. In one realization, the signal providing unit 37 provides as the signals electric voltages that depend on the induced electric currents provided by the coil 36. The electric voltages may be derived from an electric supply voltage that is "modulated" with an electric voltage resulting from a voltage drop across a resistor upon a flow of electric current in the coil 36. The electric voltages are then provided to the signal comparison unit 38, which may comprise, for example, a dedicated comparator or an operational amplifier (op-amp) used as a comparator or the like, where they are compared with a specified signal threshold, in this case, a specified electric voltage. If an electric voltage provided by the signal providing unit 37 (i.e., a signal) is larger than the specified electric voltage (i.e., the specified signal threshold), a digital pulse is generated to indicate that a temporal variation of a switched magnetic field gradient was identified and the timestamping unit 35 generates a magnetic field detection timestamp. It should be noted that other realizations of the signal providing unit 37 and/or of the signal comparison unit 38 are also possible and may be utilized by a person skilled in the art in practicing the claimed invention. For example, the signal providing unit 37 may provide as the signals electric currents or other suitable parameters and the signal processing may be either analog or digital or may be based on a combination thereof.

The switched magnetic field gradients generated by the magnetic field gradient coils 22 of the MRI apparatus 20 do not only vary with time but also vary with position in space. Moreover, respective MR pulse sequences may differ in a number of parameters, such as the maximum strength and/or the switching slope (i.e., the change of strength per time interval) of the switched magnetic field gradients. For a reliable detection, it is therefore preferred that the sensitivity of detecting the temporally varying magnetic field,

here, a switched magnetic field gradient, can be adjusted to fit the respective circumstances. In this embodiment, this is realized by the signal comparison unit 38 being adapted to enable an adjustment of the specified signal threshold (illustrated by the arrow in Fig. 2), i.e., the specified signal threshold may be suitably increased or decreased. Since the law of induction states that induction is proportional to the rate of change of a magnetic field through the area of a coil, the electric currents that are induced by a switched magnetic field gradient in the coil 36 depend both on the position and/or orientation of the PET data detection device 31, in particular, of the coil 36, relative to the switched magnetic field gradient and on the parameters of the respective MR pulse sequence. By adjusting the specified signal threshold according to need, the combined effect of these different parameters can be suitably taken into account.

Preferably, the specified signal threshold will be adjusted such that the magnetic field detection unit 34 will not falsely react on noise or any other unwanted signal. A value just above the noise level will allow detection of as much temporal variations of a switched magnetic field gradient as possible. In one embodiment, a PET data detection device 31 comprising a magnetic field detection unit 34 may be positioned within the MRI apparatus 20 in a region where the switched magnetic field gradient in the x direction (denoted " G_x " by convention) is particularly strong, and the magnetic field detection unit 34 may be adjusted to "trigger" on temporal variations of the switched magnetic field gradient G_x . In another embodiment, an additional or an alternative PET data detection device 31 comprising a magnetic field detection unit 34 may be positioned within the MRI apparatus 20 in a region where the switched magnetic field gradient in the y direction (denoted " G_y " by convention) is particularly strong, and the magnetic field detection unit 34 may be adjusted to "trigger" on temporal variations of the switched magnetic field gradient G_y . Of course, other embodiments are also conceivable. For example, in the imaging system 10 shown in Fig. 1, the twelve PET data detection devices 31 may each comprise a magnetic field detection unit 34 and the respective detection results may be logically combined in a most suitable manner in order to increase detection reliability. Moreover, a magnetic field detection unit 34 may be adapted to only "trigger" on certain temporal variations of a switched magnetic field gradient, e.g., only on the respective build-up of the switched magnetic field gradient.

The coil 36 can be realized in the magnetic field detection unit 34 by different means. For example, the PET data detection device 31 of this embodiment comprises a printed circuit board (PCB) 40, as is shown schematically and exemplarily in Fig. 4. On the PCB, different components of the PET electronics are realized. In this embodiment, two coils

36 that are substantially made from PCB traces 41 are provided, but a coil 36 can also comprise an air-core inductor that can, for example, be soldered to the PCB. A first coil 36, shown on the right side of the figure at the margin of the PCB, extends on both the front- and the backside of the PCB, thereby providing a loop that is suitably oriented for detecting the switched magnetic field gradients generated by the MRI apparatus 20 when the PET data detection device 31 is positioned within the imaging system 10 as shown in Fig. 1. (The switched magnetic field gradients are generally aligned with the static magnetic field B_0 , i.e., they extend in the z direction.) A second coil 36, shown on the frontside of the PCB, is arranged to be (substantially) perpendicular to the first coil 36 and may be used to detect "stray" components of the switched magnetic field gradients perpendicular to the static magnetic field B_0 . Such "stray" components are usually unwanted, but may occur in the MRI apparatus 20 because a magnetic field gradient system can never be 100% ideal. If a third coil 36 (not shown) is arranged to be (substantially) perpendicular to both the first and second coil 36 and if this third coil 36 is also used to detect such "stray" components, the information provided by the three (substantially) perpendicularly arranged coils 36 can be used to determine the positioning and/or the orientation of the PET data detection device relative to the switched magnetic field gradients – provided that sufficient knowledge about the characteristics of the "stray" components generated by the MRI apparatus 20 is available, e.g. from earlier measurements.

The timestamping unit 35 is adapted to generate the magnetic field detection timestamps in accordance with a common time base that is also utilized for generating data timestamps for data detected by the PET data detection device 31. In this embodiment, the twelve PET data detection devices 31 shown in Fig. 1 each comprise an interface for receiving timing information from a common system clock of the PET apparatus 30 (not shown) to facilitate consistent timestamping of 511 keV gamma ray detection events (i.e., to consistently generate data timestamps for detected PET data) in the twelve PET data detection devices 31. The timestamping unit 35 makes use of the same timing information from the common system clock to generate the magnetic field detection timestamps. Here, the generated magnetic field detection timestamps are stored with other PET "metadata", such as device temperatures, et cetera.

As described above, the magnetic field detection timestamps generated by the magnetic field detection unit provide a temporal relation to the acquired MRI data that enables an enhanced PET image reconstruction. For example, if the PET acquisition is started earlier than the MRI acquisition (which usually is the case because of the longer time

required for acquiring PET data), the generated magnetic field detection timestamps provide the necessary information for determining when the MRI acquisition was started relative to the PET acquisition. Moreover, it is possible to temporally relate individual reconstructed MRI images to acquired PET data.

5 In the following, an imaging method will be described with reference to a flowchart shown in Fig. 5.

In step 101, magnetic resonance imaging (MRI) is performed. In addition, data detection, in this embodiment, PET data detection is performed, wherein, in step 102, a temporally varying magnetic field generated by the MRI method is detected, and wherein, in
10 step 103, magnetic field detection timestamps are generated in dependence of the detected temporally varying magnetic field. Here, the temporally varying magnetic field is detected by a magnetic field detection unit 34 and the magnetic field detection timestamps are generated by a timestamping unit 35. An embodiment of such components is shown, schematically and exemplarily, in Fig. 2.

15 Steps 102 and 103 can be regarded as being steps of a data detection method for use in combination with a magnetic resonance imaging (MRI) method.

In the embodiments described above, the data detection device for use in combination with a magnetic resonance imaging (MRI) apparatus is a positron emission tomography (PET) data detection device, but it can also be another type of nuclear data
20 detection device, such as a single photon emission computed tomography (SPECT) data detection device, or it can be, for example, an ultrasound data detection device, or any other data detection device that may suitably be used in combination with an MRI apparatus and that can benefit from the ability to determine a temporal relation to acquired MRI data. In particular, the data detection device can also be a device that is provided for medical
25 purposes other than imaging, for example, it can be a device for detecting one or more vital parameters of a patient.

The magnetic field detection unit can, in some embodiments, also utilize a Hall effect sensor or a comparable device to detect a temporally varying magnetic field generated by a magnetic resonance imaging (MRI) apparatus. Other embodiments can even
30 be based on utilizing the orientation of elements that align themselves along the lines of a magnetic field or on similar, compass-type effects.

It is possible that the magnetic field detection unit is adjusted, for example, by a suitable adjustment of the specified signal threshold(s), such that it only detects particularly strong temporal variations of the temporally varying magnetic field, which may appear in a

respective MR pulse sequence only at specific temporal positions. This may minimize the amount of redundant data to be processed. It is also thinkable that such particularly strong temporal variations of the temporally varying magnetic field (which may not be used by the MRI imaging process) are explicitly incorporated in an MR pulse sequence, e.g., at any one time before an MRI image is taken, or before a navigator is measured, for the purpose of detection by the magnetic field detection unit.

It is also conceivable that in the magnetic field detection unit, a coil or another component that is sensitive to a temporally varying magnetic field is orientably positioned. This may allow to orient the coil or other component in the most suitable manner, e.g., in such a way that it is most sensitive to the temporally varying magnetic field, depending on the position and/or orientation of the data detection device relative to the temporally varying magnetic field. For example, the coil or other component may be installed on a joint or pivot that allows a change in orientation in at least one dimension, preferentially, in all three dimensions.

As described above, it is possible that the temporally varying magnetic field to be detected by the magnetic field detection unit is the pulse RF magnetic field B_1 . In the case where the data detection device is a PET data detection device or another device with comparable sensitive electronics, the electronics may nonetheless be housed in a radio frequency shield made from a material with suitable RF shielding characteristics, such as copper or carbon, but the magnetic field detection unit, resp., if applicable, at least the coil or other component that is sensitive to the pulse RF magnetic field B_1 may be provided outside the radio frequency shield.

In some embodiments, the magnetic field detection unit can comprise, for example, at least three substantially parallel oriented coils that are arranged in a triangle extending in each of the x, y, and z directions. By making use of knowledge about the spatially varying nature of the switched magnetic field gradients generated by the MRI apparatus, e.g., by knowing their maximum strength and their switching slope, it is therewith possible to determine, from the induced electric currents provided by the at least three substantially parallel oriented coils, the position and/or the orientation of the data detection device.

In the embodiments described above, the temporally varying magnetic field to be detected by the magnetic field detection unit is a switched magnetic field gradient and the electronics of the PET data detection device are housed in a radio frequency shield made from a material with suitable RF shielding characteristics, such as copper or carbon. If such

an RF shielding is not utilized, it is possible to reduce and/or compensate the influence of the pulse RF magnetic field B_1 on the detection of the switched magnetic field gradient by means of suitable filter techniques.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

A single unit or device may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Operations like the detecting of a temporally varying magnetic field, the generating of magnetic field detection timestamps, et cetera performed by one or several units or devices can be performed by any number of units or devices. For example, steps like the providing of electric currents induced by temporal variations of the temporally varying magnetic field and the providing of signals in dependence of the provided electric currents can be performed by a single unit, by two different units, or by any other number of different units. These operations and/or the control of the data detection device in accordance with the data detection method and/or the control of the imaging apparatus in accordance with the imaging method can be implemented as program code means of a computer program and/or as dedicated hardware.

A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium, supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A data detection device (31) for use in combination with a magnetic resonance imaging (MRI) apparatus (20), the data detection device (31) comprising:

- a magnetic field detection unit (34) for detecting a temporally varying magnetic field generated by the MRI apparatus (20), and

5 - a timestamping unit (35) for generating magnetic field detection timestamps in dependence of the detected temporally varying magnetic field.

2. The data detection device (31) as defined in claim 1, wherein the magnetic field detection unit (34) comprises:

10 - at least one coil (36) for providing electric currents induced by temporal variations of the temporally varying magnetic field, and

- a signal providing unit (37) for providing signals in dependence of the provided electric currents,

15 wherein the timestamping unit (35) is adapted to generate the magnetic field detection timestamps in dependence of the provided signals.

3. The data detection device (31) as defined in claim 2, wherein the magnetic field detection unit (34) further comprises:

20 - a signal comparison unit (38) for comparing the provided signals to a specified signal threshold,

wherein the timestamping unit (35) is adapted to generate the magnetic field detection timestamps when the provided signals cross the specified signal threshold.

4. The data detection device (31) as defined in claim 1, wherein the magnetic field detection unit (34) is adapted to enable an adjustment of the sensitivity of detecting the temporally varying magnetic field.

25

5. The data detection device (31) as defined in claim 1, further comprising a printed circuit board (PCB) (40), wherein the at least one coil (36) is made substantially from PCB traces (41) or comprises an air-core inductor.

6. The data detection device (31) as defined in claim 1, wherein the magnetic field detection unit (34) comprises three coils (36) that are arranged to be perpendicular to each other.

7. The data detection device (31) as defined in claim 1, wherein the temporally varying magnetic field to be detected is a switched magnetic field gradient generated by the MRI apparatus (20).

8. The data detection device (31) as defined in claim 1, further comprising a radio frequency shield (39) for shielding the magnetic field detection unit (34) from a pulse radio frequency (RF) magnetic field B_1 generated by the MRI apparatus (20).

9. The data detection device (31) as defined in claim 1, wherein the timestamping unit (35) is adapted to generate the magnetic field detection timestamps in accordance with a common time base that is also utilized for generating data timestamps for data detected by the data detection device (31).

10. The data detection device (31) as defined in claim 1, the data detection device (30) being a nuclear data detection device, in particular, a positron emission tomography (PET) data detection device or a single photon emission computed tomography (SPECT) data detection device.

11. An imaging apparatus (10), comprising:
- a magnetic resonance imaging (MRI) apparatus (20), and
- a data detection device (31) as defined in claim 1.

12. A data detection method for use in combination with a magnetic resonance imaging (MRI) method, the data detection method comprising:
- detecting a temporally varying magnetic field generated by the MRI method, by a magnetic field detection unit (34),

- generating magnetic field detection timestamps in dependence of the detected temporally varying magnetic field, by a timestamping unit (35).

13. An imaging method, comprising:

- 5 - magnetic resonance imaging (MRI), and
- data detection as defined in claim 12.

14. A data detection computer program comprising program code means for causing a data detection device as defined in claim 1 to carry out the steps of the data

10 detection method as defined in claim 12, when the data detection computer program is run on a computer controlling the data detection device.

15. An imaging computer program comprising program code means for causing an imaging apparatus as defined in claim 11 to carry out the steps of the imaging method as

15 defined in claim 13, when the imaging computer program is run on a computer controlling the imaging apparatus.

1/5

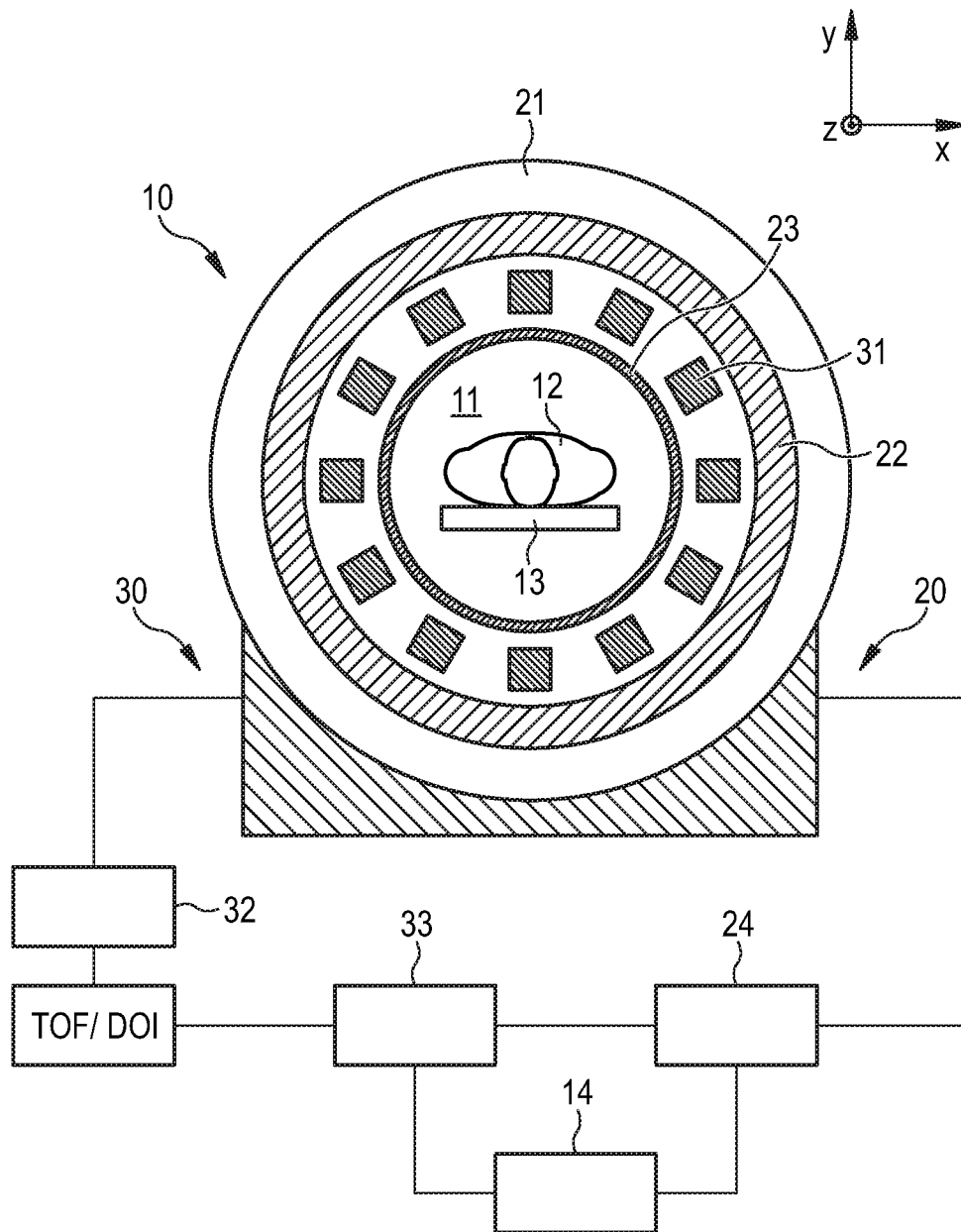


FIG. 1

2/5

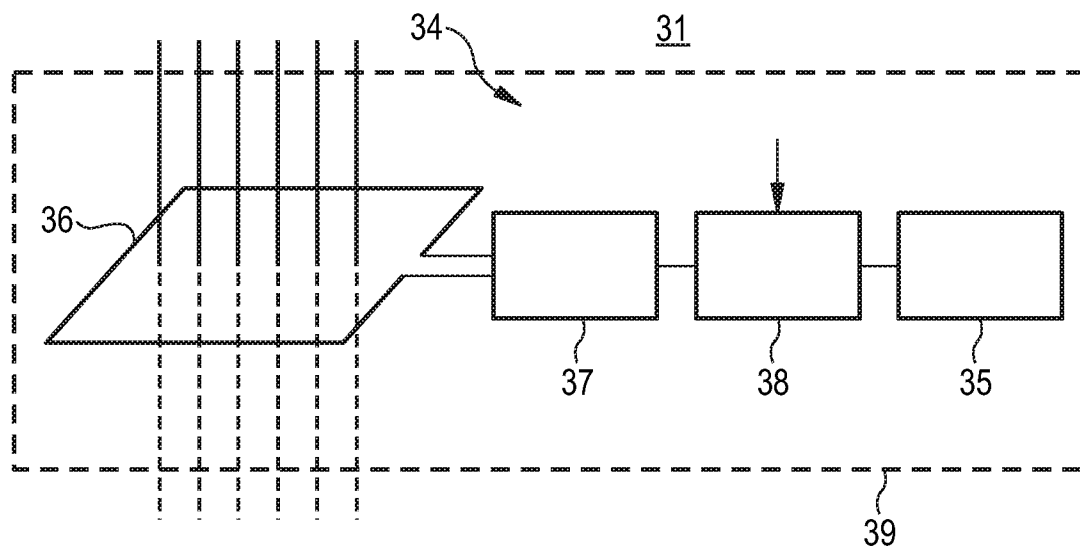


FIG. 2

3/5

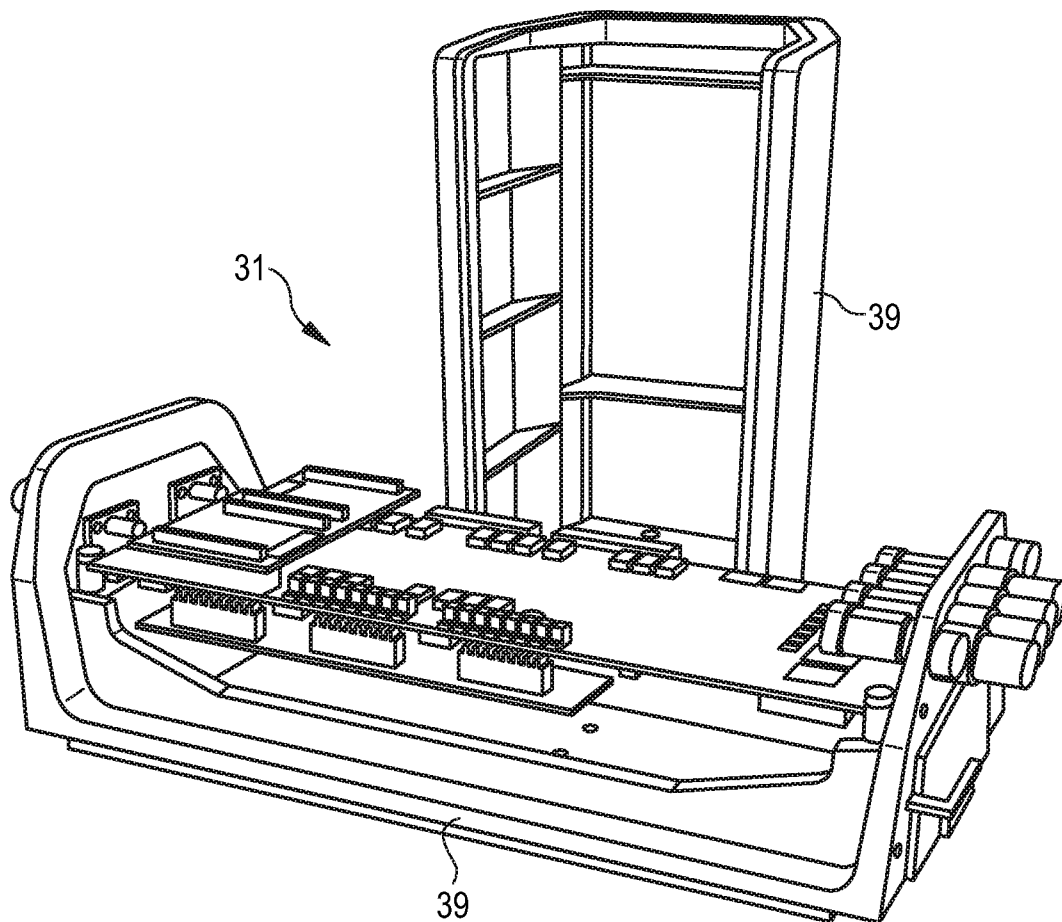


FIG. 3

4/5

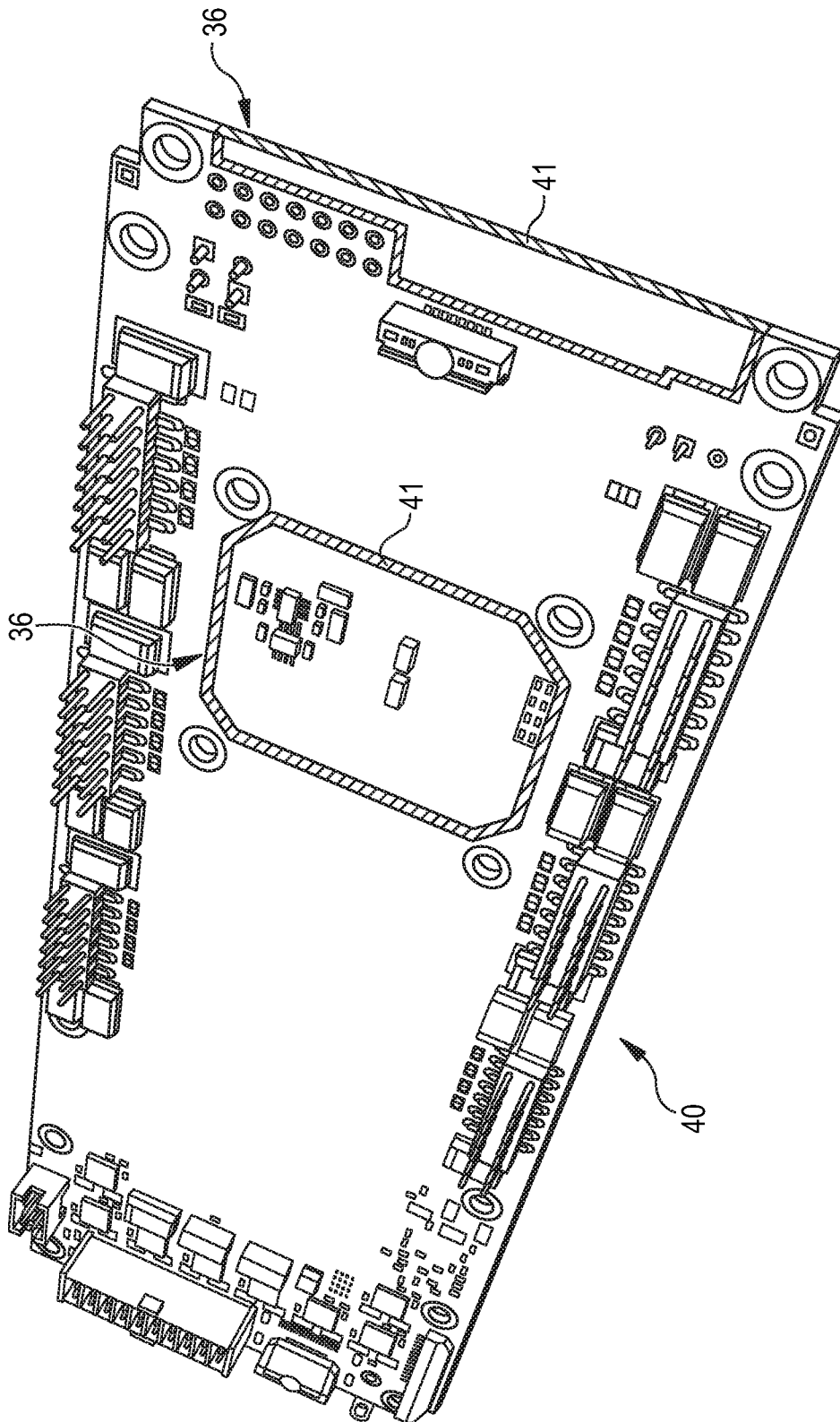


FIG. 4

5/5

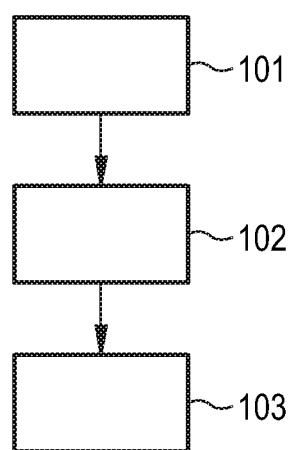


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/050981

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01R33/48 A61B6/03 A61B6/00 A61B5/055
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)

G01R 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)

EP0-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 2011/257509 A1 (OLSEN JAMES M [US] ET AL) 20 October 2011 (2011-10-20)	1-9, 11-15
Y	paragraphs [0030] - [0033] paragraphs [0088] - [0096] paragraphs [0111] - [0112] paragraphs [0122] - [0124] claims	10
Y	----- WO 2006/111869 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS CORP [US]; FIEDLER KLAUS) 26 October 2006 (2006-10-26) page 10, line 26 - page 1, line 20 abstract figures ----- -/--	10



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

29 May 2013

Date of mailing of the international search report

07/06/2013

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

Bataille, Frédéric

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/050981

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 2011/092802 A1 (STECKNER MICHAEL [US]) 21 April 2011 (2011-04-21) paragraphs [0035] - [0044] -----	1-15
A	WO 02/082112 A1 (US GOV HEALTH & HUMAN SERV [US]; BOWMAN JOSEPH D [US]) 17 October 2002 (2002-10-17) page 5, line 29 - page 6, line 5 figures -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2013/050981

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011257509	A1	20-10-2011	NONE
-----	-----	-----	-----
WO 2006111869	A2	26-10-2006	AT 534045 T 15-12-2011
		CN 101163989 A	16-04-2008
		EP 1875273 A2	09-01-2008
		JP 2008536600 A	11-09-2008
		RU 2384866 C2	20-03-2010
		US 2008284428 A1	20-11-2008
		WO 2006111869 A2	26-10-2006
-----	-----	-----	-----
US 2011092802	A1	21-04-2011	NONE
-----	-----	-----	-----
WO 02082112	A1	17-10-2002	US 2004068174 A1 08-04-2004
		WO 02082112 A1	17-10-2002
-----	-----	-----	-----