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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 June 2018 (21.06.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/108821 A1

(51) International Patent Classification:
*A61B 5/00* (2006.01) *G01R 33/567* (2006.01)
*A61B 5/055* (2006.01) *A61B 5/113* (2006.01)

(21) International Application Number:
PCT/EP2017/082237

(22) International Filing Date:
11 December 2017 (11.12.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/433,835 14 December 2016 (14.12.2016) US

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

(72) Inventors: **SENEGAS, Julien**; High Tech Campus 5, 5656 AE Eindhoven (NL). **KRUEGER, Sascha**; High Tech Campus 5, 5656 AE Eindhoven (NL).

(74) Agent: **VAN IERSEL, Hannie, Cornelia, Patricia, Maria** et al.; Philips International B.V. – Intellectual Property & Standards, High Tech Campus 5, 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, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,

(54) Title: AUTOMATED COMPUTATION OF TRIGGER DELAY FOR TRIGGERED MAGNETIC RESONANCE IMAGING SEQUENCES

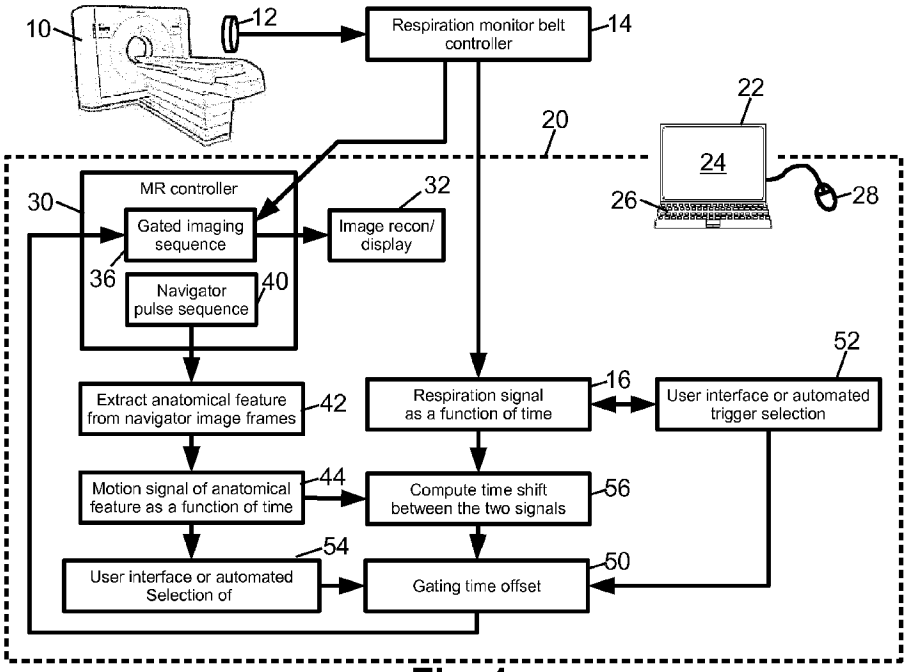



Fig. 1

(57) Abstract: A magnetic resonance (MR) imaging device (10) repeatedly executes a navigator pulse sequence (40) to generate navigator data in image space as a function of time, and a motion signal (44) of an anatomical feature that moves with a physiological cycle (e.g. respiration) as a function of time is extracted from the navigator data. A concurrent physiological signal (16) as a function of time is generated by a physiological monitor (12, 14) concurrently with the repeated execution of the navigator pulse sequence. A gating time offset (50) is determined by comparing the motion signal of the anatomical feature as a function of time and the concurrent physiological signal as a function of time. The MR imaging device performs a prospective or retrospective gated MR imaging sequence (36) using gating times defined as occurrence times of gating events detected by the physiological monitor modified by the gating time offset.

*[Continued on next page]*

WO 2018/108821 A1

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

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

**Declarations under Rule 4.17:**

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

**Published:**

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

# AUTOMATED COMPUTATION OF TRIGGER DELAY FOR TRIGGERED MAGNETIC RESONANCE IMAGING SEQUENCES

## FIELD

The following relates generally to the medical imaging arts, gated medical imaging arts, magnetic resonance imaging arts, and related arts.

## BACKGROUND

Where imaging artefacts due to respiration or cardiac pulsation in magnetic resonance (MR) imaging scans are of concern, a physiology sensor may be used during MR examinations to measure the relevant physiology signal and compute a physiology curve. This signal can be used during imaging to trigger the data acquisition or for gating. The physiological sensor may, for example, measure respiratory motion using an air-filled belt attached to a pressure sensor, or an optical camera can track the motion of a body part or of a dedicated marker and the respiratory signal derived from the imaged motion. Cardiac pulsation is often measured using a pulse pickup photoplethysmography (PPG) sensor or an electrocardiogram (ECG) device. Alternatively, optical camera systems measuring the variation of reflected light over a skin area can be used to monitor cardiac activity. The respiration or cardiac signal measured by such a physiological sensor is a surrogate for the motion of the internal organs being imaged by the MR imaging.

The following discloses new and improved systems and methods.

## SUMMARY

In one disclosed aspect, a gating device is disclosed for a magnetic resonance (MR) imaging device. The gating device includes a physiological monitor, an electronic processor, and a non-transitory storage medium that stores a navigator pulse sequence, a gated MR imaging sequence, and instructions readable and executable by the electronic processor to perform a gated MR imaging method. The method includes: operating the MR imaging device to repeatedly execute the navigator pulse sequence to generate navigator data in image space as a function of time; extracting a motion signal of an anatomical feature as a function of time from the navigator data; concurrently with operating the MR imaging device to repeatedly execute the navigator sequence, acquiring a concurrent physiological signal as a function of time generated by the physiological monitor; determining a gating time offset by comparing the motion signal of the anatomical feature as a function of time and the

concurrent physiological signal as a function of time; and operating the MR imaging device to perform the gated MR imaging sequence using gating times defined as occurrence times of gating events detected by the physiological monitor modified by the gating time offset.

In another disclosed aspect, a non-transitory storage medium stores a navigator pulse sequence, a gated magnetic resonance (MR) imaging sequence, and instructions readable and executable by an electronic processor to perform a gated MR imaging method comprising: operating an MR imaging device to repeatedly execute the navigator pulse sequence to generate navigator data in image space as a function of time; extracting a motion signal of an anatomical feature as a function of time from the navigator data; concurrently with operating the MR imaging device to repeatedly execute the navigator sequence, acquiring a concurrent respiratory or cardiac cycling signal as a function of time generated by a respiratory or cardiac monitor; determining a gating time offset by comparing the motion signal of the anatomical feature as a function of time and the concurrent respiratory or cardiac cycling signal as a function of time; and operating the MR imaging device to perform the gated MR imaging sequence using gating times defined as occurrence times of gating events detected by the respiratory or cardiac monitor modified by the gating time offset.

In another disclosed aspect, a gated magnetic resonance (MR) imaging method comprises: repeatedly executing a navigator pulse sequence using an MR imaging device to generate navigator data in image space as a function of time; extracting a motion signal of an anatomical feature as a function of time from the navigator data; concurrently with operating the MR imaging device to repeatedly execute the navigator sequence, acquiring a concurrent respiratory cycling signal as a function of time generated by a respiratory monitor; determining a gating time offset by comparing the motion signal of the anatomical feature as a function of time and the concurrent respiratory cycling signal as a function of time; and operating the MR imaging device to perform a gated MR imaging sequence using gating times defined as occurrence times of gating events detected by the respiratory monitor modified by the gating time offset.

One advantage resides in providing physiological gating with improved fidelity to a desired state of the internal organ(s) being imaged.

Another advantage resides in providing gated MR imaging more accurately targeting a desired state of the internal organ(s) being imaged.

Another advantage resides in providing gated MR imaging with user selection of the desired state of the internal organ(s) isolated by the gating.

A given embodiment may provide none, one, two, more, or all of the foregoing advantages, and/or may provide other advantages as will become apparent to one of ordinary skill in the art upon reading and understanding the present disclosure.

## BRIEF DESCRIPTION OF THE DRAWINGS

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

FIGURE 1 diagrammatically illustrates a magnetic resonance (MR) imaging device including respiratory gating as disclosed herein.

FIGURE 2 diagrammatically illustrates a respiratory monitor waveform as a function of time.

FIGURE 3 diagrammatically illustrates a navigator feature waveform as a function of time.

FIGURE 4 diagrammatically illustrates respiratory monitor and navigator feature waveforms plotted together, with certain salient measurements indicated.

## DETAILED DESCRIPTION

An implicit assumption made during typical gated MR imaging is that the physiological signal (e.g. respiration or cardiac cycling signal) measured by a physiological sensor is closely correlated with, and "in phase with", the dominant motion of the internal organs and that motion state of the internal organ, such as end-expiration or end-inspiration (or end-diastole and end-systole). In some gating devices, a pre-set or operator-set constant time delay can be added to the physiological signal gating event detected within each respiratory or cardiac cycle measured by the physiological device. It is recognized herein that these assumptions may be in error for a particular patient or a particular MR imaging examination. In gating approaches disclosed herein, for optimal image quality the gating time offset is set individually for each patient and each MR imaging examination.

With reference to FIGURE 1, a gated magnetic resonance (MR) imaging system includes an MR imaging device **10**, which may by way of non-limiting illustration comprise an Ingenia™ MR imaging device available from Koninklijke Philips N.V., Eindhoven, the Netherlands. A physiological monitor **12** is provided to monitor a physiological signal which is used for the gating. In the illustrative embodiments, the

physiological monitor **12** is a respiratory monitor in the form of an air-filled belt attached to a pressure sensor, such that as the patient inhales the pressure in the air-filled belt increases and as the patient exhales the pressure decreases, so that the pressure as a function of time is a representation of the patient respiration as a function of time. (While the term "patient" is used herein for brevity, it will be understood that the MR imaging subject may be a hospital patient, an out-patient, a human subject receiving a medical screening, an athlete or other person receiving a medical clearance including an MR imaging examination, or so forth). The illustrative belt-based respiratory monitor **12** is merely an example, and it will be understood that the respiratory monitor may be chosen to monitor another chosen physiological variable used for the gating. As another example, the physiological monitor may be an electrocardiographic (ECG) device monitoring cardiac cycling – such a physiological monitor is suitable for cardiac gating. The physiological monitor **12** includes or is connected with a physiological monitor controller **14**, e.g. an electronic processor connected to read the pressure sensor and output an analog or digital pressure reading in the illustrative belt-based respiratory monitor **12**, or an ECG controller in the case of an ECG-based cardiac monitor. The output of the physiological monitor **12**, **14** is a physiological signal (e.g. respiration signal) **16** as a function of time.

An electronic processor **20** is programmed to perform various functions as disclosed herein. The illustrative electronic processor **20** is embodied as a computer **22** having a display **24** and at least one user input device (e.g. illustrative keyboard **26** and mouse **28**, and/or a touch-sensitive overlay of the display **24** or so forth). More particularly, a non-transitory storage medium (not shown) is provided which stores instructions readable and executable by the electronic processor **20** to perform the disclosed various functions. The non-transitory storage medium may, by way of non-limiting example, include a hard disk drive or other magnetic storage medium; an optical disk or other optical storage medium; a solid state drive (SSD) or other electronic storage medium; various combinations thereof; or so forth. The electronic processor **20** implements an MR controller **30** that controls the MR imaging device **10** to perform MR imaging data acquisition, and implements MR image reconstruction and display processing **32**, e.g. performing a Fourier reconstruction or other MR image reconstruction to convert acquired k-space MR imaging data to an image in image space and operating the display **24** to display the reconstructed image.

With continuing reference to FIGURE 1, a gated MR imaging sequence **36** is stored on a non-transitory storage medium (e.g. the same non-transitory storage medium storing instructions read and executed by the electronic processor **20**). Additionally, a

navigator pulse sequence **40** is stored on the non-transitory storage medium. The MR controller **30** is programmed to operate the MR imaging device **10** to perform the gated MR imaging sequence **36** using gating times defined as occurrence times of gating events detected by the physiological monitor **12**, **14** modified by a gating time offset determined, as disclosed herein, using the navigator pulse sequence **40**.

The navigator pulse sequence **40** is a fast MRI sequence that generated MR data (e.g. k-space samples) that can be converted to image space. The navigator pulse sequence **40** can be a fast two-dimensional (2D) or three-dimensional (3D) imaging sequence that acquires a 2D or 3D navigator image, respectively. Alternatively, the navigator pulse sequence **40** can be one or more one-dimensional (1D) pencil beam navigators that acquire one or more 1D navigator data set in image space. The navigator pulse sequence **40** is generally designed to produce a 1D, 2D, or 3D image dataset that intersects an anatomical feature having motion corresponding to the motive physiology that is the basis of the gating. For example, in the case of respiratory-gated MR imaging, a suitable anatomical feature is a thoracic diaphragm boundary or a liver boundary, as these boundaries are expected to move with the respiratory cycle. The thoracic diagram boundary moves since contraction and consequent movement of the thoracic diaphragm provides motive force for inspiration. The liver boundary is expected to move with the respiratory cycle since the liver is close to, and moves with, the thoracic diaphragm. Other anatomical features may instead be used, e.g. a selected rib of the ribcage. In the case of cardiac-gated MR imaging, a suitable anatomical feature whose movement may be monitored by a navigator includes a myocardial tissue boundary making up a cardiac muscle wall, or a major artery or vein having motion induced by blood pressure waves imparted by the beating heart. These are merely illustrative examples.

The gating device (e.g. MR controller **30** and ancillary components) determines the gating time offset by operating the MR imaging device **10** to repeatedly execute the navigator pulse sequence **40** to generate navigator data in image space as a function of time. A motion signal **44** of an anatomical feature as a function of time is extracted **42** from the navigator data. For example, in the case of a feature comprising the thoracic diaphragm boundary, the operation **42** may include identifying this boundary as a steep intensity gradient in each 2D or 3D navigator image (or each 1D navigator data set in image space, in the case of a 1D pencil beam navigator), and the position of this boundary is plotted as a function of time for the time sequence of images or 1D navigator data sets to produce the motion signal **44**. Concurrently with operating the MR imaging device **10** to

repeatedly execute the navigator sequence **40**, a concurrent physiological signal **16** as a function of time is generated by the physiological monitor **12**, **14**. This is straightforward since the physiological monitor **12** (e.g. air-filled belt) is designed to operate with the patient loaded into the MR imaging device **10** in order to provide the gating signal; thus, the same physiological monitoring is performed during the repeated execution of the navigator pulse sequence **40** to generate the concurrent physiological signal **16**. A gating time offset **50** is then determined by comparing the motion signal **44** of the anatomical feature as a function of time and the concurrent physiological signal **16** as a function of time. This gating time offset **50** is thereafter used in the gating. That is, the MR controller **30** operates the MR imaging device **10** to perform gated MR imaging (i.e. executing the gated MR imaging sequence **36**) using gating times defined as occurrence times of gating events detected by the physiological monitor **12**, **14** modified by the gating time offset **50**.

In the illustrative example of FIGURE 1, the gating time offset **50** is determined by comparing the signals **16**, **50** as follows. An occurrence of the chosen gating event is identified in the physiological signal **16** in an operation **52**. This may be done automatically, e.g. the gating event may be defined as the pressure maximum (or minimum) measured for the illustrative air-filled belt respiratory monitor and such maxima (or minima) are readily detected automatically in the pressure-versus-time waveform. Alternatively, the operation **52** may be performed manually, e.g. the pressure-versus-time waveform may be plotted and the MR operator manually selects the event using the mouse **28**. Similarly, in an operation **54** an occurrence of a desired start of MR imaging data acquisition is identified in the motion signal **44**. Again, this may be done either automatically or manually. For example, the motion signal **44** may be plotted as a function of time and the user selects the desired start on the plot of the motion signal **44** of the anatomical feature. Alternatively, the desired start may be selected automatically using some criterion, such as identifying the beginning of a quiescent period in which the motion is small. In the case of respiration, this usually corresponds to an end-expiration period, and it will be expected that the diaphragm (and hence its boundary) will have little motion during this period. The gating time offset **50** is then selected as a time difference between the time of the chosen gating event and the time of the desired start of MR imaging data acquisition.

It should be noted that gating can be performed either prospectively or retrospectively. In embodiments in which the gated MR imaging employs prospective gating, the MR imaging data acquisition is triggered at the gating times defined as occurrence times of gating events detected by the physiological monitor modified by the gating time offset **50**.

In this case, the gating time offset **50** should be a gating delay, i.e. the modification is to delay the start of MR imaging data acquisition by the gating time offset.

In the case of retrospective gating, MR imaging data are acquired continuously while recording the gating events detected using the physiological monitor **12**, **14**, and the collected imaging data are retrospectively gated using the recorded gating events modified by the gating time offset **50**. The events are marked with the event times + offset as start point of acceptance windows to validate or invalidate respective data and track the data measured until completion.

In a variant embodiment, the gating time offset **50** is determined automatically in an operation **56** by computing a time shift between the two signals **16**, **44**. This approach recognizes that both the physiological signal **16** and the motion signal **44** are expected to be at least quasiperiodic (in the case of respiratory or cardiac gating) so that a phase shift can be defined between the two signals **16**, **44**. In this case, the phase shift is used as the gating time offset **50**.

The foregoing are merely illustrative examples of some approaches for determining the gating time offset **50** by comparing the motion signal **44** of the anatomical feature as a function of time and the concurrent physiological signal **16** as a function of time. Moreover, the disclosed approaches are not mutually exclusive. For example, the approach of identifying **52** a trigger event in the physiological signal **16** and identifying **54** a desired start time in the motion signal **44** and taking the difference as the gating time offset **50** can be augmented by computing the time difference by correlation **56** in order to ensure the times identified in the operations **52**, **54** are in the same respiratory cycle (or same cardiac cycle, et cetera). Other approaches are also contemplated. In general, the motion signal **44** of the anatomical feature as a function of time is leveraged to account for patient-specific or even imaging scan-specific variations in the time offset between the measured physiological signal (e.g. respiratory signal or cardiac signal) and the motion of the imaged anatomy produced by the physiological process (e.g. respiration or cardiac cycling).

In the illustrative examples herein, while a single electronic processor **20** is illustrated for brevity, it will be understood that the electronic processing disclosed herein may alternatively be embodied by a plurality of operatively interconnected electronic processors. For example, the MR controller **30** may be implemented as a dedicated electronic controller while the reconstruction/display **32** may be implemented by a different computer. It is also contemplated for the physiological monitor controller to be integrated with the electronic processor that controls the MR imaging device **10** and/or with the electronic

processor that reconstructs and displays the MR images. Likewise, wherever herein the term "non-transitory storage medium" or the like is employed, it is to be understood that the storage medium may be a single storage medium or may include a plurality of storage media. For example, it is contemplated to store the instructions executed by the MR controller **30** on a different storage medium from the storage medium that stores the imaging and navigator sequences **36**, **40**.

With reference now to FIGURES 2-4, a more specific illustrative example is presented, relating to respiratory-gated MR imaging. In this example, at the beginning of the imaging exam, the navigator (1D, 2D or 3D) signal is acquired using the MR imaging device **10** repeatedly executing the navigator pulse sequence **40**. The navigator is positioned (either manually, e.g. using scout scans, or automatically) at the location of the target moving structure (i.e., the anatomical feature whose motion is tracked). Real-time navigator images of the moving anatomical feature over a few respiratory or cardiac cycles (or other physiological cycle used for the gating) are acquired. The motion curve **44** representative of the main motion direction is computed **42** from the navigator images using image analysis techniques, e.g. edge detection, region segmentation, or so forth. Simultaneously, the physiology signal **16** measured by the physiology sensor **12**, **14** is acquired. In this example, the gating time offset **50** is determined as follows. The mean (or median) shift between the two signals **16**, **44** is computed (operation **56**), for example based on maximizing the correlation between these two signals. The motion state of the internal organ which is desired for imaging (e.g. end-expiration or end-inspiration) is defined (operations **52**, **54**), either manually by the operator or automatically based on some pre-settings. This may be done, for example, manually using a graphical user interface. The gating time offset **50** is computed based on the mean shift and the position of the desired motion state within one respiration cycle (for the illustrative example of respiratory gating). FIGURE 2 illustrates a suitable example of the physiological signal **16**, here embodied as a breathing signal determined from analyzing movement of a shadow of the chest on a wall of a magnet bore of the MR imaging device **10**. (By contrast, in the embodiment of FIGURE 1, this breathing signal is provided by the air-filled belt **12**). FIGURE 3 illustrates the motion curve **44** of an anatomical feature, namely the liver dome in the illustrative example of FIGURE 3, due to breathing measured by a 1D pencil beam navigator sequence over the same respiratory cycles that produced the breathing signal of FIGURE 2. In FIGURE 3, the arrow shows the motion state at the desired start of imaging data acquisition. FIGURE 4 illustrates display of both signals **16**, **44** plotted against a common time axis. In FIGURE 4, the mean or median time shift **TS** between these

two curves **16**, **44** is indicated by a time shift determined by maximizing the cross-correlation between these two curves. As the signals **16**, **44** are (quasi-)periodic, this time shift can also be thought of as a phase shift between the motion signal **44** of the anatomical feature and the concurrent physiological signal **16**.

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

**CLAIMS:**

1. A gating device for a magnetic resonance (MR) imaging device, the gating device comprising:

a physiological monitor (12, 14);

an electronic processor (20); and

a non-transitory storage medium storing a navigator pulse sequence (40), a gated MR imaging sequence (36), and instructions readable and executable by the electronic processor to perform a gated MR imaging method including:

operating the MR imaging device to repeatedly execute the navigator pulse sequence to generate navigator data in image space as a function of time;

extracting a motion signal (44) of an anatomical feature as a function of time from the navigator data;

concurrently with operating the MR imaging device to repeatedly execute the navigator sequence, acquiring a concurrent physiological signal (16) as a function of time generated by the physiological monitor;

determining a gating time offset (50) by comparing the motion signal of the anatomical feature as a function of time and the concurrent physiological signal as a function of time; and

operating the MR imaging device to perform the gated MR imaging sequence using gating times defined as occurrence times of gating events detected by the physiological monitor modified by the gating time offset.

2. The gating device of claim 1 wherein determining the gate time offset (50) comprises:

computing (56) a time corresponding to a phase shift between the motion signal (44) of the anatomical feature and the concurrent physiological signal (16).

3. The gating device of any one of claims 1-2 further comprising:

a display (24); and

a user input device (26, 28);

wherein the gated MR imaging method further includes:

operating the display to plot the motion signal (44) of the anatomical feature and the concurrent physiological signal (16) against a common time axis;

via the user input device, receiving (52) a user input indicating a gating event on the plot of the concurrent physiological signal;

via the user input device, receiving (54) a user input indicating a desired start of MR imaging data acquisition on the plot of the motion signal of the anatomical feature; and

computing the gate time offset (50) based on a time difference between the indicated gating event and the indicated desired start of MR imaging data acquisition.

4. The gating device of any one of claims 1-3 wherein the gated MR imaging employs prospective gating in which MR imaging data acquisition is triggered at the gating times.

5. The gating device of any one of claims 1-3 wherein the gated MR imaging employs retrospective gating in which MR imaging data are acquired continuously while recording the gating events detected using the physiological monitor (12, 14) and retrospectively gated using the recorded gating events modified by the gating time offset (50).

6. The gating device of any one of claims 1-5 wherein the physiological monitor (12, 14) comprises a respiratory monitor and the gated MR imaging is respiratory-gated MR imaging.

7. The gating device of claim 6 wherein the extracting comprises:

extracting a motion signal (44) of a thoracic diaphragm boundary as a function of time from the navigator data.

8. The gating device of any one of claims 1-5 wherein the physiological monitor comprises an electrocardiograph (ECG) and the gated MR imaging is ECG-gated MR imaging.

9. The gating device of any one of claims 1-8 wherein the navigator pulse sequence (40) is a pencil beam navigator and operating the MR imaging device (10) to repeatedly execute the pencil beam navigator pulse sequence generates a time sequence of one-dimensional (1D) navigator data sets in image space.

10. The gating device of any one of claims 1-8 wherein the navigator pulse sequence (40) is a two- or three-dimensional (2D or 3D) navigator pulse sequence and operating the MR imaging device (10) to repeatedly execute the 2D or 3D navigator pulse sequence generates a time sequence of 2D or 3D images.

11. A non-transitory storage medium storing:

a navigator pulse sequence (40);

a gated magnetic resonance (MR) imaging sequence (36); and

instructions readable and executable by an electronic processor (20) to perform a gated MR imaging method comprising:

operating an MR imaging device (10) to repeatedly execute the navigator pulse sequence to generate navigator data in image space as a function of time;

extracting a motion signal (44) of an anatomical feature as a function of time from the navigator data;

concurrently with operating the MR imaging device to repeatedly execute the navigator sequence, acquiring a concurrent respiratory or cardiac cycling signal (16) as a function of time generated by a respiratory or cardiac monitor (12, 14);

determining a gating time offset (50) by comparing the motion signal of the anatomical feature as a function of time and the concurrent respiratory or cardiac cycling signal as a function of time; and

operating the MR imaging device to perform the gated MR imaging sequence using gating times defined as occurrence times of gating events detected by the respiratory or cardiac monitor modified by the gating time offset.

12. The non-transitory storage medium of claim 11 wherein determining the gate time offset (50) comprises:

computing (56) a time corresponding to a phase shift between the motion signal (44) of the anatomical feature and the concurrent respiratory or cardiac signal (16).

13. The non-transitory storage medium of any one of claims 11-12 wherein the gated MR imaging method further includes:

operating a display (24) to plot the motion signal (44) of the anatomical feature and the concurrent respiratory or cardiac signal (16) against a common time axis.

14. The non-transitory storage medium of any one of claims 11-13 wherein the gated MR imaging method further includes:

receiving identification of, or automatically identifying, a gating event (52) in the concurrent respiratory or cardiac signal;

receiving identification of, or automatically identifying, a desired start (54) of MR imaging data acquisition in the motion signal of the anatomical feature; and

computing the gate time offset (50) based on a time difference between the indicated gating event and the indicated desired start of MR imaging data acquisition.

15. The non-transitory storage medium of any one of claims 11-14 wherein the gated MR imaging employs one of:

prospective gating in which MR imaging data acquisition is triggered at the gating times; and

retrospective gating in which MR imaging data acquisition is acquired continuously while recording the gating events detected using the respiratory or cardiac monitor (12, 14) and retrospectively gated using the recorded gating events modified by the gating time offset (50).

16. The non-transitory storage medium of any one of claims 11-15 wherein the extracting comprises:

extracting a motion signal (44) of an organ boundary as a function of time from the navigator data.

17. The non-transitory storage medium of any one of claims 11-16 wherein one of:

the navigator pulse sequence (40) is a pencil beam navigator and operating the MR imaging device (10) to repeatedly execute the pencil beam navigator pulse sequence generates a time sequence of one-dimensional (1D) navigator data sets in image space;

the navigator pulse sequence is a two-dimensional (2D) navigator pulse sequence and operating the MR imaging device to repeatedly execute the 2D navigator pulse sequence generates a time sequence of 2D images; or

the navigator pulse sequence is a three-dimensional (3D) navigator pulse sequence and operating the MR imaging device to repeatedly execute the 3D navigator pulse sequence generates a time sequence of 3D images.

18. A gated magnetic resonance (MR) imaging method comprising:

repeatedly executing a navigator pulse sequence (40) using an MR imaging device (10) to generate navigator data in image space as a function of time;

extracting a motion signal (44) of an anatomical feature as a function of time from the navigator data;

concurrently with operating the MR imaging device to repeatedly execute the navigator sequence, acquiring a concurrent respiratory cycling signal (16) as a function of time generated by a respiratory monitor (12, 14);

determining a gating time offset (50) by comparing the motion signal of the anatomical feature as a function of time and the concurrent respiratory cycling signal as a function of time; and

operating the MR imaging device to perform a gated MR imaging sequence (36) using gating times defined as occurrence times of gating events detected by the respiratory monitor modified by the gating time offset.

19. The gated MR imaging method of claim 18 wherein the anatomical feature is an organ boundary.

20. The gated MR imaging method of any one of claims 18-19 wherein determining the gating time offset (50) includes:

computing the gate time offset as a time difference between a gating event in the respiratory cycling signal (16) and a reference point in the motion signal (44) of the anatomical feature.

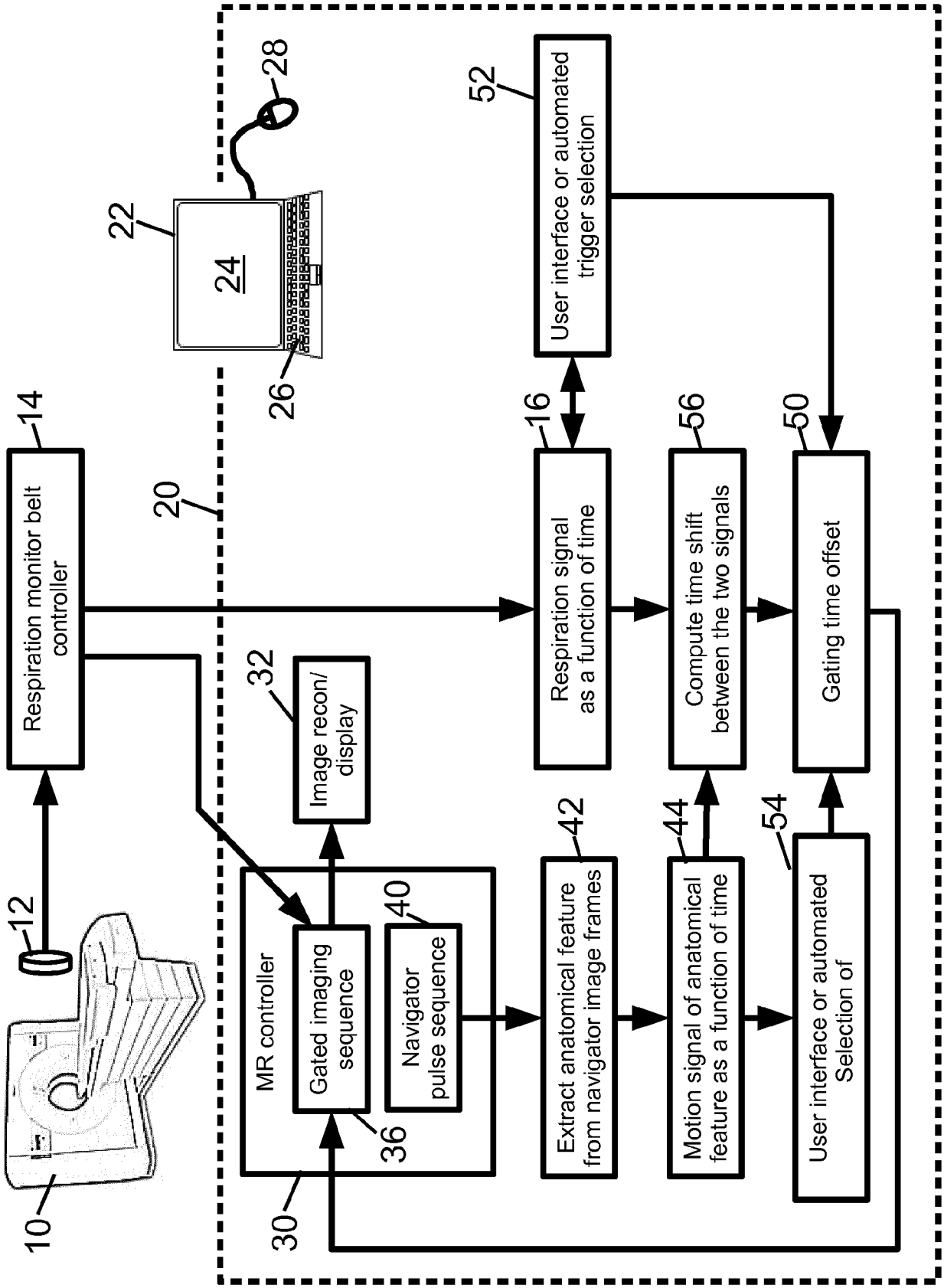

Respiration monitor belt controller
14
20
22
24
26
28
User interface or automated trigger selection
52
16
Respiration signal as a function of time
56
Compute time shift between the two signals
50
Gating time offset
32
Image recon/ display
MR controller
Gated imaging sequence
36
Navigator pulse sequence
40
42
Extract anatomical feature from navigator image frames
44
Motion signal of anatomical feature as a function of time
54
User interface or automated Selection of
12
10
30

Fig. 1

Fig. 2

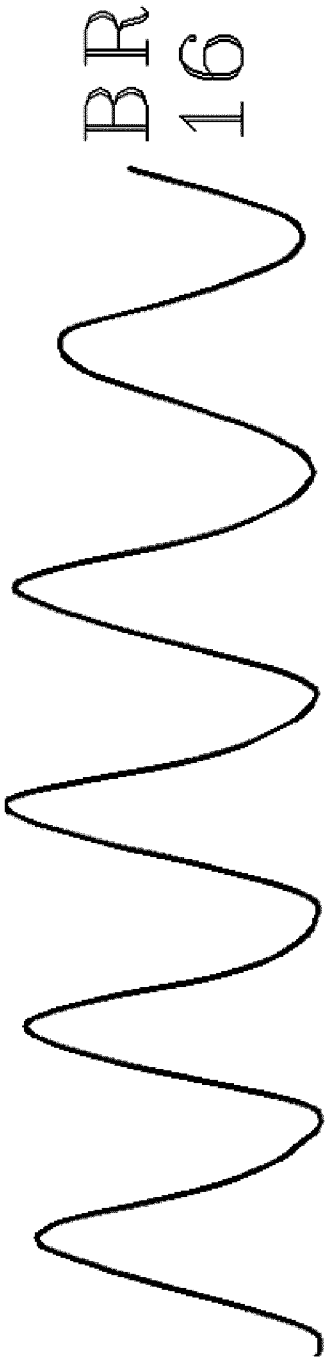
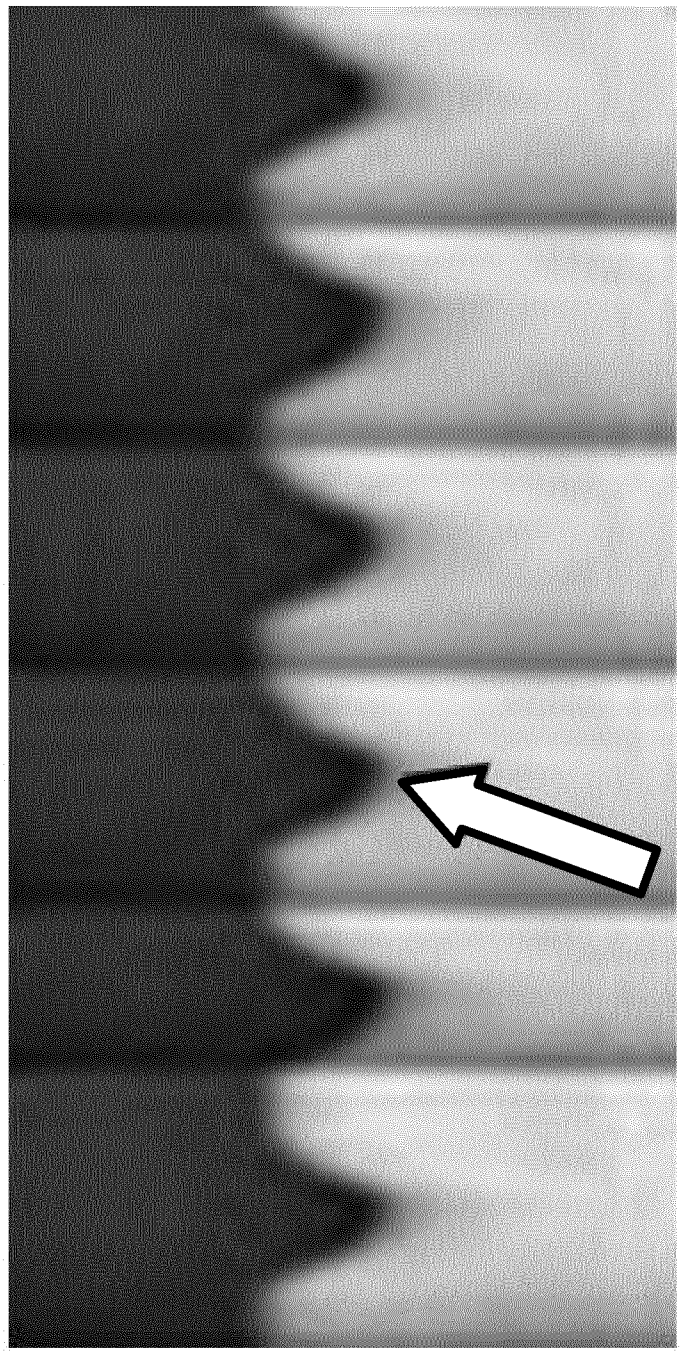



Fig. 3



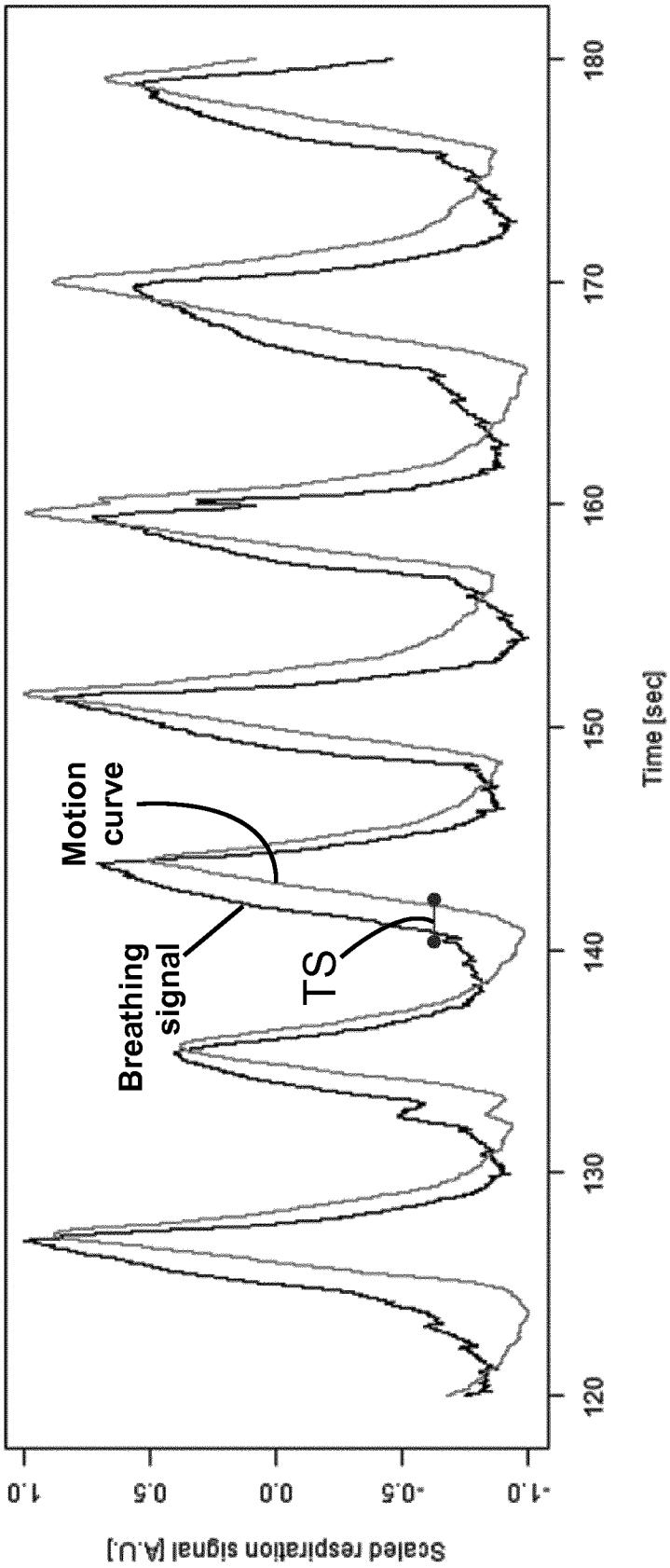

Scaled respiration signal [A.U.]
1.0
0.5
0.0
-0.5
-1.0
120
130
140
150
160
170
180
Time [sec]
Motion curve
Breathing signal
TS

Fig. 4

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/082237

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/00 A61B5/055 G01R33/567
ADD. A61B5/113

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 2015/157277 A1 (GOTO TOMOHIRO [JP] ET AL) 11 June 2015 (2015-06-11) figures 1-3,5-7 paragraphs [0010], [0030], [0036] - [0055] | 1-20 |
| A | US 2006/183999 A1 (LORENZ CHRISTINE [US] ET AL) 17 August 2006 (2006-08-17) paragraphs [0003] - [0006], [0030], [0031], [0037], [0048] | 8,10 |
| A | WO 2015/024110 A1 (SUNNYBROOK RES INST [CA]) 26 February 2015 (2015-02-26) page 2, line 19 - page 3, line 13 | 8,10 |

☐ 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 | Date of mailing of the international search report |
|---|---|
| 23 March 2018 | 04/04/2018 |

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

1

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/082237

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US 2015157277 A1 | 11-06-2015 | CN 104427934 A | 18-03-2015 |
| | | JP 6151697 B2 | 21-06-2017 |
| | | JP WO2014027547 A1 | 25-07-2016 |
| | | US 2015157277 A1 | 11-06-2015 |
| | | WO 2014027547 A1 | 20-02-2014 |
| US 2006183999 A1 | 17-08-2006 | JP 2006198407 A | 03-08-2006 |
| | | US 2006183999 A1 | 17-08-2006 |
| WO 2015024110 A1 | 26-02-2015 | CA 2918481 A1 | 26-02-2015 |
| | | EP 3036553 A1 | 29-06-2016 |
| | | US 2016198970 A1 | 14-07-2016 |
| | | WO 2015024110 A1 | 26-02-2015 |

| | | | |
|---|---|---|---|
| 专利名称(译) | 触发磁共振成像序列的触发延迟的自动计算 | | |
| 公开(公告)号 | EP3554341A1 | 公开(公告)日 | 2019-10-23 |
| 申请号 | EP2017825151 | 申请日 | 2017-12-11 |
| [标]申请(专利权)人(译) | 皇家飞利浦电子股份有限公司 | | |
| 申请(专利权)人(译) | 皇家飞利浦N.V. | | |
| 当前申请(专利权)人(译) | 皇家飞利浦N.V. | | |
| [标]发明人 | SENEGAS JULIEN<br>KRUEGER SASCHA | | |
| 发明人 | SENEGAS, JULIEN<br>KRUEGER, SASCHA | | |
| IPC分类号 | A61B5/00 A61B5/055 G01R33/567 A61B5/113 | | |
| CPC分类号 | A61B5/055 A61B5/113 A61B5/7289 A61B5/7292 G01R33/5673 G01R33/5676 A61B5/7282 | | |
| 代理机构(译) | COHEN，朱利叶斯SIMON | | |
| 优先权 | 62/433835 2016-12-14 US | | |
| 外部链接 | Espacenet | | |


摘要(译)

磁共振（MR）成像设备（10）重复执行导航器脉冲序列（40）以生成作为时间的函数的图像空间中的导航器数据以及与生理周期一起移动的解剖特征的运动信号（44）（例如呼吸）作为时间的函数从导航器数据中提取。生理监测器（12,14）在重复执行导航器脉冲序列的同时生成随时间变化的并发生理信号（16）。选通时间偏移（50）通过比较作为时间的函数的解剖特征的运动信号和作为时间的函数的同时的生理信号来确定。 MR成像设备使用被定义为由门控时间偏移修改的生理监测器检测到的门控事件的发生时间的门控时间来执行预期或回顾门控式MR成像序列（36）。