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(54) **SYSTEMS AND METHODS FOR DETECTING AND/OR MEASURING MOTION AND POSITION ASSOCIATED WITH A PATIENT**

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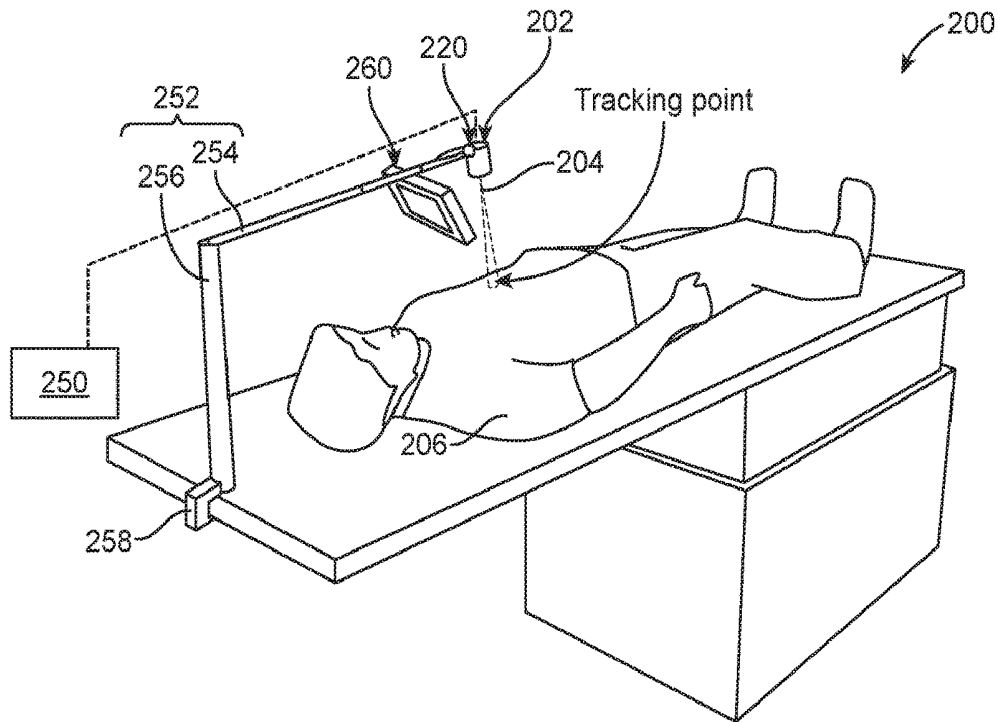
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(60) Provisional application No. 62/316,743, filed on Apr. 1, 2016.

(57) **ABSTRACT**

An apparatus for patient position or motion monitoring includes: an energy source configured to emit energy from a first location to a second location, or vice versa, wherein the second location that is moveable relative to the first location in response to a movement by a patient; and a processing unit coupled to receive an input that is based on the emitted energy, and to determine a characteristic associated with the patient based on the input.



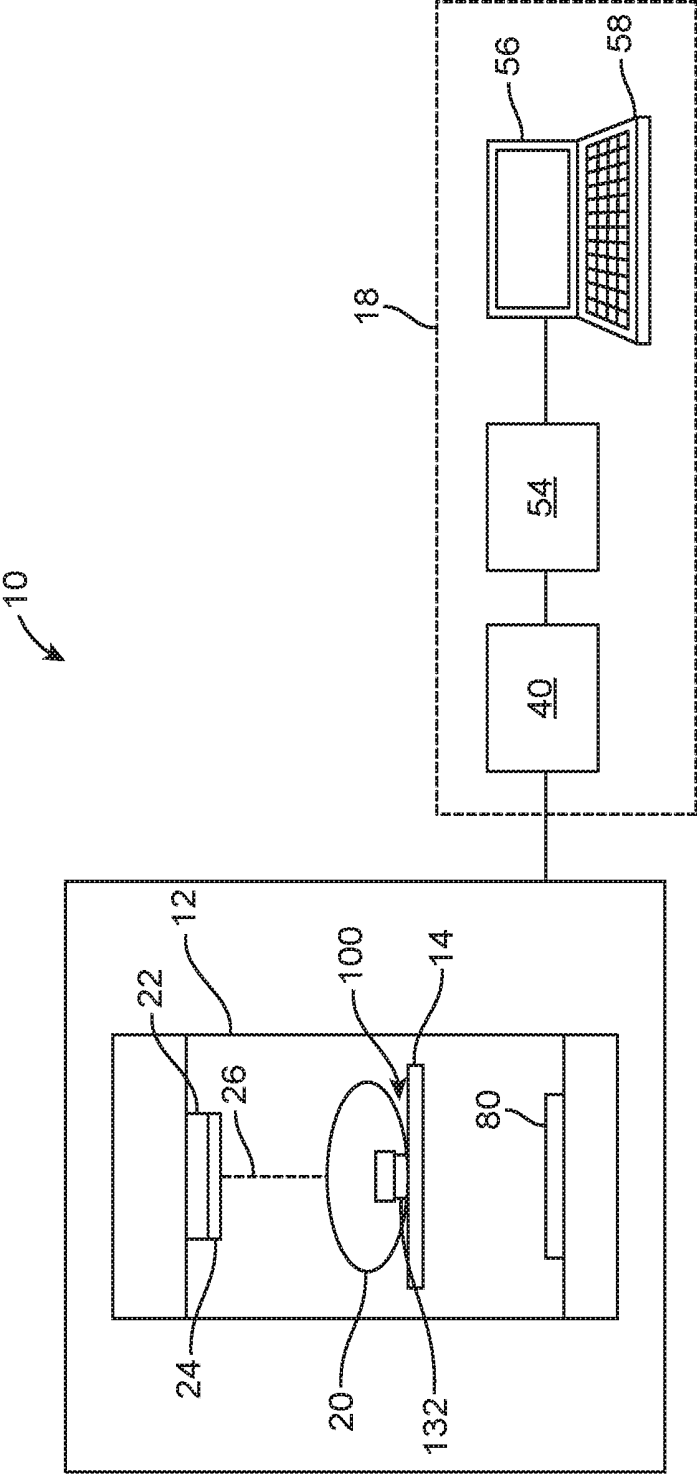


FIG. 1

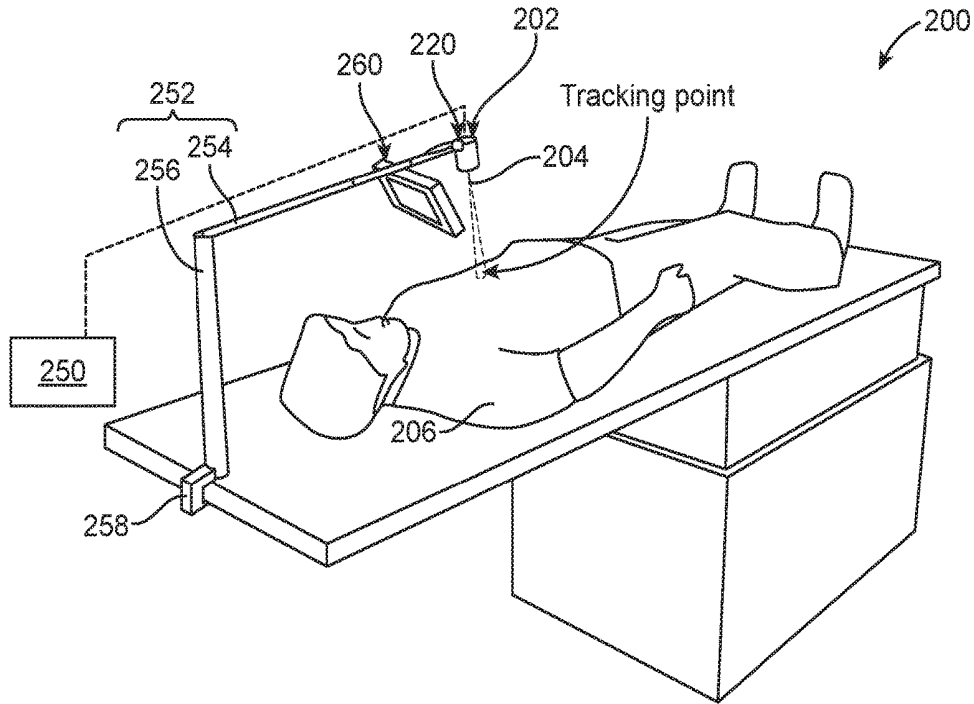


FIG. 2

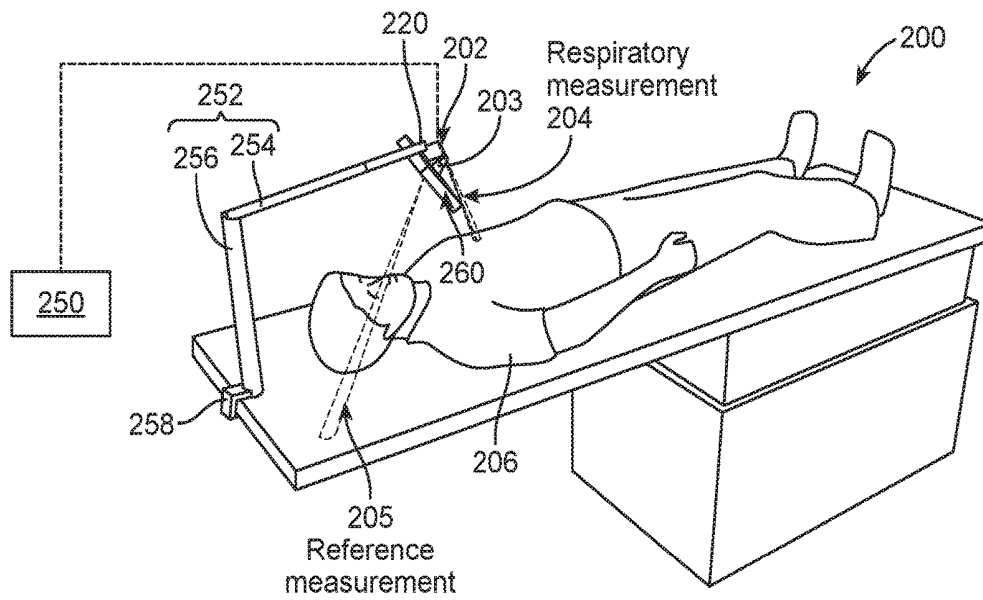


FIG. 3

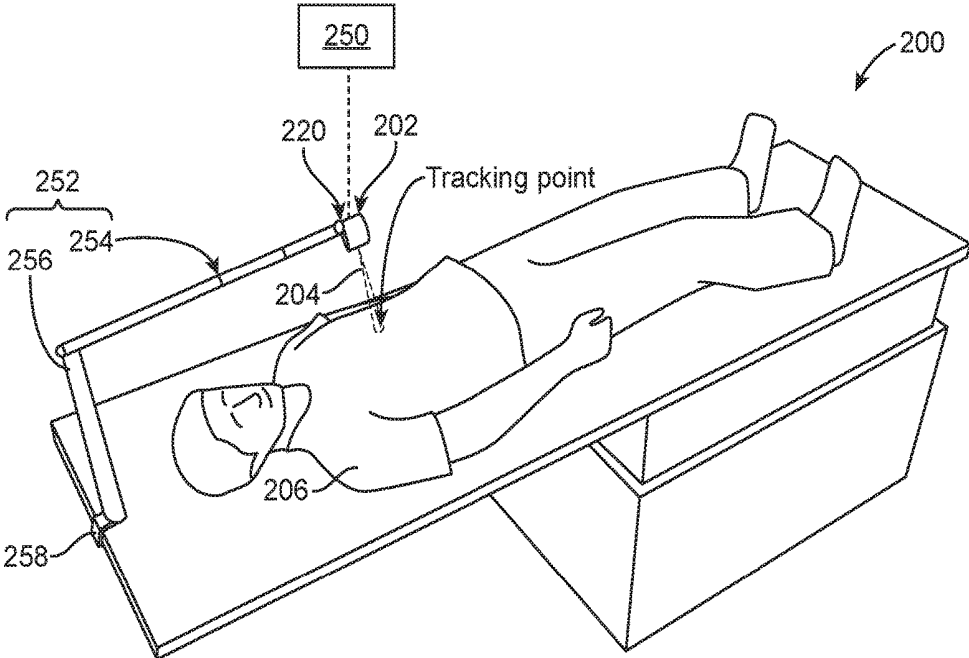


FIG. 4

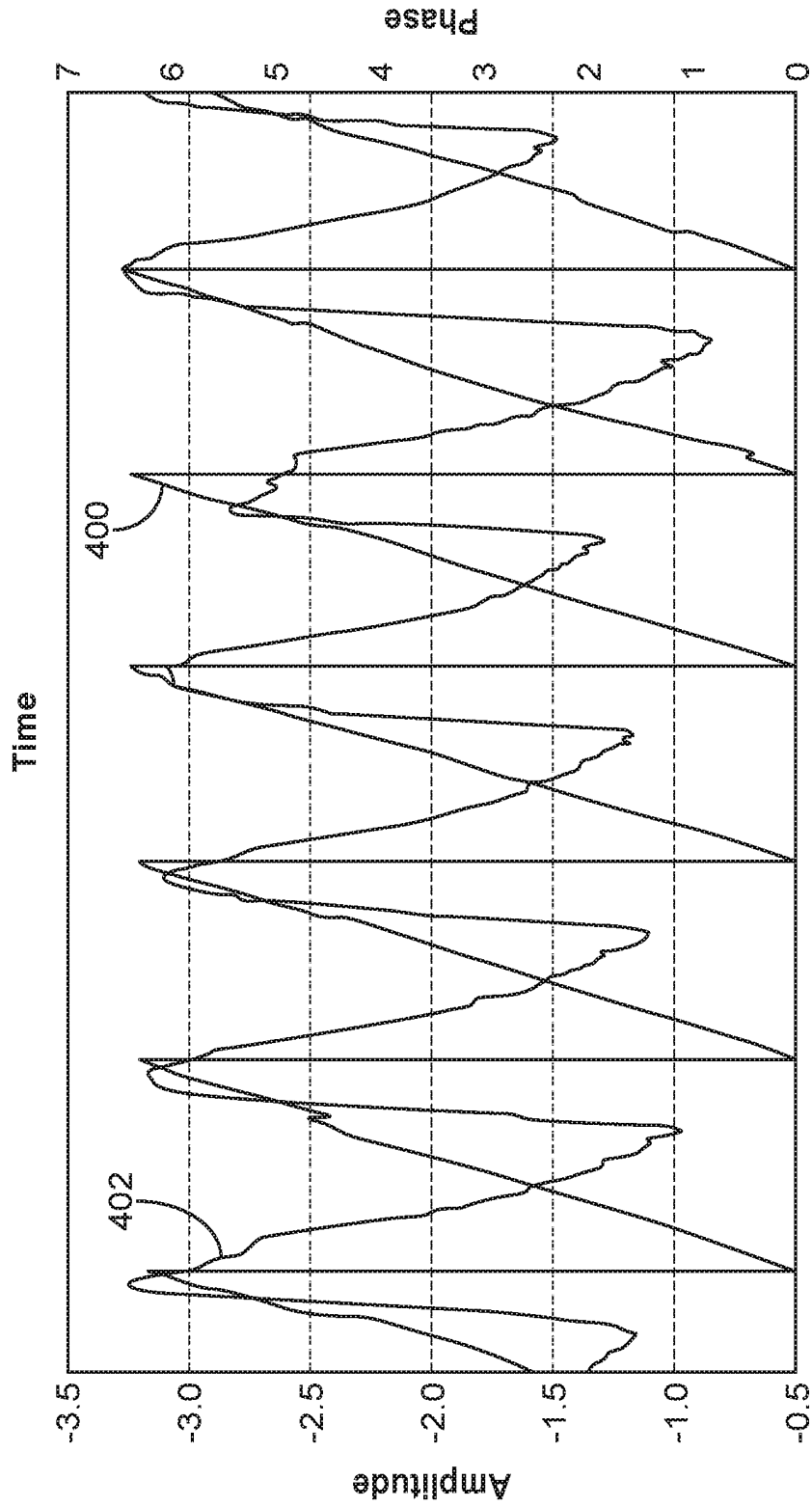


FIG. 5

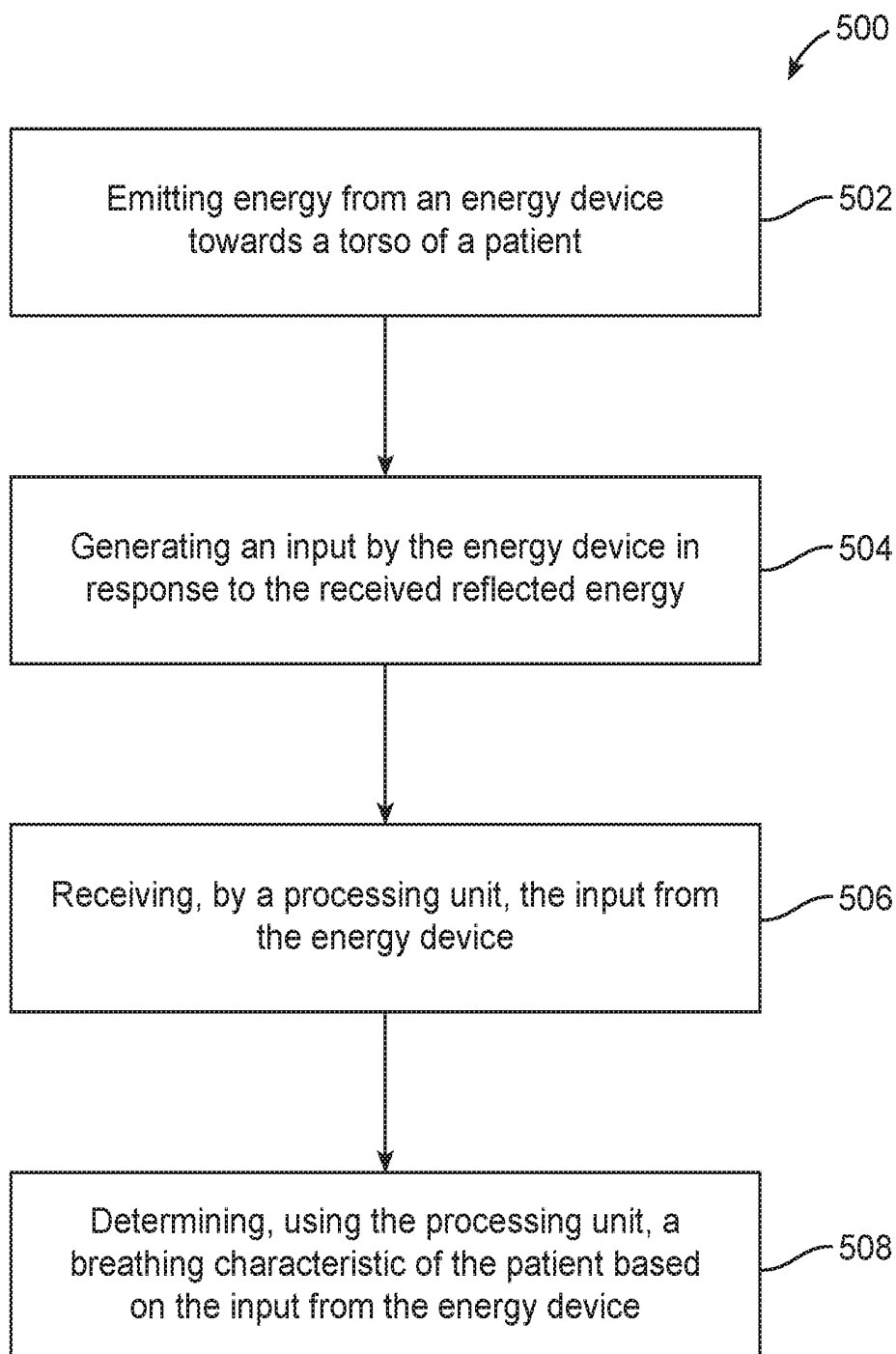


FIG. 6

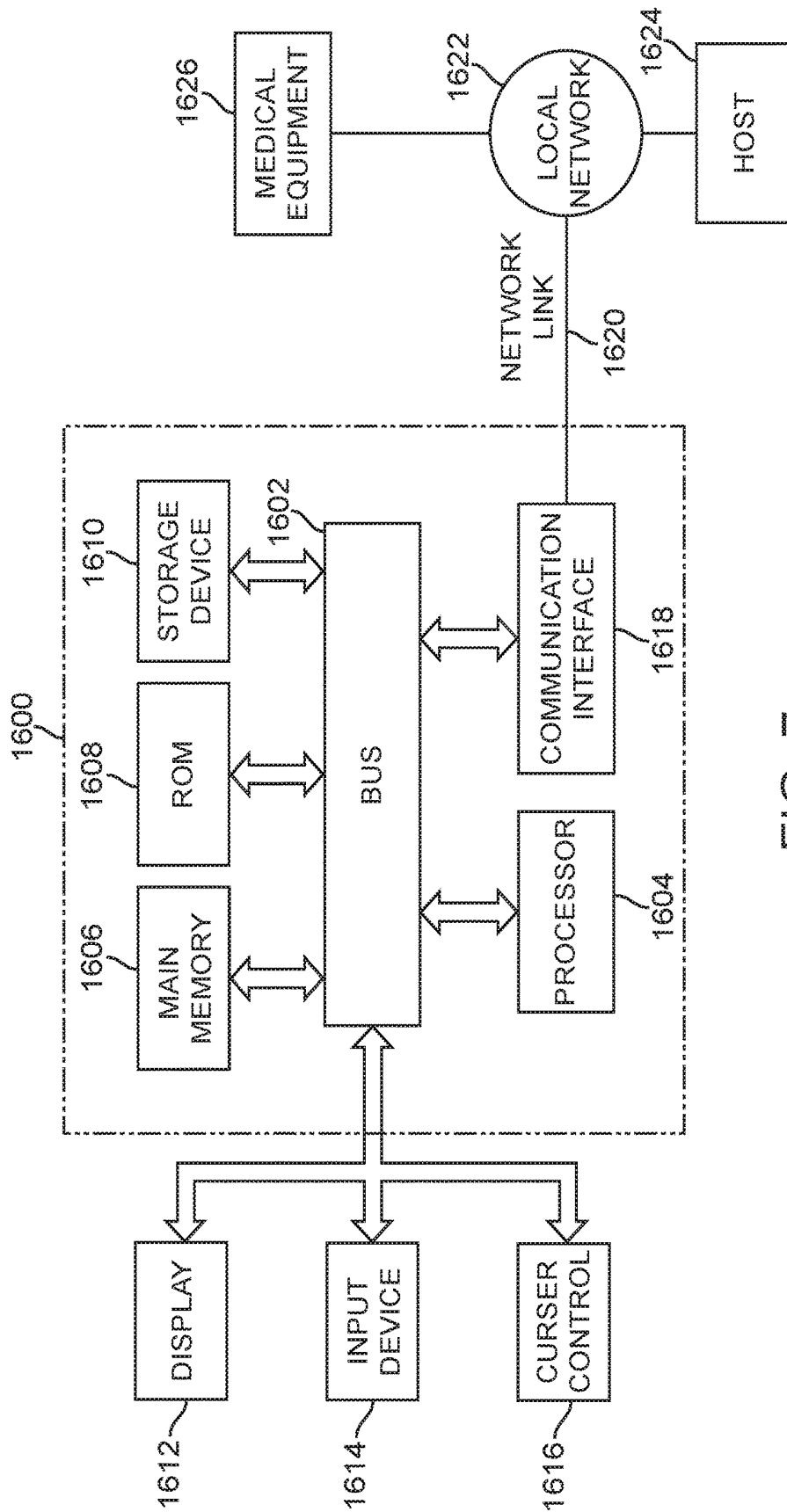


FIG. 7

**SYSTEMS AND METHODS FOR DETECTING
AND/OR MEASURING MOTION AND
POSITION ASSOCIATED WITH A PATIENT**

RELATED APPLICATION DATA

[0001] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 62/316,743, filed on Apr. 1, 2016, pending. The entire disclosure of the above application is expressly incorporated by reference herein.

FIELD

[0002] The field of the application relates to systems and methods for detecting and/or measuring patient motion, such as respiratory motion.

BACKGROUND

[0003] Radiation therapy involves medical procedures that selectively expose certain areas of a human body, such as cancerous tumors, to high doses of radiation. The intent of the radiation therapy is to irradiate the targeted biological tissue such that the harmful tissue is destroyed. During a radiation therapy, a radiation source may be rotated around a patient to deliver radiation from different angles at target region inside the patient. The radiation source may be mounted on an arm or a ring gantry. In certain radiation therapy, the patient support supporting the patient may also be moved.

[0004] During radiation therapy, it may be desirable to measure respiratory motion of the patient. For example, the measured respiratory motion of the patient may be used to gate a delivery of radiation.

[0005] In other types of therapy that may or may not involve use of radiation, it may also be desirable to measure respiratory motion of a patient. For examples, in ultrasound therapy or proton therapy, sometimes it may also be desirable to use a measured respiratory motion to gate a delivery of therapeutic energy.

[0006] Furthermore, in some cases, it may also be desirable to measure respiratory motion of a patient during a diagnostic procedure. For example, in a 4D computed tomography (CT) imaging process, the respiratory motion of the patient may be measured. The different phases of the breathing of the patient may then be correlated with different projection images. Projection images belonging to the same breathing phase may then be used in an image reconstruction process to reconstruct a three dimensional image.

[0007] Applicant of the subject disclosure determines that it may be desirable to provide a new system and method for measuring respiratory motion of a patient.

SUMMARY

[0008] An apparatus for patient position or motion monitoring includes: an energy source configured to emit energy from a first location to a second location, or vice versa, wherein the second location that is moveable relative to the first location in response to a movement by a patient; and a processing unit coupled to receive an input that is based on the emitted energy, and to determine a characteristic associated with the patient based on the input.

[0009] Optionally, the energy source is configured to emit energy from the first location to the second location, not from the second location to the first location.

[0010] Optionally, the apparatus further includes a receiver for operation with the energy source.

[0011] Optionally, the receiver is at the second location, and is configured to receive the energy directly from the energy source.

[0012] Optionally, the receiver is configured to receive reflected energy from the second location.

[0013] Optionally, the receiver is closer to the first location than the second location.

[0014] Optionally, the receiver and the energy source are integrated into a single device.

[0015] Optionally, the energy source is configured to emit energy from the second location to the first location, not from the first location to the second location.

[0016] Optionally, the apparatus further includes a receiver for operation with the energy source.

[0017] Optionally, the receiver is at the first location, and is configured to receive the energy directly from the energy source.

[0018] Optionally, the receiver is configured to receive reflected energy from the first location.

[0019] Optionally, the processing unit is configured to determine the characteristic of the patient based on time-of-flight technique.

[0020] Optionally, the processing unit is configured to determine the characteristic of the patient based on observation of geometric pattern or based on input from laser interferometer(s).

[0021] Optionally, the characteristic comprises a breathing characteristic, and the processing unit is configured to determine the breathing characteristic of the patient.

[0022] Optionally, the breathing characteristic comprises a breathing amplitude, a breathing phase, a period of a respiratory cycle, a breathing pattern, or any combination of the foregoing.

[0023] Optionally, the apparatus further includes a receiver for operation with the energy source.

[0024] Optionally, the apparatus further includes a mounting device configured to mount the energy source or the receiver to a patient support.

[0025] Optionally, the apparatus further includes a mounting device configured to mount the energy source or the receiver to a gantry of another component of a radiation machine.

[0026] Optionally, the gantry comprises a ring gantry.

[0027] Optionally, the apparatus further includes a mounting device configured to mount the energy source or the receiver to a ceiling or a wall.

[0028] Optionally, the energy source or the receiver has an operative position that is above a torso, a belly, or a head, of the patient.

[0029] Optionally, the apparatus further includes a screen for displaying an image for viewing by the patient.

[0030] Optionally, the image is for instructing the patient to control a breathing of the patient.

[0031] Optionally, the apparatus further includes a support structure, wherein the energy source or the receiver is moveably mounted to the support structure, and wherein the screen is also mounted to the support structure.

[0032] Optionally, the apparatus further includes a support structure, wherein the energy source or the receiver is rotatably mounted to the support structure.

[0033] Optionally, the energy source or the receiver is also slidably mounted to the support structure.

[0034] Optionally, the support structure comprises a telescopic arm.

[0035] Optionally, the energy source comprises an ultrasound device, a laser device, an infrared device, or a light device configured to emit ultraviolet light or visible light.

[0036] Optionally, the apparatus further includes an additional energy source configured to emit energy.

[0037] Optionally, the apparatus further includes one or more receivers for operation with the energy source, or for operation with the energy source and the additional energy source.

[0038] Optionally, the additional energy source is configured to emit the energy for measuring a distance between the energy source and an object that is fixed in position with respect to the energy source.

[0039] Optionally, the object comprises a patient support.

[0040] Optionally, the apparatus further includes one or more accelerometer(s) for determining an orientation of the energy source with respect to one or more axes.

[0041] Optionally, the apparatus further includes a measurement device configured to determine, or to provide information for determining, a distance between the first and second locations.

[0042] Optionally, the measurement device comprises a time-of-flight measurement device.

[0043] Optionally, the apparatus further includes a fiducial, wherein the energy source is configured to emit energy towards the fiducial.

[0044] Optionally, the fiducial comprises a marker, a marker plate, or a marker block.

[0045] Optionally, the marker comprises an active marker.

[0046] A medical system includes the apparatus described herein, and a medical device.

[0047] Optionally, the medical device comprises an imaging device.

[0048] Optionally, the medical device comprises a treatment device.

[0049] Optionally, the medical device comprises a ring gantry.

[0050] A method for determining a breathing of a patient, includes: emitting energy from an energy source from a first location to a second location, or vice versa, wherein the second location is moveable in response to a movement by the patient; generating an input by an energy receiver; receiving, by a processing unit, the input from the receiver; and determining, using the processing unit, a characteristic of the patient based on the input from the receiver.

[0051] Optionally, the characteristic comprises a breathing characteristic of the patient.

[0052] Optionally, the breathing characteristic comprises a breathing amplitude, a breathing phase, a period of a respiratory cycle, a breathing pattern, or any combination of the foregoing.

[0053] Optionally, the energy source or the receiver is above a torso, a belly, or a head, of the patient.

[0054] Optionally, the energy source or the receiver is mounted to a patient support, a gantry, a ceiling, or a wall.

[0055] Optionally, the energy source comprises an ultrasound device, a laser device, an infrared device, or a light device configured to emit ultraviolet light or visible light.

[0056] Optionally, the method further includes displaying an image on a screen for viewing by the patient.

[0057] Optionally, the image is for instructing the patient to control a breathing of the patient.

[0058] Other and further aspects and features will be evident from reading the following detailed description.

DESCRIPTION OF THE DRAWINGS

[0059] The drawings illustrate the design and utility of embodiments, in which similar elements are referred to by common reference numerals. These drawings are not necessarily drawn to scale. In order to better appreciate how the above-recited and other advantages and objects are obtained, a more particular description of the embodiments will be rendered, which are illustrated in the accompanying drawings. These drawings depict only exemplary embodiments and are not therefore to be considered limiting in the scope of the claims.

[0060] FIG. 1 illustrates a radiation treatment system.

[0061] FIG. 2 illustrates a respiratory motion measuring apparatus.

[0062] FIG. 3 illustrates a respiratory motion measuring apparatus.

[0063] FIG. 4 illustrates a respiratory motion measuring apparatus.

[0064] FIG. 5 illustrates an amplitude diagram aligned with a phase diagram.

[0065] FIG. 6 illustrates a method for determining a breathing characteristic of a patient.

[0066] FIG. 7 illustrates a specialized processing system with which embodiments described herein may be implemented.

DETAILED DESCRIPTION

[0067] Various embodiments are described hereinafter with reference to the figures. It should be noted that the figures are not drawn to scale and that elements of similar structures or functions are represented by like reference numerals throughout the figures. It should also be noted that the figures are only intended to facilitate the description of the embodiments. They are not intended as an exhaustive description of the invention or as a limitation on the scope of the invention. In addition, an illustrated embodiment needs not have all the aspects or advantages shown. An aspect or an advantage described in conjunction with a particular embodiment is not necessarily limited to that embodiment and can be practiced in any other embodiments even if not so illustrated, or if not so explicitly described.

[0068] FIG. 1 illustrates a radiation treatment system 10. The system 10 includes an arm gantry 12, a patient support 14 for supporting a patient 20, and a control system 18 for controlling an operation of the gantry 12 and delivery of radiation. The system 10 also includes a radiation source 22 that projects a beam 26 of radiation towards the patient 20 while the patient 20 is supported on support 14, and a collimator system 24 for changing a cross sectional shape of the radiation beam 26. The radiation source 22 may be configured to generate a cone beam, a fan beam, or other types of radiation beams in different embodiments. Also, in other embodiments, the source 22 may be configured to generate proton beam as a form of radiation for treatment purpose. Also, in other embodiments, the system 10 may have other form and/or configuration. For example, in other embodiments, instead of an arm gantry 12, the system 10 may have a ring gantry 12.

[0069] In the illustrated embodiments, the radiation source 22 is a treatment radiation source for providing treatment

energy. In other embodiments, in addition to being a treatment radiation source, the radiation source 22 can also be a diagnostic radiation source for providing diagnostic energy for imaging purpose. In such cases, the system 10 will include an imager, such as the imager 80, located at an operative position relative to the source 22 (e.g., under the support 14). In further embodiments, the radiation source 22 may be a treatment radiation source for providing treatment energy, wherein the treatment energy may be used to obtain images. In such cases, in order to obtain imaging using treatment energies, the imager 80 is configured to generate images in response to radiation having treatment energies (e.g., MV imager). In some embodiments, the treatment energy is generally those energies of 160 kilo-electron-volts (keV) or greater, and more typically 1 mega-electron-volts (MeV) or greater, and diagnostic energy is generally those energies below the high energy range, and more typically below 160 keV. In other embodiments, the treatment energy and the diagnostic energy can have other energy levels, and refer to energies that are used for treatment and diagnostic purposes, respectively. In some embodiments, the radiation source 22 is able to generate X-ray radiation at a plurality of photon energy levels within a range anywhere between approximately 10 keV and approximately 20 MeV. In further embodiments, the radiation source 22 can be a diagnostic radiation source. In such cases, the system 10 may be a diagnostic system with one or more moving parts. In the illustrated embodiments, the radiation source 22 is carried by the arm gantry 12. Alternatively, the radiation source 22 may be located within a bore (e.g., coupled to a ring gantry).

[0070] In the illustrated embodiments, the control system 18 includes a processing unit 54, such as a processor, coupled to a control 40. The control system 18 may also include a monitor 56 for displaying data and an input device 58, such as a keyboard or a mouse, for inputting data. The operation of the radiation source 22 and the gantry 12 are controlled by the control 40, which provides power and timing signals to the radiation source 22, and controls a rotational speed and position of the gantry 12, based on signals received from the processing unit 54. Although the control 40 is shown as a separate component from the gantry 12 and the processing unit 54, in alternative embodiments, the control 40 can be a part of the gantry 12 or the processing unit 54.

[0071] In some embodiments, the system 10 may be a treatment system configured to deliver treatment radiation beam towards the patient 20 at different gantry angles. During a treatment procedure, the source 22 rotates around the patient 20 and delivers treatment radiation beam from different gantry angles towards the patient 20. While the source 22 is at different gantry angles, the collimator 24 is operated to change the shape of the beam to correspond with a shape of the target tissue structure. For example, the collimator 24 may be operated so that the shape of the beam is similar to a cross sectional shape of the target tissue structure. In another example, the collimator 24 may be operated so that different portions of the target tissue structure receive different amount of radiation (as in an IMRT procedure).

[0072] FIG. 2 illustrates a respiratory motion measuring apparatus 200. The respiratory motion measuring apparatus 200 may be used with the radiation treatment system 10, or with other medical devices or systems. The apparatus 200 includes an energy device 202 configured to emit energy 204

towards a torso of a patient 206; and a processing unit 250 coupled to the energy device 202, wherein the processing unit 250 is configured to receive an input from the energy device 202, and determine a breathing characteristic of the patient 206. It should be noted that the processing unit 250 is not limited to being physically coupled to the energy device 202, and that the processing unit 250 may be communicatively coupled to the energy device 202 (e.g., wirelessly). Also, in some cases, the processing unit 250 and the energy device 202 may be in different respective rooms. In other cases, they may be in the same room.

[0073] The energy device 202 is configured to provide energy towards the patient 206, and sense the energy after the energy has been reflected from the patient 206. The energy device 202 may include an energy source configured to provide the energy 204 and/or an energy receiver to receive (e.g., detect) the energy 204 after it has been reflected from the patient 206. In some cases, the energy source and the energy receiver may be integrated into a single component. In other cases, the energy source and the energy receiver may be separate components. By means of non-limiting examples, the energy device 202 may comprise an ultrasound device configured to provide ultrasound energy and/or to sense reflected ultrasound energy, a laser device configured to provide laser and/or to sense reflected laser, an infrared device configured to provide infrared energy and/or to sense reflected infrared energy, a light device configured to emit ultraviolet light or visible light, and/or to sense reflected ultraviolet light or visible light, or any of other types of energy device configured to provide and/or sense energy.

[0074] In some cases, the energy 204 from the energy device 202 may be delivered to the patient (e.g., to the skin of the patient, to a cloth being worn by the patient, or to a blanket covering the patient). In other cases, the respiratory motion measuring apparatus 200 may include a fiducial that is configured to be coupled to the torso of the patient. In such cases, the energy device 202 is configured to emit the energy 204 towards the fiducial and/or to sense the energy 204 after it has been reflected from the fiducial. By means of non-limiting examples, the fiducial may include one or more marker(s), a marker plate, or a marker block. The marker(s) may be passive marker(s) and/or active marker(s), e.g., marker(s) that sends out a signal, such as infrared, visible light, ultraviolet ray, ultrasound, etc. In some cases, the cloth being worn by the patient 206 or a blanket covering the patient 206 may be considered to be a part of the patient, or the fiducial itself. Providing a fiducial coupled to the patient may be advantageous because it allows the respiratory motion measuring apparatus 200 to detect and track the measurement reference so that the same location with respect to the patient is always used for obtaining the measurement. Also, in other cases, the energy 204 from the energy device 202 may be delivered to a belly, or to a fiducial coupled to the belly, of the patient, thereby using the belly directly or indirectly as a measurement reference.

[0075] It should be noted that the respiratory motion measuring apparatus 200 is not limited to having only one energy device 202. In other cases, the respiratory motion measuring apparatus 200 may include one or more additional energy device(s) configured to emit energy or energies towards the torso of the patient, or to different parts of the patient. The additional energy device(s) may provide additional measurement points to monitor patient movements.

The multiple measurements may provide redundancy for tracking a certain part (e.g., torso) of the patient 206, or may track multiple different parts of the patient 206.

[0076] In the illustrated embodiments, the energy device 202 of the respiratory motion measuring apparatus 200 is configured to function as a measurement device configured to determine, or to provide information for determining, a distance from a torso of the patient. For example, in some cases, the energy device 202 itself may include a timer that measures the time it takes for the energy 204 to reach the patient or a fiducial, and to travel back to the receiver of the energy device 202. The energy device 202 may provide the time information to the processing unit 250, which then determines a distance between the energy device 202 (e.g., the receiver in the energy device 202) and the patient 206 (or a fiducial coupled to the patient 206) based on a speed of travel of the energy 204. In other cases, the energy device 202 may include a processing unit to determine the distance based on the time information.

[0077] In other embodiments, the respiratory motion measuring apparatus 200 may include another measurement device (e.g., a time-of-flight measurement device) configured to determine, or to provide information for determining, a distance from a fixed object. In particular, the respiratory motion measuring apparatus 200 may optionally further include a second energy device 203 configured to provide energy 205 for measuring a distance relative to a fixed object, e.g., a surface of the patient support (FIG. 3). The second energy device 203 is communicatively coupled to the processing unit 250 using a cable or a wireless system. The second energy device 203 may include an energy source configured to provide the energy 205 and/or an energy receiver to receive (e.g., detect) the energy 205 after it has been reflected from the object. In some cases, the energy source and the energy receiver may be integrated into a single component. In other cases, the energy source and the energy receiver may be separate components. By means of non-limiting examples, the second energy device 203 may comprise an ultrasound device configured to provide ultrasound energy and/or to sense reflected ultrasound energy, a laser device configured to provide laser and/or to sense reflected laser, an infrared device configured to provide infrared energy and/or to sense reflected infrared energy, a light device configured to emit ultraviolet light or visible light, and/or to sense reflected ultraviolet light or visible light, or any of other types of energy device configured to provide and/or sense energy. Although only one additional energy device 203 is shown in FIG. 3, in other embodiments, there may be more than one additional energy device 203. For example, in other cases, there may be a first additional energy device 203 and a second additional energy device 203 configured to provide respective energies to fixed objects. The additional energy devices 203 may be configured to receive reflected energies from the respective fixed objects, and distances from the fixed objects can then be determined by the processing unit 250 using time-of-flight technique.

[0078] Returning to FIG. 2, in some cases, the processing unit 250 may be configured to determine the breathing characteristic of the patient 206. In some embodiments, the energy device 202 provides time information to the processing unit 250 regarding a time it takes for the energy 204 to travel from the energy source 202 to the patient 206 (or a fiducial coupled to the patient 206), and then back to the

energy device 202. In such cases, the processing unit 250 includes a distance determination module configured to receive the time information and information regarding a speed of travel for the energy 204, and calculate a distance between the energy device 202 and the patient 206 (or a fiducial that is coupled to the patient 206) based on time-of-flight technique. In other cases, the energy device 202 may itself determine the distance, and transmit the distance to the processing unit 250. In either case, after obtaining the distance, the processing unit 250 may determine one or more breathing characteristic of the patient 206. By means of non-limiting examples, the breathing characteristic may be one or more breathing amplitude(s), one or more breathing phase(s), a period of a respiratory cycle, a breathing pattern, or any combination of the foregoing. It should be noted that the embodiments described herein are not limited to using time-of-flight technique to determine the distance between the energy device 202 and the patient 206, and that other techniques may be used in other embodiments. For example, in other embodiments, observation of geometric pattern or laser interferometer(s) may be used.

[0079] In some cases, the processing unit 250 may include a breathing amplitude determination module configured to determine breathing amplitudes. In some cases, the distance information obtained by the processing unit 250 may be used as the breathing amplitudes. In other cases, the breathing amplitude determination module may perform scaling, averaging, normalization, or any combination of the foregoing, using the distance values to determine breathing amplitudes. The breathing amplitudes may be stored in a non-transitory medium for later use. In addition, or alternatively, the breathing amplitudes may be displayed on a screen for presentation to a user.

[0080] Also, in some cases, the processing unit 250 may include a breathing phase determination module configured to determine breathing phases. In particular, by determining a plurality of positions of the patient's torso or fiducial over a period of time, the processing unit 250 can be configured to obtain a plurality of phase points that correspond to different levels of completeness of a breathing cycle at various time points. For example, a phase value may have a value from 0° to 360°, with 0° representing a beginning of a respiratory cycle, and 360° representing an end of the respiratory cycle. FIG. 5 illustrates an example of a phase diagram 400 that is aligned with a corresponding amplitude/position diagram 402. Amplitude diagram 402 includes positional points of the patient (e.g., torso) or fiducial determined using embodiments of the technique described herein. Each point in the amplitude diagram 402 represents a position of a bodily part or fiducial at a certain point in time. In the illustrated example, a phase value of 0° (and 360°) represents a peak of an inhale state, and the phase value varies linearly between 0° and 360° in a physiological cycle. As shown in the diagram, for each point in the amplitude diagram 402 at certain point in time, a corresponding phase value at the same point in time may be obtained. Thus, for each breathing amplitude, the processing unit 250 can determine the corresponding phase of the respiratory cycle.

[0081] The breathing phases may be stored in a non-transitory medium for later use. In addition, or alternatively, the breathing phases may be displayed on a screen for presentation to a user.

[0082] In some embodiments, the determined phase values may be used to gate an execution of a procedure, such as, to gate an application of a treatment radiation to the patient 206 for treatment, or to gate an application of an imaging radiation to the patient 206 for imaging purpose. In further embodiments, the phase values may be used to perform tracking of a target region while IMRT is being performed.

[0083] In other embodiments, the determined phase values may be used to gate a binning of image data, either in real time while the image data is being obtained, or after the image data has been obtained. For example, in a 4D-CT imaging session, the respiratory motion measuring apparatus 200 may be used to determine the positions of the patient's torso representing different breathing amplitudes of the patient 206, while a CT machine generates different projection images of the patient 206 at different respective gantry angles. The positions of the patient's torso may be used to determine breathing phases for association with different projection images. For example, different projection images generated at different gantry angles but belonging to a same phase range (phase bin) may be associated together. The associated projection images may then be used to construct a volumetric CT image for that particular phase bin. Also, in some embodiments, different volumetric CT images for different phase bins may be constructed (e.g., using the processing unit 250 or another processor), and the sequence of volumetric CT images may be displayed in a video.

[0084] Furthermore, in some embodiments, the processing unit 250 may include a breathing period determination module configured to determine a breathing period of a patient. In one technique, the breathing period determination module of the processing unit 250 may be configured to determine two maximum amplitudes in the breathing amplitude graph, and then determine the period between the two maximum amplitudes. The period may then be used as the period of the breathing cycle. Alternatively, the breathing period determination module of the processing unit 250 may be configured to determine two minimum amplitudes in the breathing amplitude graph, and then determine the period between the two minimum amplitudes. The period may then be used as the period of the breathing cycle. In further embodiments, the breathing period determination module may be configured to determine a duration between a first phase value (e.g., 0°) and a second phase value (e.g., 360°), and use the duration as the breathing period. The breathing period may be stored in a non-transitory medium for later use. In addition, or alternatively, the breathing period may be displayed on a screen for presentation to a user.

[0085] In further embodiments, the processing unit 250 may include a breathing pattern determination module configured to determine a breathing pattern of the patient 206. In one implementation, the processing unit 250 is configured to receive a plurality of breathing amplitude data, and store the breathing amplitude data with their corresponding time points in a non-transitory medium. In some cases, the breathing amplitude data and their corresponding time points form a breathing pattern, which may be used as a reference breathing pattern for later use. For example, after the reference breathing pattern has been established, the respiratory motion measuring apparatus 200 may continue to monitor a breathing of the patient 206. As the breathing of the patient 206 is being monitored, the respiratory motion measuring apparatus 200 continues to generate breathing amplitude data for processing by the processing unit 250.

The processing unit 250 may use the breathing amplitude data to determine a current breathing pattern of the patient 206. The processing unit 250 may also compare the current breathing pattern with the reference breathing pattern to determine if the patient 206 is breathing regularly or not. In some cases, if the processing unit 250 detects a deviation from periodicity for the breathing of the patient 206, the processing unit 250 may then generate a signal to stop a medical procedure, and/or to warn a technician.

[0086] In some cases, the breathing pattern may be stored in a non-transitory medium for later use. In addition, or alternatively, the breathing pattern may be displayed on a screen for presentation to a user.

[0087] Returning to FIG. 2, in some embodiments, the processing unit 250 may be coupled to the energy device 202 using a cable. In other embodiments, the processing unit 250 may be coupled to the energy device 202 using a wireless system. In such cases, the energy device 202 may include a first wireless device, and the processing unit 250 may include a second wireless device for communication with the first wireless device.

[0088] As shown in the figure, the respiratory motion measuring apparatus 200 further includes a support structure 252, wherein the energy device 202 is moveably mounted to the support structure 252. In the illustrated embodiments, the support structure 252 includes a telescopic arm 254 and a vertical support 256. The telescopic arm 254 allows the energy device 202 to translate relative to the vertical support 256 of the support structure 252. Accordingly, the energy device 202 is slidably mounted to a part of the support structure 252. Also, in the illustrated embodiments, the energy device 202 is rotatably mounted to one end of the telescopic arm 254 via a moveable connector 220, e.g., a hinge or a ball joint. In some cases, the energy device 202 is coupled to the support structure 252 such that the energy device 202 may translate in three degrees of freedom (e.g., along X-axis, Y-axis, and Z-axis that are orthogonal to each other), and/or rotate in three degrees of freedom (e.g., rotate about X-axis, Y-axis, and Z-axis).

[0089] It should be noted that the support structure 252 is not limited to the example shown in the figure, and that the support structure 252 may have other configurations in other embodiments. For example, in other cases, the support structure 252 may have a different form. Also, in other cases, the support structure 252 may not include any telescopic arm. In addition, in other cases, instead of mounting above the head of the patient 206, the support structure 252 may be mounted to a side of the patient support or to a bottom part of the patient support supporting the patient's feet. Accordingly, the telescopic arm 254 does not need to extend above the patient's head, and may extend above the patient's shoulder, above the bottom torso of the patient, etc. Furthermore, in other cases, instead of mounting to the patient support, the support structure 252 may be configured to be mounted to another object, such as a gantry of a radiation machine (e.g., CT machine, radiation treatment machine, etc.), a ceiling, a wall, etc. Furthermore, in other embodiments, the support structure 252 may not be needed. Instead, the energy device 202 may be mounted directly to an object, such as a patient support, a gantry, an arm, a ceiling, etc.

[0090] As shown in the figure, the energy device 202 has an operative position that is above the torso of the patient 206. In other embodiments, the energy device 202 may have an operative position that is located at other places with

respect to the patient 206. For example, the energy device 202 may be located above a head of the patient 206, or above the feet of the patient 206.

[0091] In addition, as shown in the figure, the respiratory motion measuring apparatus 200 further includes a mounting device 258 configured to mount the energy device 202 with respect to the patient support. In the illustrated example, the mounting device 258 is a clamp located at a bottom end of the vertical support 256 configured to detachably mount the vertical support 256 to the patient support. In other cases, the mounting device 258 may include a snap-fit connector, one or more screws, and/or other type of connectors for securing the respiratory motion measuring apparatus 200 relative to an object, such as the patient support, a gantry, a ceiling, a wall, etc.

[0092] Also, as shown in the figure, the respiratory motion measuring apparatus 200 further includes a screen 260 for displaying an image for viewing by the patient 206. The screen 260 is mounted to the telescopic arm 254 of the support 252. In other cases, the screen 260 may be mounted to the vertical support 256, or to another support structure. In some cases, the image may be for instructing the patient 206 to control a breathing of the patient 206. For example, the image in the screen 260 may display a command for instructing the patient 206 to hold breath, to inhale, to exhale, or any combination of the foregoing. In some embodiments, the screen 260 may provide an animation (e.g., in a form of a game) for allowing the patient 206 to play, wherein an object in the image may be controlled by the patient's breathing. In the animation, the patient 206 may be instructed to control the object using his/her breathing so that the position of the object coincides with one or more target objects in the screen 260. By means of non-limiting examples, the one or more target objects may include a first horizontal bar representing a desired inhale level, a second horizontal bar representing a desired exhale level, or both. Also, in other examples, the one or more target objects may include multiple target objects that are moving in the screen 260 (e.g., blocks moving linearly across the screen 260).

[0093] In other embodiments, the screen 260 is optional, and the respiratory motion measuring apparatus 200 may not include the screen 260 (FIG. 4).

[0094] During use of the respiratory motion measuring apparatus 200, the energy device 202 is first positioned at its intended operative position relative to the patient 206. In the illustrated example, the energy device 202 is placed above the torso of the patient 206 aiming downward towards the torso of the patient 206. The energy device 202 then emits the energy 204 towards the patient 206. The energy 204 reflected from the patient 206 and travels back towards the energy device 202. A receiver in the energy device 202 receives (e.g., detects) the reflected energy, and the energy device 202 or the processing unit 250 may then determine a time it takes for the energy 204 to travel to the patient 206 and to reflect back to the receiver. Based on the time information, the energy device 202 and/or the processing unit 250 may then use time-of-flight technique to determine a distance between the energy device 202 and the torso of the patient 206. As the patient 206 breathes, the chest of the patient 206 moves up and down. Accordingly, the distance between the energy device 202 and the moving torso varies during a breathing cycle. The energy device 202 is configured to provide the energy 204 and to receive the reflected energy at a frequency that is much higher than a frequency

of the patient's breathing. Thus, as the patient 206 breathes, the respiratory motion measuring apparatus 200 generates multiple positional data representing different positions of the torso of the patient 206 during to breathing. It should be noted that the respiratory motion apparatus 200 is not limited to using time-of-flight technique to determine the distance between the energy device 202 and the torso of the patient 206, and that other techniques may be used in other embodiments. For example, in other embodiments, observation of geometric pattern or laser interferometer(s) may be used.

[0095] The respiratory motion measuring apparatus 200 and the method 500 are advantageous because they require no or minimal calibration effort, and they do not require use of any camera system. Also, in the embodiments in which the respiratory motion measuring apparatus 200 is mounted to the patient support, the use of the apparatus 200 is independent of the position of the patient support. In addition, in some cases, the apparatus 200 may allow for couch kick. Furthermore, in the embodiments in which the energy device 202 delivers energy 204 directly to the patient 206 (i.e., without use of any marker block), use of the apparatus 200 provides biocompatibility and cleaning advantageous because there is no marker block that touches the patient 206.

[0096] FIG. 6 illustrates a method 500 for determining a breathing characteristic of a patient. The method 500 includes emitting energy from an energy device towards a torso of a patient (item 502) receiving reflected energy by the energy device. The method 500 also includes generating an input by the energy device in response to the received reflected energy (item 504). The method 500 further includes receiving, by a processing unit, the input from the energy device (item 506). In addition, the method 500 further includes determining, using the processing unit, a breathing characteristic of the patient based on the input from the energy device (item 508).

[0097] Optionally, the breathing characteristic of the patient is determined based on time-of-flight technique.

[0098] Optionally, the breathing characteristic comprises a breathing amplitude, a breathing phase, a period of a respiratory cycle, or a breathing pattern.

[0099] Optionally, the energy device is above the torso.

[0100] Optionally, the energy device is mounted to a patient support, a gantry, a ceiling, or a wall.

[0101] Optionally, the energy device comprises an ultrasound device, a laser device, an infrared device, or a light device configured to emit ultraviolet light or visible light.

[0102] Optionally, the method further includes displaying an image on a screen for viewing by the patient.

[0103] Optionally, the image is for instructing the patient to control a breathing of the patient.

[0104] It should be noted that the apparatus and method described herein are not limited to monitoring patient movement, and that they can be applied for monitoring a position of a patient. For example, the apparatus described herein may be used to determine whether the patient did move or not during a procedure (e.g., imaging procedure, and/or a treatment procedure).

[0105] Also, in other embodiments, instead of using the torso as a reference point, other features may be used as reference point. For example, a marker or a marker block

placed on the belly may be used as a reference point. In another example, a head of the patient may be used as a reference point.

[0106] Furthermore, in any of the embodiments described herein, the apparatus may further include one or more accelerometer(s) for sensing an orientation of the energy device 202 with respect to one or more axes. The accelerometer(s) may be incorporated inside a housing of the energy device 202, or may be coupled to the energy device 202, so that an orientation of the energy device 202 can be sensed by the accelerometer(s). During use of the energy device 202, the energy device 202 may not be aiming vertically towards a torso of the patient. For example, the energy device 202 may be aiming at a non-vertical direction towards the torso of the patient. The accelerometer(s) is advantageous because it can sense the orientation of the energy device 202, which indicates the direction of aiming by the energy device 202. The sensed orientation may be transmitted to the processing unit (e.g., by wire, or wirelessly). Based on the sensed orientation of the energy device 202, and time of flight information, the processing unit may then calculate a vertical distance between the patient and a reference location (which vertical distance may be the vertical component of the distance between the energy device 202 and the patient along the aiming direction). In other embodiments, instead of using accelerometer(s), the apparatus may use other types of orientation sensor(s) for sensing an orientation of the energy device 202.

[0107] It should be noted that the processing unit is not limited to determining a vertical distance, and that the processing unit may be configured to determine any distance along any axis in other embodiments.

[0108] As discussed, the energy device 202 includes an energy source for emitting energy, and a receiver for receiving (e.g., detecting) reflected energy, wherein both the energy source and the receiver are fixedly coupled to a same reference location. In other embodiments, the energy source and the receiver of the energy device 202 may be at different respective locations. Accordingly, it should be noted that the term “device” or “energy device” is not limited to a single item/object at a single location, and may refer to multiple components/items that are at different respective locations. For example, in some cases, the receiver may be placed at or coupled directly or indirectly to the patient, while the energy source is fixedly mounted to a reference location (e.g., a support, the patient support, or a part of a medical machine). Thus, movement of the patient will cause the receiver to move correspondingly relative to the energy source. During use, the energy source emits energy towards the patient. The processing unit keeps track of the time at which energy is emitted. When the receiver receives (e.g., detects) the emitted energy, it transmits to the processing unit the time at which the energy is received. Based on the time of energy emission, and the time of energy reception, the processing unit can then determine a distance between the energy source and the receiver. In other embodiments, the energy source may be placed at or coupled directly or indirectly to the patient, while the receiver is fixedly mounted to a reference location. In such cases, movement of the patient will cause the energy source to move correspondingly relative to the receiver.

[0109] In further embodiments, both the energy source and the receiver may be placed at or coupled directly or indirectly to the patient. During use, the energy source of the

energy device 202 emits energy towards a reference location (that is fixed with respect to some coordinate system), which may be an object that is fixedly coupled directly or indirectly to the patient support or to a component of a medical machine. The energy is reflected from the reference location, and travels back towards the receiver. Based on the time it takes for the emitted energy to travel from the energy source and to come back to the receiver, the processing unit can then determine the distance between the energy device 202 and the reference location.

[0110] Also, in any of the embodiments described herein, there may be multiple energy sources operating with one receiver, or one energy source operating with multiple receivers, or multiple energy sources operating with multiple receivers.

[0111] Specialized Processing System

[0112] FIG. 7 is a block diagram illustrating an embodiment of a specialized processing system 1600 that can be used to implement various embodiments described herein. For example, the processing system 1600 may be configured to implement the method of FIG. 6 in accordance with some embodiments. Also, in some embodiments, the processing system 1600 may be used to implement the processing unit 54 of FIG. 1, the processing unit 250 of FIG. 2, 3, or 4, or any processing unit described herein.

[0113] Processing system 1600 includes a bus 1602 or other communication mechanism for communicating information, and a processor 1604 coupled with the bus 1602 for processing information. The processor 1604 may be an example of the processor 54 of FIG. 1, or an example of any processor described herein. The processing system 1600 also includes a main memory 1606, such as a random access memory (RAM) or other dynamic storage device, coupled to the bus 1602 for storing information and instructions to be executed by the processor 1604. The main memory 1606 also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor 1604. The processing system 1600 further includes a read only memory (ROM) 1608 or other static storage device coupled to the bus 1602 for storing static information and instructions for the processor 1604. A data storage device 1610, such as a magnetic disk or optical disk, is provided and coupled to the bus 1602 for storing information and instructions.

[0114] The processing system 1600 may be coupled via the bus 1602 to a display 167, such as a cathode ray tube (CRT), for displaying information to a user. An input device 1614, including alphanumeric and other keys, is coupled to the bus 1602 for communicating information and command selections to processor 1604. Another type of user input device is cursor control 1616, such as a mouse, a trackball, or cursor direction keys for communicating direction information and command selections to processor 1604 and for controlling cursor movement on display 167. This input device typically has two degrees of freedom in two axes, a first axis (e.g., x) and a second axis (e.g., y), that allows the device to specify positions in a plane.

[0115] In some embodiments, the processing system 1600 can be used to perform various functions described herein. According to some embodiments, such use is provided by processing system 1600 in response to processor 1604 executing one or more sequences of one or more instructions contained in the main memory 1606. Those skilled in the art will know how to prepare such instructions based on the

functions and methods described herein. Such instructions may be read into the main memory 1606 from another computer-readable medium, such as storage device 1610. Execution of the sequences of instructions contained in the main memory 1606 causes the processor 1604 to perform the process steps described herein. One or more processors in a multi-processing arrangement may also be employed to execute the sequences of instructions contained in the main memory 1606. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement the various embodiments described herein. Thus, embodiments are not limited to any specific combination of hardware circuitry and software.

[0116] The term “computer-readable medium” as used herein refers to any medium that participates in providing instructions to the processor 1604 for execution. Such a medium may take many forms, including but not limited to, non-volatile media, volatile media, and transmission media. Non-volatile media includes, for example, optical or magnetic disks, such as the storage device 1610. A non-volatile medium may be considered an example of non-transitory medium. Volatile media includes dynamic memory, such as the main memory 1606. A volatile medium may be considered an example of non-transitory medium. Transmission media includes coaxial cables, copper wire and fiber optics, including the wires that comprise the bus 1602. Transmission media can also take the form of acoustic or light waves, such as those generated during radio wave and infrared data communications.

[0117] Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, or any other magnetic medium, a CD-ROM, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, a RAM, a PROM, and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave as described hereinafter, or any other medium from which a computer can read.

[0118] Various forms of computer-readable media may be involved in carrying one or more sequences of one or more instructions to the processor 1604 for execution. For example, the instructions may initially be carried on a magnetic disk of a remote computer. The remote computer can load the instructions into its dynamic memory and send the instructions over a telephone line using a modem. A modem local to the processing system 1600 can receive the data on the telephone line and use an infrared transmitter to convert the data to an infrared signal. An infrared detector coupled to the bus 1602 can receive the data carried in the infrared signal and place the data on the bus 1602. The bus 1602 carries the data to the main memory 1606, from which the processor 1604 retrieves and executes the instructions. The instructions received by the main memory 1606 may optionally be stored on the storage device 1610 either before or after execution by the processor 1604.

[0119] The processing system 1600 also includes a communication interface 1618 coupled to the bus 1602. The communication interface 1618 provides a two-way data communication coupling to a network link 1620 that is connected to a local network 1622. For example, the communication interface 1618 may be an integrated services digital network (ISDN) card or a modem to provide a data communication connection to a corresponding type of telephone line. As another example, the communication interface 1618 may be a local area network (LAN) card to

provide a data communication connection to a compatible LAN. Wireless links may also be implemented. In any such implementation, the communication interface 1618 sends and receives electrical, electromagnetic or optical signals that carry data streams representing various types of information.

[0120] The network link 1620 typically provides data communication through one or more networks to other devices. For example, the network link 1620 may provide a connection through local network 1622 to a host computer 1624 or to equipment 1626 such as a radiation beam source or a switch operatively coupled to a radiation beam source. The data streams transported over the network link 1620 can comprise electrical, electromagnetic or optical signals. The signals through the various networks and the signals on the network link 1620 and through the communication interface 1618, which carry data to and from the processing system 1600, are exemplary forms of carrier waves transporting the information. The processing system 1600 can send messages and receive data, including program code, through the network(s), the network link 1620, and the communication interface 1618.

[0121] In the above embodiments, the respiratory motion measuring apparatus 200 has been described with reference to it being used with a radiation machine in a radiation procedure (e.g., CT imaging, radiation treatment, etc.). However, it should be noted that the respiratory motion measuring apparatus 200 and the method 500 may be used with other types of machine and in other procedures. For example, the respiratory motion measuring apparatus 200 may be used with a proton machine in a proton treatment procedure, with an ultrasound machine in an ultrasound imaging and/or treatment procedure. Also, in other embodiments, the respiratory motion measuring apparatus 200 may be used in a data collection process that does not involve any treatment or medical imaging. For example, in other cases, the method 500 may be performed to determine a plurality of positional data representing breathing amplitudes of a patient. The positional data may be stored in a non-transitory medium for later use. For example, the positional data may be used later in a treatment process.

[0122] Although particular embodiments have been shown and described, it will be understood that it is not intended to limit the claimed inventions to the preferred embodiments, and it will be obvious to those skilled in the art that various changes and modifications may be made without departure from the spirit and scope of the claimed inventions. The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense. The claimed inventions are intended to cover alternatives, modifications, and equivalents.

1. An apparatus for patient position or motion monitoring, comprising:

an energy source configured to emit energy from a first location to a second location, or vice versa, wherein the second location that is moveable relative to the first location in response to a movement by a patient; and
a processing unit coupled to receive an input that is based on the emitted energy, and to determine a characteristic associated with the patient based on the input.

2. The apparatus of claim 1, wherein the energy source is configured to emit energy from the first location to the second location, not from the second location to the first location.

3. The apparatus of claim 2, further comprising a receiver for operation with the energy source.

4. The apparatus of claim 3, wherein the receiver is at the second location, and is configured to receive the energy directly from the energy source.

5. The apparatus of claim 3, wherein the receiver is configured to receive reflected energy from the second location.

6. The apparatus of claim 5, wherein the receiver is closer to the first location than the second location.

7. The apparatus of claim 6, wherein the receiver and the energy source are integrated into a single device.

8. The apparatus of claim 1, wherein the energy source is configured to emit energy from the second location to the first location, not from the first location to the second location.

9. The apparatus of claim 8, further comprising a receiver for operation with the energy source.

10. The apparatus of claim 9, wherein the receiver is at the first location, and is configured to receive the energy directly from the energy source.

11. The apparatus of claim 9, wherein the receiver is configured to receive reflected energy from the first location.

12. The apparatus of claim 1, wherein the processing unit is configured to determine the characteristic of the patient based on time-of-flight technique.

13. The apparatus of claim 1, wherein the processing unit is configured to determine the characteristic of the patient based on observation of geometric pattern or based on input from laser interferometer(s).

14. The apparatus of claim 1, wherein the characteristic comprises a breathing characteristic, and the processing unit is configured to determine the breathing characteristic of the patient.

15. The apparatus of claim 14, wherein the breathing characteristic comprises a breathing amplitude, a breathing phase, a period of a respiratory cycle, a breathing pattern, or any combination of the foregoing.

16. The apparatus of claim 1, further comprising a receiver for operation with the energy source.

17. The apparatus of claim 16, further comprising a mounting device configured to mount the energy source or the receiver to a patient support.

18. The apparatus of claim 16, further comprising a mounting device configured to mount the energy source or the receiver to a gantry of another component of a radiation machine.

19. The apparatus of claim 18, wherein the gantry comprises a ring gantry.

20. The apparatus of claim 16, further comprising a mounting device configured to mount the energy source or the receiver to a ceiling or a wall.

21. The apparatus of claim 16, wherein the energy source or the receiver has an operative position that is above a torso, a belly, or a head, of the patient.

22. The apparatus of claim 16, further comprising a screen for displaying an image for viewing by the patient.

23. The apparatus of claim 22, wherein the image is for instructing the patient to control a breathing of the patient.

24. The apparatus of claim 22, further comprising a support structure, wherein the energy source or the receiver is moveably mounted to the support structure, and wherein the screen is also mounted to the support structure.

25. The apparatus of claim 16, further comprising a support structure, wherein the energy source or the receiver is rotatably mounted to the support structure.

26. The apparatus of claim 25, wherein the energy source or the receiver is also slidably mounted to the support structure.

27. The apparatus of claim 25, wherein the support structure comprises a telescopic arm.

28. The apparatus of claim 1, wherein the energy source comprises an ultrasound device, a laser device, an infrared device, or a light device configured to emit ultraviolet light or visible light.

29. The apparatus of claim 1, further comprising an additional energy source configured to emit energy.

30. The apparatus of claim 29, further comprising one or more receivers for operation with the energy source, or for operation with the energy source and the additional energy source.

31. The apparatus of claim 29, wherein the additional energy source is configured to emit the energy for measuring a distance between the energy source and an object that is fixed in position with respect to the energy source.

32. The apparatus of claim 31, wherein the object comprises a patient support.

33. The apparatus of claim 1, further comprising one or more accelerometer(s) for determining an orientation of the energy source with respect to one or more axes.

34. The apparatus of claim 1, further comprising a measurement device configured to determine, or to provide information for determining, a distance between the first and second locations.

35. The apparatus of claim 34, wherein the measurement device comprises a time-of-flight measurement device.

36. The apparatus of claim 1, further comprising a fiducial, wherein the energy source is configured to emit energy towards the fiducial.

37. The apparatus of claim 36, wherein the fiducial comprises a marker, a marker plate, or a marker block.

38. The apparatus of claim 37, wherein the marker comprises an active marker.

39. A medical system comprising the apparatus of claim 1, and a medical device.

40. The medical system of claim 39, wherein the medical device comprises an imaging device.

41. The medical system of claim 39, wherein the medical device comprises a treatment device.

42. The medical system of claim 39, wherein the medical device comprises a ring gantry.

43. A method for determining a breathing of a patient, comprising:

emitting energy from an energy source from a first location to a second location, or vice versa, wherein the second location is moveable in response to a movement by the patient;

generating an input by an energy receiver;

receiving, by a processing unit, the input from the receiver; and

determining, using the processing unit, a characteristic of the patient based on the input from the receiver.

44. The method of claim 43, wherein the characteristic comprises a breathing characteristic of the patient.

45. The method of claim 44, wherein the breathing characteristic comprises a breathing amplitude, a breathing

phase, a period of a respiratory cycle, a breathing pattern, or any combination of the foregoing.

46. The method of claim **43**, wherein the energy source or the receiver is above a torso, a belly, or a head, of the patient.

47. The method of claim **43**, wherein the energy source or the receiver is mounted to a patient support, a gantry, a ceiling, or a wall.

48. The method of claim **43**, wherein the energy source comprises an ultrasound device, a laser device, an infrared device, or a light device configured to emit ultraviolet light or visible light.

49. The method of claim **43**, further comprising displaying an image on a screen for viewing by the patient.

50. The method of claim **49**, wherein the image is for instructing the patient to control a breathing of the patient.

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摘要(译)

一种用于患者位置或运动监测的装置，包括：能量源，被配置为从第一位置向第二位置发射能量，或反之亦然，其中第二位置可相对于第一位置响应于患者的运动而移动；处理单元，被耦合以接收基于所发射的能量的输入，并基于所述输入确定与患者相关联的特征。

