PET-MRI HYBRID APPARATUS AND METHOD OF IMPLEMENTING THE SAME

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ABSTRACT
There is provided a PET-MRI hybrid apparatus and method for integrating a PET image and an MRI image so that anatomical, hemodynamic and molecular information on human tissues are simultaneously presented in a single image. The PET-MRI hybrid system comprises a first scanner for obtaining anatomical and hemodynamic information, and a second scanner for obtaining molecular and functional information on the human tissues. Along a path between the first scanner and the second scanner, a transferring railway system which includes a bed for supporting a subject installed on the railway. The PET-MRI hybrid system also comprises a "RF+magnetic" shield and a "magnetic" shield between paths between the first scanner and the second scanner, which switch between an open status and a close status in a completely synchronized manner to assure a complete magnetic shield for the PET system at any given time. The subject is fastened to the bed and transferred along the railway between the first and second scanner to provide accurately fused MRI and PET images.
FIG. 1
(PRIOR ART)
FIG. 3

1. SHIELDING FOR TAKING AN MRI IMAGE
2. OBTAINING DATA FOR AN MRI IMAGE
3. MOVING FOR TAKING A PET/CT IMAGE
4. OBTAINING DATA FOR A PET/CT IMAGE
5. RETURNING
6. FUSING AN MRI IMAGE AND A PET/CT IMAGE
FIG. 4

PROCESSOR

CONTROLLER
FIG. 5A
FIG. 6

- Shielding for taking an MRI image (620)
- Obtaining data for an UHF-MRI image (630)
- Performing synchronous shielding control for taking a PET image (640)
- Obtaining data for a HRRT-PET image (650)
- Fusing an UHF-MRI image and a HRRT-PET image (660)
FIG. 7

UHF MRI ---+--- HRRT PET
FIG. 8

[Diagram showing a processor and various numbered components 800, 870, 810, 820, 822, 840, 850, 860, 880, 890]
FIG. 9

1. Shielding for taking a micro-MRI image
2. Obtaining data for a micro-MRI image
3. Moving for taking a micro-PET image
4. Obtaining data for a micro-PET image
5. Fusing a micro-MRI image and a micro-PET image
PET-MRI HYBRID APPARATUS AND
METHOD OF IMPLEMENTING THE SAME

RELATED APPLICATION

[0001] This application is a continuation of U.S. patent
application Ser. No. 11/027,599 filed Dec. 28, 2004, which is
hereby fully incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention generally relates to an appara-
tratus and method for non-invasively obtaining an image fea-
turing information on internal human tissues, and more par-
ticularly to an apparatus and method for integrating position-
emission tomography (PET) and magnetic resonance im-
ing (MRI) to provide a single high spatial resolution image
which features anatomical information, as well as molecular
and functional information on the internal human tissues.

BACKGROUND OF THE INVENTION

[0003] PET was first developed in 1975 by two different
groups of scientists. The first group is comprised of Dr. Zang-
Hee Cho, et al. at University of California at Los Angeles
(UCLA), while the second group is comprised of Dr. M.
Ter-Pogossian and Dr. M. Phelps, et al. at Washington Uni-
versity, St. Louis, Mo. Since then, PET has been further
developed and innovated by several different commercial
companies, including CPS-CTI. PET has been the only
machine capable of performing molecular and functional
imaging both on the body and the brain until 1992 (Although
fMRI appeared in 1992, it was limited to the brain and the
hemodynamics).

[0004] MRI, on the other hand, has been developed in 1973
by Dr. P. Lauterbur. It is somewhat similar to CT or PET, but
is different in terms of physical principle. Over 10,000 MRI
units are now in use at various hospitals throughout the world.
MRI is essentially a morphological or anatomical imaging
tool rather than functional, and thus lacks molecular specific-
ity. However, MRI has much higher temporal and anatomical
resolutions than PET. In 1992, a functional imaging capabil-
ity has been incorporated into MRI by Dr. S. Ogawa, hence
resulting in the creation of fMRI. By incorporating the use of
such additional capability, fMRI became one of the most
powerful brain imaging tools in the field of neuroscience.

[0005] When the fMRI was first introduced into the world,
it was so impressive in brain imaging that the entire neuro-
science community embraced this new device with great
enthusiasm. The fMRI had indeed changed the landscape of
neuroscience research. This excitement was short lived, how-
ever, as the demands for molecular specificity arose, which
essentially renewed the interest in PET. As is well known in
the art, PET has two major functional capabilities, namely,
the functional capabilities for measuring metabolism of cer-
tain substrates such as glucose and ganciclovir and affinity/
distributions of specific neuro-receptors for a certain ligand
(i.e., molecular specificity and sensitivity). Theses capabili-
ties are generally lacking in fMRI or MRI.

[0006] As explained above, PET and MRI are characterized
by their own advantages and disadvantages. More specifi-
cally, PET is capable of providing molecular and functional
information on human tissues with exceptionally high con-
trast. However, PET is limited in providing accurate anatom-
ical information since it has inherently lower spatial resolu-
tion. Contrary to PET, however, MRI is capable of providing
detailed anatomical information on human tissues, but cannot
provide molecular and functional information.

[0007] Due to the foregoing pros and cons of PET and MRI,
there have been many attempts in the art to integrate them
together. However, none of the prior attempts achieved any
practical success. For example, FIG. 1 shows a prior attempt
for integrating conventional MRI (using 1.5-3.0 T magnetic
field) and PET (or PET/CT (Computer Tomography)). More
specifically, a conventional system 100 is comprised of an
MRI device 120 and a PET/CT device 130. As is well known
in the art, the MRI device 120 measures atomic, chemical
and physical aspects of a given tissue by using magnetic prop-
erties of subject materials that are present in the human body.
As shown in FIG. 1, the MRI device 120 manipulates the
measurements in order to produce an MRI image 122, which
include anatomical information on human tissues. As is fur-
ther well known in the art, the PET/CT device 130 detects gamma
rays (i.e., the 511 kev annihilation photons), which are used to
produce a PET image 132 representing molecular and func-
tional information on human tissues. The gamma rays origi-
nate from a biological sample that is marked by a positron-
emitting radionuclide, such as F18, and are introduced into
the human body. When a positron is emitted from the radio-
uclide and encounters an electron in the body, a pair of gamma rays is generated.

[0008] In such conventional system, the MRI device 120
and the PET/CT device 130 are totally separated from each
other. They are placed distantly apart from each other and
located in different spaces. The reason why the MRI device
120 and the PET/CT device 130 cannot be placed in close
proximity of each other is due to the strong magnetic field
generated by the MRI device 120, which can damage the
PET/CT device 130. In particular, a photomultiplier used
in the PET/CT device 130 is very sensitive to even a small
external magnetic field. Therefore, the PET/CT device 130
cannot normally operate when the MRI device 120 is located
in close proximity thereto.

[0009] In the conventional system, a patient has to be fre-
quently transported in and out. This is because the patient has
to be moved from one place, which is installed with the MRI
device 120, to a different place where the PET/CT device 130
is located. A PET imaging is usually taken after an MRI
imaging. However, an MRI imaging may precede a PET
imaging. Therefore, even if the MRI and PET images are
obtained, it is very difficult to combine them with a precision
that is needed in image fusion. This is due to the physical
separation between the MRI device 120 and the PET/CT
device 130, especially when the desired resolution is high.
Thus, there is a difficulty in combining a molecular image
from the PET device 130 with an anatomical image from the
MRI device 120, with an arrangement as shown, that is, when
they are separated.

[0010] In addition, because the two images (i.e., one from
MRI and the other from PET) are taken at different places
different environments or conditions) and times (metabolic
changes will occur between them), it is highly possible that
the conditions between such times and places may change
and thus inconsistency is likely to be introduced. In other
words, it is generally not suitable to combine an anatomical
image from the MRI device 120 (or an oxygen consumption
or hemodynamic image from fMRI) with a molecular image
from the PET/CT device 130 in a conventional setting, espe-
sically in brain imaging due to the fine details of the brain
structures.
Accordingly, there is a need for a system capable of providing a medical image that is truly integrated and contains both the anatomical information and molecular information within a time frame that is suitable for brain's functional changes or dynamics.

SUMMARY OF THE INVENTION

Therefore, the primary object of the present invention is to provide a PET-MRI hybrid apparatus (i.e., a PET and MRI integrated system) and a method of implementing the same so that molecular and anatomical information on human tissues can be simultaneously obtained in a single image (Hardware part).

Another object of the present invention is to provide a set of software for performing mathematical and computer techniques to integrate an MRI image and a PET image in order to provide a high spatial resolution molecular image.

In accordance with an embodiment of the present invention, the present invention is directed to an apparatus for providing anatomical information, as well as molecular and functional information, of a subject. Such apparatus comprises: a first scanner for obtaining said hemodynamical and anatomical information; a second scanner for obtaining said molecular and functional information; and an RF shield capable of switching between an open status and a close status, and for further sheltering a predetermined space including said first scanner from external RF fields in said close status. A transferring railway is provided which runs along a path from said first scanner via said RF shield to said second scanner. A bed is also provided to move and support said subject along said transferring railway.

In accordance with another embodiment of the present invention, there is provided an imaging apparatus for providing anatomical information, as well as molecular and functional information, of a subject. The apparatus comprises: a first scanner for obtaining said anatomical information, as well as functional information on said subject; a second scanner for obtaining said molecular and functional information; a RF+magnetic shield for sheltering a space including said first scanner from external RF fields, and for further preventing magnetic fields of said first scanner from leaking outside; a magnetic shield for sheltering a space including said second scanner from said magnetic fields out of said first scanner; a transferring railway running along a line from said first scanner via said RF+magnetic shield and said magnetic shield to said second scanner; and a bed movable along said transferring railway and for supporting said subject.

In accordance with still another embodiment of the present invention, there is provided a method of providing anatomical information, as well as molecular and functional information, of a subject. Such method comprises the steps of: transferring said subject to a space where said anatomical information is obtained, sheltering from external RF fields said space where said anatomical information is obtained; obtaining said anatomical information; transferring said subject to a second space where said molecular and functional information can be obtained; sheltering from external magnetic fields said second space where said molecular and functional information is obtained; and obtaining said molecular and functional information, in a totally synchronized manner so that at an any given time, said second space is not exposed to magnetic fields from said first space.

BRIEF DESCRIPTION OF THE DRAWINGS

The above object and features of the present invention will become more apparent from the following description of the preferred embodiments given in conjunction with the accompanying drawings.

FIG. 1 shows a schematic diagram illustrating a conventional system in the art.

FIG. 2 shows a schematic diagram of a first embodiment of a low field MRI+PET/CT hybrid system in accordance with the present invention.

FIG. 3 is a flowchart illustrating the operation of a first embodiment of a low field MRI+PET/CT hybrid system in accordance with the present invention.

FIG. 4 shows a schematic diagram of a second embodiment of an ultra high field (UHF) MRI+High Resolution Research Tomography (HRRT) PET hybrid system in accordance with the present invention.

FIG. 5A shows a simplified structure of a HRRT PET scanner used in a second embodiment of a UHF MRI+HRRT PET hybrid system in accordance with the present invention.

FIG. 5B shows an UHF-MRI entrance sketch in a second embodiment of a UHF MRI+HRRT PET hybrid system in accordance with the present invention.

FIG. 6 is a flowchart illustrating the operation of a second embodiment of a UHF MRI+HRRT PET hybrid system in accordance with the present invention.

FIG. 7 shows a fusion image that the present invention generates.

FIG. 8 shows a schematic diagram of a third embodiment of a micro MRI+micro PET hybrid system in accordance with the present invention.

FIG. 9 is a flowchart illustrating the operation of a third embodiment of a micro MRI+micro PET hybrid system in accordance with the present invention.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

1. An Embodiment of the Low Field MRI+PET/CT Hybrid System

In FIG. 2, there is provided an embodiment of the low field MRI+PET/CT hybrid system. In the embodiment of FIG. 2, a system generally comprises an MRI scanner 210, a radio field (RF) shield 220, a PET/CT scanner 240, a patient bed 250, a transferring railway 260, and an imaging processor 270.

As is well known in the art, the MRI scanner 210 provides anatomical and structural information as well as functional imaging on human tissues by using magnetic fields of 1.5-3.0 T. The MRI scanner 210 is self-shielded so as to prevent the magnetic fields from leaking out of the scanner when in use.
The RF shield 220 protects the MRI block 202 from being adversely affected by external RF field. In the MRI block 202, electrical stimuli are applied to nuclei in the human tissues in order to place the nuclei in an excitation status. When the nuclei in the excitation status return to deexcitation status, they emit high frequency RF signals. The MRI scanner 210 receives the RF signals emitted from the nuclei by an RF coil to reconstruct anatomical information on the human tissues. The RF signals, which are generated when the nuclei change from excitation to de-excitation, are overlapped in a frequency range with those used in an ordinary radiobroadcast or communication system. Unless the MRI block 202 is sheltered from that of the external RF signals, the MRI block 202 cannot tell RF signals from the human tissues from that of the external RF signals, and thus fails to correctly obtain anatomical information. Therefore, the RF shield 220 shelters the MRI block 202 from the external RF signals to avoid such a problem.

The PET/CT scanner 240 is able to obtain data about internal human tissues using X-rays together with positron-emitting radionuclide. Thus, both anatomical and molecular imaging can be obtained. It should be noted herein that the PET/CT scanner 240 was recently developed.

The patient bed 250 supports and moves a patient back and forth between the MRI scanner 210 and the PET/CT scanner 240. The patient bed 250 also locates a patient to a RF coil of the MRI scanner 210.

The transferring railway 260 extends between the MRI scanner 210 and the PET/CT scanner 240. The railway 260 is required to maintain a prescribed relationship between image-taking origins for the MRI scanner 210 and the PET/CT scanner 240 when the patient is transferred along the railway between the scanners. However, it is important that the railway 260 performs the above task comfortably with minimal positional and psychological disturbances.

The imaging processor 270 performs the necessary algorithms for generating both the MRI and PET images, such as the Fourier transformation and three-dimensional reconstruction. The algorithms can be also directed to other mathematical transformations such as geometrical error calibration and correction in combining MRI and PET images.

FIG. 3 illustrates a method performed in the first embodiment in accordance with the present invention. In step 320, the method of the first embodiment starts by shielding the MRI block 202 when taking an MRI image. In this step, a patient is fixed on the patient bed 250. Then, the patient bed 250 moves along the transferring railway 260 toward the MRI scanner 210. When the patient bed 250 reaches a predetermined distance prior to the RF shield 220, a shutter 222 equipped thereon starts to open. After the patient’s feet pass through the shutter 222, the shutter 222 then closes. The patient bed 250 continues to move toward the MRI scanner 210 until the patient’s head becomes located inside the RF coil.

In step 330, the MRI scanner 210 applies RF fields and gradients to the patient’s head, from where the anatomical information is obtained, and emits RF pulse signals. Generally, each of nuclei, of which human tissues are composed, has its own Larmor frequency when it is placed in a given magnetic field. Thus, the patient’s tissues, where the RF pulse signals are applied, emit magnetic resonance (MR) signals corresponding to the Larmor frequency. The MR signals are collected by the RF coil of the MRI scanner 210 and are transmitted to the imaging processor 270. The imaging processor 270 performs a signal processing, such as the Fourier transformation, on the MR signals to generate an MRI image 280. The method for collecting and processing the MR signals for the MRI image will not be explained herein in detail since such method does not have a direct relationship with the invention.

In step 340, the patient bed 250 moves along the transferring railway 260 toward the PET/CT scanner 240 in order to take a PET/CT image. As explained above, when the patient bed 250 reaches a predetermined distance prior to the RF shield 220, a shutter 222 equipped thereon starts to open. After the patient bed 250 goes through the shutter 222, it closes.

In step 350, the patient bed 250 arrives within the PET/CT scanner 240. The PET/CT scanner 240 starts to detect gamma rays (annihilation photons) from the same patient’s parts as the MRI scanner 210 examined.

The gamma rays are originated from a biological probe that is a substrate, such as glucose marked by a positron-emitting radionuclide and is introduced via an intravenous injection into a human body. More specifically, the radionuclide decays by emitting a positron and neutron, and the emitted positron collides with an electron in the human tissues. The collision causes an annihilation of the positron and electron to generate a pair of gamma rays. In the annihilation process, a pair of gamma (annihilation photons) rays is generated in 180 degree opposite directions since the momentum must be conserved. Due to this property of the annihilation, detectors of the PET/CT scanner 240 are arranged to form a circle such that a pair of detectors in the opposite direction simultaneously receives a set of gamma rays, 511 kev photons. This reception means that there was a collision of a positron and an electron somewhere along the line extending between the two receiving detectors, which is called a coincidence line. A plurality of coincidence lines is obtained in the PET/CT scanner 240 to form a tomographic image, through mathematical reconstruction at a process 270.

The PET/CT scanner 240 transmits the coincidence data to the imaging processor 270. Then sufficient number of coincidence lines is obtained, the imaging processor 270 performs signal processing such as filtered backprojection and correction of gamma ray attenuation for the final image reconstruction of a PET image 242. The method for processing the coincidence data for PET images will not be explained herein in detail since such method does not have a direct relationship with the invention.

Next, in step 352, the patient bed 250 moves backward along the transferring railway 260 to the mid point between the MRI scanner 210 and PET/CT scanner 240. The patient is withdrawn at this position when the patient bed 250 stops at the middle of the MRI scanner 210, and the PET/CT scanner 240.

In step 360, the imaging processor 270 generates two images (i.e., the MRI image 280 and the PET image 242) and fuses together and obtains a fused image of anatomical MRI image 210 and the PET/CT image 240. In order to fuse the MRI and PET images as correctly as possible, the transferring railway 260 is rigidly and accurately maintained to meet the desired geometrical and mechanical accuracy. To further assist fusion accuracy, a laser-guided calibrating device is also equipped in both the MRI scanner 210 and the PET/CT scanner 240. Finally, the imaging processor 270 produces a fusion image on a display apparatus (not shown), thereby providing a medical image that contains anatomical,
hemodynamical, molecular and functional information, which are truly synchronized in terms of time and space.

2. An Embodiment of the Brain Dedicated UHF-MRI+HRRT-PET Hybrid System

FIG. 4 shows another embodiment of the brain dedicated UHF-MRI+HRRT-PET hybrid system. As illustrated in FIG. 4, a system 400 comprises a brain dedicated MRI scanner 410, a RF+magnetic shield 420 for MRI, a magnetic shield 430 for HRRT-PET, a HRRT-PET scanner 440, a patient bed 450, a transferring railway 460, a controller 480 for synchronously controlling the RF+magnetic shield 420 and a magnetic shield 430, and an imaging processor 470.

The UHF-MRI scanner 410 provides anatomical, structural as well as functional information on a brain by using ultra-high magnetic fields over 7.0 T. Using the ultra-high magnetic field, the UHF-MRI scanner 410 can construct a medical image showing even cortical laminae of a brain. However, the unusually high magnetic fields of the UHF-MRI scanner 410 may influence even at a longer distance. Thus, a specialized shield is required to completely shield the magnetic fields (e.g., stray fields), especially when a device vulnerable to the magnetic fields, such as the PET scanner, is placed in close proximity.

In this embodiment, the RF+magnetic shield 420 for MRI prevents the high magnetic field of the UHF-MRI scanner 410 from leaking outside. In addition, the magnetic shield 430 further protects PET scanner (HRRT-PET) 440 against the stray magnetic fields of the UHF-MRI scanner 410. In the present embodiment, these two shields 420 and 430 are synchronously controlled to completely shield the magnetic field of the UHF-MRI scanner 410 by the controller 480. With these double magnetic field shields, the HRRT-PET scanner 440, which is extremely sensitive to a magnetic field, can safely be placed sufficiently close to the UHF-MRI scanner 410.

In the present embodiment, in addition to preventing the magnetic fields of the UHF-MRI scanner 410 from leaking, the RF+magnetic shield 420 also stops external RF fields from being introduced to the UHF-MRI scanner 410. With respect to stopping RF fields, the RF+magnetic shield 420 also comprises a high frequency RF shield 426.

As illustrated in FIG. 5A, the recently developed HRRT-PET scanner 440 has a total of 59,904×2 detectors and 1,290 EMJs. More specifically, the HRRT-PET scanner 440 includes 8 batches of detectors 510-580, wherein each batch is comprised of 9×13 blocks 512. In FIG. 5B, an entrance sketch of UHF-MRI (7.0 T) is shown. In this illustration, an element 590 is a head-only RF coil for maximizing of head imaging. Further in the illustration, an element 591 is a gradient (w) designed for a brain, while an element 592 is the magnet (7.0 T).

The patient bed 460 supports and moves a patient back and forth between the UHF-MRI scanner 410 and the HRRT-PET scanner 440. It can locate a patient to a RF coil of the UHF-MRI scanner 410, like the bed 250 of the first embodiment.

The transferring railway 460 runs between the UHF-MRI scanner 410 and the HRRT-PET scanner 440. It can locate a patient to a RF coil of the UHF-MRI scanner 410, like the bed 250 of the first embodiment.

The transferring railway 460 further comprises a rotary table 462 to rotate a patient by 180 degrees, which is installed between the RF+magnetic shield 420 and the magnetic shield 430. After being out of the UHF-MRI scanner 410, the rotary table 462 makes it easy for a patient’s head to enter the HRRT-PET scanner 440, whose bore is too small to pass a patient’s trunk.

The imaging processor 470 performs the necessary algorithms for generating both the MRI and PET images, such as the Fourier transformation and three-dimensional reconstruction. The algorithms can also be directed to other mathematical transformation and geometrical error correction in combining the MRI and PET image.

The controller 480 controls the RF+magnetic shield 420 and the magnetic shield 430 in a synchronous manner such that the above-described high magnetic fields of the UHF-MRI scanner 410 do not reach the HRRT-PET scanner 440 at any given time. In more detail, the controller 480 controls movements of the patient bed 450 along the railway 460, and opening and closing of the RF+magnetic shield 420 and the magnetic shield 430 based on the position of the patient bed 450 to absolutely prevent the magnetic fields of the UHF-MRI scanner 410 from leaking outside and reaching to the HRRT-PET scanner 440.

FIG. 6 illustrates a method performed in the second embodiment in accordance with the present invention.

In step 620, a patient is fixed on the patient bed 450. The patient bed 450 moves in a manner as to direct the head first along the railway 460 to transfer toward the UHF-MRI scanner 410. When the patient is moving, the RF+magnetic shield 420 should be opened and the magnetic shield 430 should be closed. After the patient’s feet pass through the shutter, the shutter then closes. The patient bed 450 continues to move toward the UHF-MRI scanner 410 until the patient’s head is located inside an RF coil 414 of the UHF-MRI scanner 410.

In step 630, the UHF-MRI scanner 410 applies RF fields and gradients. The patient emits RF signals, which belong to the patient’s head inserted within the RF coil 414. In general, the higher the magnetic fields are, the more larger and reliable information can be obtained. Thus, compared with the conventional MRI scanner, the UHF-MRI scanner 410 of 7.0 T can provide a resolution much higher than the conventional system and provides even an image of cortical laminae of a brain. RF signals are emitted from the patient’s brain tissues responsive to the RF pulses, and are collected by the RF coil 414 of the MRI scanner 410. They are then transmitted to the imaging processor 470. The imaging processor 470 performs a signal processing such as the Fourier transformation on the received signals to generate an MRI image 420. The method for processing the received RF signals for MRI images will not be explained herein in detail since such method does not have a direct relationship with the invention.

In step 640, the patient bed 450 starts moving along the transferring railway 460 from the UHF-MRI scanner 410 toward the RF+magnetic shield 420 after all UHF-MRI image data collecting procedures for generating an MRI image are finished. When the patient’s feet fixed on the patient bed 450 reaches a predetermined distance prior to the RF+magnetic shield 420, a shutter 422 equipped thereon begins to open. After the patient’s head on the patient bed 450 goes through and completely out of the RF+magnetic shield 420, the shutter 422 closes. Then, the patient bed 450 is placed somewhere on the transferring railway 460 between the RF+magnetic shield 420 and the magnetic shield 430.
At this point, it should be noted that the HRRT-PET scanner 440 can be adversely influenced by the magnetic fields leaked via the shutter 422 from the UHF-MRI scanner 410. Thus, it is important that the RF+ magnetic shield 420 and the magnetic shield 430 are controlled in a synchronous way such that both shields should never be in an open status at the same time at any given time. In other words, since the UHF-MRI scanner 410 utilizes high magnetic fields over 7.0 T, the shutter 422 (RF+ magnetic shield also) equipped on the RF+ magnetic shield 420 must be closed after the patient bed 450 is out of the RF+ magnetic shield 420. Before the patient bed 450 reaches a predetermined distance from the shutter 432 (magnetic shield) equipped on the magnetic shield 430 starts to open.

Design is made so that before the patient bed 450 approaches the magnetic shield 430, the patient is rotated 180 degrees by the rotary table 462 to make it easy for the patient’s head to enter the HRRT-PET scanner 440, whose bore is for the head only and therefore is small. Once the patient is rotated, the patient’s head is placed toward the HRRT-PET scanner gantry 440 and moves toward the magnetic shield 430. When the patient bed 450 reaches a predetermined distance prior to the magnetic shield 430, the shutter 432 equipped thereon starts to open. After the patient bed 450 goes through the shutter 432, the shutter closes again to prevent the magnetically sensitive HRRT-PET scanner 440 from being influenced by the magnetic fields from the UHF-MRI. As described above, when the shutter 432 equipped on the magnetic shield 430 is in an open status, the shutter 422 equipped on the RF+ magnetic shield 420 must be in a close status.

Next, in step 650 of the present embodiments, the patient bed 450 arrives within the HRRT-PET scanner 440 to take an HRRT-PET image. The HRRT-PET scanner 440 detects gamma rays from the same areas of patient as the UHF-MRI scanner 410 examined. Compared to the conventional scanner, the HRRT-PET scanner 440 has much large number of detectors, therefore the more efficient in detecting gamma rays from the subject. In addition, the bore of the HRRT-PET scanner 440 is small to improve the detection efficiency. With these characteristics, the HRRT-PET scanner 440 can generate a PET image 490, whose spatial resolution and efficiency are much more superior than the existing PET scanners.

The HRRT-PET scanner 440 collects data from the patient and transmits them to the imaging processor 470. The method for processing the data for constructing PET images will not be explained herein in detail since such method does not have a direct relationship with the invention.

After the HRRT-PET scanner 440 obtains data sufficiently enough to construct a PET image, the patient bed 450 moves along the transferring railway 460 back to a point between the RF+ magnetic shield 420 and the magnetic shield 430 in order to conduct another examination.

In step 660, the imaging processor 470 fuses data obtained from the UHF-MRI scanner 410 and the HRRT-PET scanner 440 to construct a medical image wherein anatomical information and molecular information are synchronized in time and space. To further improve the image fusion, a laser-guided calibrating device is additionally used in both the UHF-MRI scanner 410 and the HRRT-PET scanner 440. FIG. 7 shows an example of a medical image wherein MRI and PET images are fused in accordance with the embodiment of the present invention.

The present embodiment of the invention provides a medical image wherein an UHF-MRI and HRRT-PET image data are fused to provide information (i.e., the identity of a molecular function of a specific human tissue) by accurately matching anatomical information with molecular information. As explained above, the present embodiment generates a medical image wherein anatomical, hemodynamical and molecular information are fused synchronously in terms of time and space. Therefore, all parameters of a neuroscience, which are necessary for medical treatment, cognitive science, emotion, learning and memory, and intelligence, among others, can be quantitatively measured by the present embodiment with a precision compatible to that of the 7.0 T MRI image resolution. This achievement of the embodiment has been not possible by prior arts.

An Embodiment of the Micro PET+Micro MRI Hybrid System

Illustrated in FIG. 8 is an embodiment of the micro PET+micro MRI hybrid system according to the present invention. A micro PET+micro MRI hybrid system 800 comprises a micro MRI scanner 810, a RF shield 820, a micro PET scanner 840, a sample bed 850, a transferring railway 860, and an imaging processor 870.

The micro MRI scanner 810 of this embodiment is mainly used in research of animal models. The micro MRI scanner 810 provides anatomical information with same peripheral molecular information on an internal tissue of a sample. Although the micro MRI scanner 810 has a structure much similar to the MRI scanner for a human body, it uses a magnet of a smaller diameter and high magnetic fields (of about 7.0 T-14.0 T) micro MRI can increase its resolution up to 100 μm or less.

The micro PET scanner 840 is used mainly for the molecular imaging of animals. The micro PET scanner 840 also has a small diameter bore and can provide an image having a resolution close to 1 mm fwhm (full width half maximum).

In this embodiment, the RF shield 820 protects the micro MRI scanner 810 from being adversely affected by external RF fields or signals, as the RF shield 220 of the first embodiment of the low field MRI+PET/CT hybrid system.

The sample bed 850 fixes the sample to be inspected in order to have the sample unmovable during a scanning process by the micro MRI scanner 810 or the micro PET scanner 840.

The transferring railway 860 runs between the micro MRI scanner 810 and the micro PET scanner 840. The railway 860 is required to maintain a prescribed relationship between image-taking origins for the micro MRI scanner 810 and the micro PET scanner 840 when the sample is transferred along the railway between the scanners.

The imaging processor 870 is for generating a medical image of the sample by performing necessary computation, such as the Fourier transformation and three-dimensional reconstruction. The algorithms can also be directed to other mathematical and geometrical calibration for reconstructing the image.

Although the micro PET needs an RF+ and magnetic shield, it can be made relatively simple and inexpensive. FIG. 9 illustrates a method of the embodiment of a micro MRI+micro PET hybrid system, which is similar to the method of the first embodiment of the low field MRI+PET/CT hybrid system.
First, in step 920, the method of this embodiment starts by shielding the micro MRI block during the imaging of the micro MRI. In this step, a sample is fixed on the sample bed 850. Then, the sample bed 850 moves along the transferring railway 860 toward the micro MRI scanner 810. After the completion of the micro MRI imaging, the sample will move toward RF shield 820. When the bed 850 reaches a predetermined distance prior to the RF shield 820, a shutter 822 (RF shield) equipped thereon starts to open. After the sample bed 850 goes through the shutter 822, the shutter 822 then closes.

In step 930, the micro MRI scanner 810 applies RF fields and gradients to the sample. In response to the RF pulse signals, the MR signals are generated from the sample and collected by the RF coil of the micro MRI scanner 810. The imaging processor 870 performs a signal processing such as the Fourier transformation on the MR signals to generate an MRI image 880. The method for collecting and processing the MR signals for an MRI image will not be explained herein in detail since such method does not have a direct relationship with the invention.

In step 940, the sample bed 850 moves along the transferring railway 860 toward the micro PET scanner 840. Then, the shutter 822 equipped on the RF shield 820 opens. Thereafter, the shutter 822 is closed completely when the patient bed 850 is out of the shutter 822.

In step 950, the sample bed 850 moves along the transferring railway 860 toward the micro PET scanner 840 until the bed 850 arrives within the micro PET scanner 840. The micro PET scanner 840 starts to detect gamma rays from the same sample's parts as the micro MRI scanner 810 did. When the micro PET scanner 840 obtains sufficient data, it transmits the data to the imaging processor 870.

In step 960, the imaging processor 870 reconstructs the MRI image and the PET image, and fuses them by using data obtained from the two, that is, micro MRI scanner 810 and the micro PET scanner 840, respectively.

While the present invention has been shown and described with respect to particular embodiments, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from the spirit and scope of the invention as defined in the appended claims.

1. An imaging apparatus, comprising:
   - a magnetic resonance imaging (MRI) scanner configured to generate magnetic fields proximate to a subject to thereby obtain anatomical and hemodynamical information on the subject; said MRI scanner being vulnerable to external RF fields from an external RF source;
   - a positron emission tomography (PET) scanner disposed in proximity to said MRI scanner and configured to operate in a way to obtain molecular and functional information on the subject, said PET scanner being vulnerable to the magnetic fields generated by said MRI scanner;
   - a first shield disposed between said MRI scanner and said PET scanner and including a RF and magnetic shield configured to shield said MRI scanner from the external RF fields and prevent the magnetic fields generated by said MRI scanner from leaking to said PET scanner;
   - a transfilling unit configured to move the subject between said MRI scanner and said PET scanner via said first shield; and
   - a processor configured to receive the anatomical and hemodynamical information on the subject obtained from said MRI scanner and the molecular and functional information on the subject obtained from said PET scanner to thereby construct a fused image.

2. The imaging apparatus of claim 1, further comprising a second shield including a magnetic shield configured to shield said PET scanner from the magnetic fields generated by said MRI scanner, whereby the magnetic fields generated by said MRI scanner are prevented from reaching said PET scanner.

3. The imaging apparatus of claim 1, wherein said PET scanner further includes functionality of a computer tomography scanner.

4. The imaging apparatus of claim 1, wherein said transferring unit includes a selectively rotatable portion configured to rotate the subject by a predetermined angle, the selectively rotatable portion being placed between said MRI scanner and said PET scanner.

5. A method, comprising:
   - operating a magnetic resonance imaging (MRI) scanner to generate magnetic fields proximate to a subject to thereby obtain anatomical and hemodynamical information on the subject;
   - shielding the MRI scanner from external RF fields generated by an external RF source by using a first shield including a RF and magnetic shield, said MRI scanner being vulnerable to the external RF fields and preventing the magnetic fields from leaking to the outside;
   - moving the subject from a first position in proximity to said MRI scanner to a second position in proximity to said MRI scanner, said MRI scanner being spaced a predetermined distance apart from said MRI scanner;
   - operating the PET scanner to obtain molecular and functional information on the subject; and
   - processing the anatomical and hemodynamical information on the subject obtained by the MRI scanner and the molecular and functional information on the subject obtained by the PET scanner to thereby construct a fused image.

6. The method of claim 5, wherein said PET scanner further includes functionality of a computer tomography scanner.

7. The method of claim 5, wherein moving the subject comprises moving the subject from the first position to the second position further through a second shield, said second shield including a magnetic shield and configured to further shield said PET scanner from the magnetic fields generated by said MRI scanner to thereby prevent said PET scanner from being reached by the magnetic fields generated by said MRI scanner.

8. The method of claim 5, wherein moving the subject comprises rotating the subject by a predetermined angle.

9. A computer-readable storage medium, storing a program comprising instructions for a computer to perform the method of claim 5.

10. The imaging apparatus of claim 2, wherein said PET scanner further includes functionality of a computer tomography scanner.

11. The imaging apparatus of claim 2, wherein said transferring unit includes a selectively rotatable portion configured to rotate the subject by a predetermined angle, the selectively rotatable portion being placed between said MRI scanner and said PET scanner.

12. The method of claim 6, wherein moving the subject comprises moving the subject from the first position to the second position further through a second shield, said second shield
shield including a magnetic shield and configured to further shield said PET scanner from the magnetic fields generated by said MRI scanner to thereby prevent said PET scanner from being reached by the magnetic fields generated by said MRI scanner.

13. The method of claim 6, wherein moving the subject comprises rotating the subject by a predetermined angle.

14. A computer-readable storage medium, storing a program comprising instructions for a computer to perform the method of claim 6.

15. A method, comprising:
   providing a magnetic resonance imaging (MRI) scanner, said MRI scanner being vulnerable to external RF fields generated by an external RF source;
   providing a positron emission tomography (PET) scanner;
   shielding the MRI scanner from the external RF fields by using a first shield including a RF and magnetic shield;
   operating the MRI scanner to generate magnetic fields to thereby obtain anatomical and hemodynamical information on a subject, said subject being placed at a first position in proximity to the MRI scanner when operating the MRI scanner and said first shield preventing the magnetic fields from leaking to the outside;
   moving the subject from the first position to a second position in proximity to the PET scanner via said first shield, the PET scanner being spaced a predetermined distance apart from the MRI scanner;
   operating the PET scanner to obtain molecular and functional information on the subject, said subject being placed at a the second position when operating the PET scanner; and
   processing the anatomical and hemodynamical information on the subject obtained by the MRI scanner and the molecular and functional information on the subject obtained by the PET scanner to thereby construct a fused image.