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Dickerson

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(54) **MEDICAL GATING USING POSITIVE AIRWAY PRESSURE DEVICES**

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A61B 6/00	(2006.01)
A61M 16/06	(2006.01)
A61B 6/03	(2006.01)
G01R 33/567	(2006.01)
A61M 16/08	(2006.01)

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(58) **Field of Classification Search**

CPC A61B 5/087; A61B 5/4836; A61B 5/6803; A61B 5/7285; A61B 6/032; A61B 6/037; A61B 6/4417; A61B 6/5288; A61B 6/541; A61M 16/0051; A61M 16/0057; A61M 16/024; A61M 16/06; A61M 16/0875; A61M 2016/0027; A61M 2016/0033; A61M 2205/502; A61N 2005/1052; A61N 2005/1055; A61N 2005/1061; A61N 5/1039; A61N 5/1068; G01R 33/5673

See application file for complete search history.

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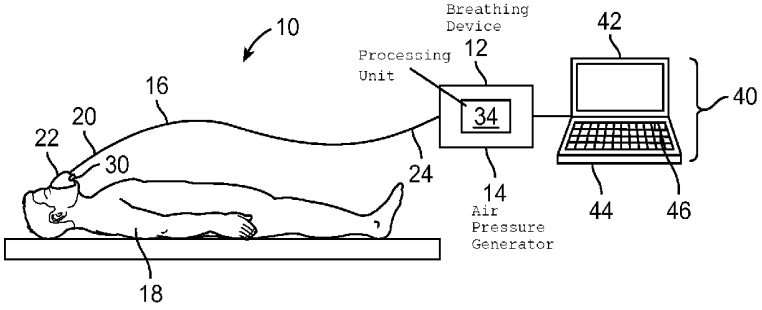
(57) **ABSTRACT**

A medical apparatus includes: a breathing device comprising an air pressure generator for generating air pressure, a tube for delivering the air pressure to a patient, and a sensor configured to sense a characteristic associated with a breathing of the patient; and a processing unit configured to receive an output from the sensor, and generate a control signal for controlling a medical device based at least in part on the output from the sensor.

59 Claims, 8 Drawing Sheets



(51) **Int. Cl.**
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A61N 5/10 (2006.01)

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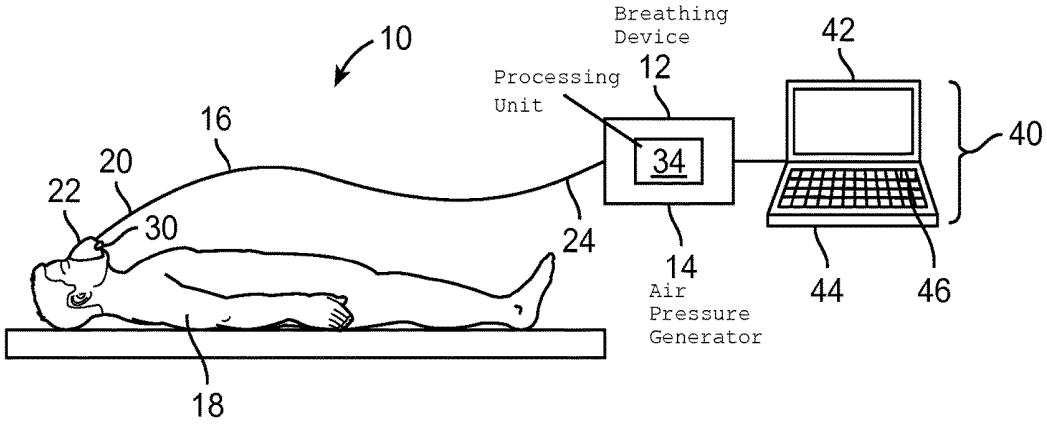
10
Breathing Device
12
Processing Unit
42
40
16
20
22
30
34
24
14
Air Pressure Generator
44
46
18

FIG. 1

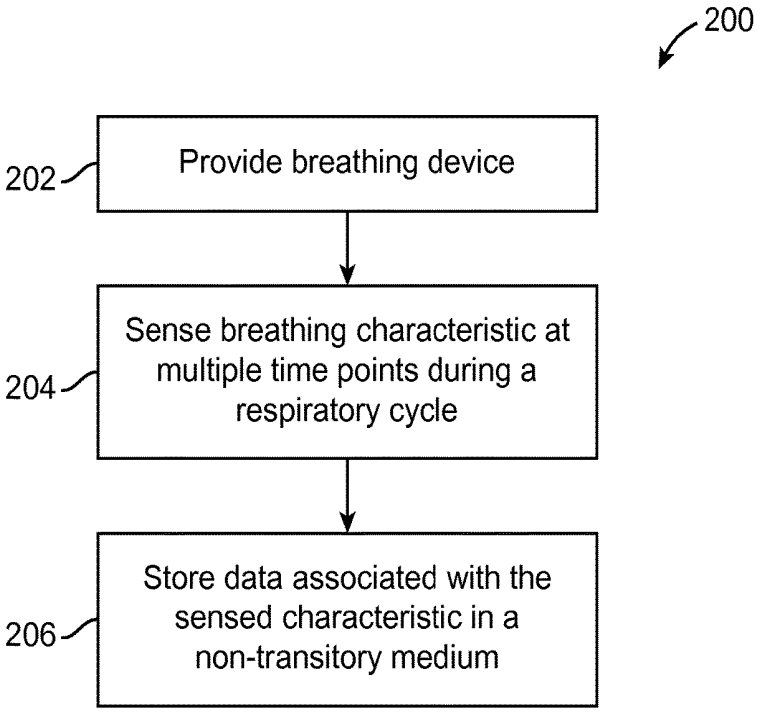
200
202
Provide breathing device
204
Sense breathing characteristic at multiple time points during a respiratory cycle
206
Store data associated with the sensed characteristic in a non-transitory medium

FIG. 2

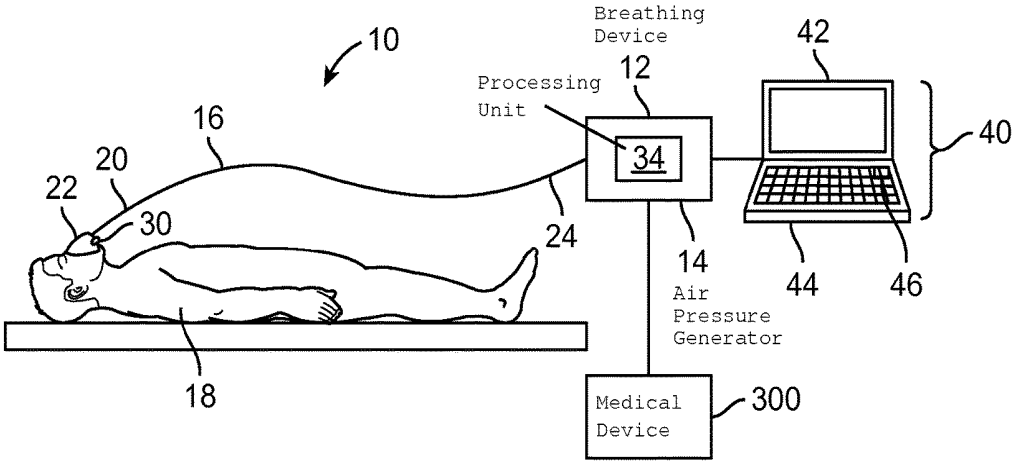
10
Breathing Device
12
42
Processing Unit
34
40
16
20
22
30
24
14
Air Pressure Generator
44
46
18
Medical Device
300

FIG. 3

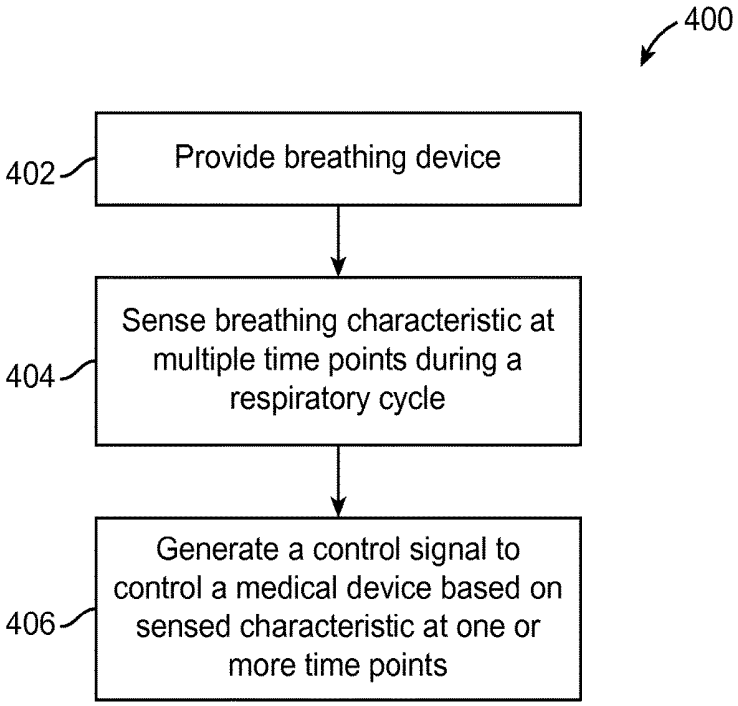
400
402
Provide breathing device
404
Sense breathing characteristic at multiple time points during a respiratory cycle
406
Generate a control signal to control a medical device based on sensed characteristic at one or more time points

FIG. 4

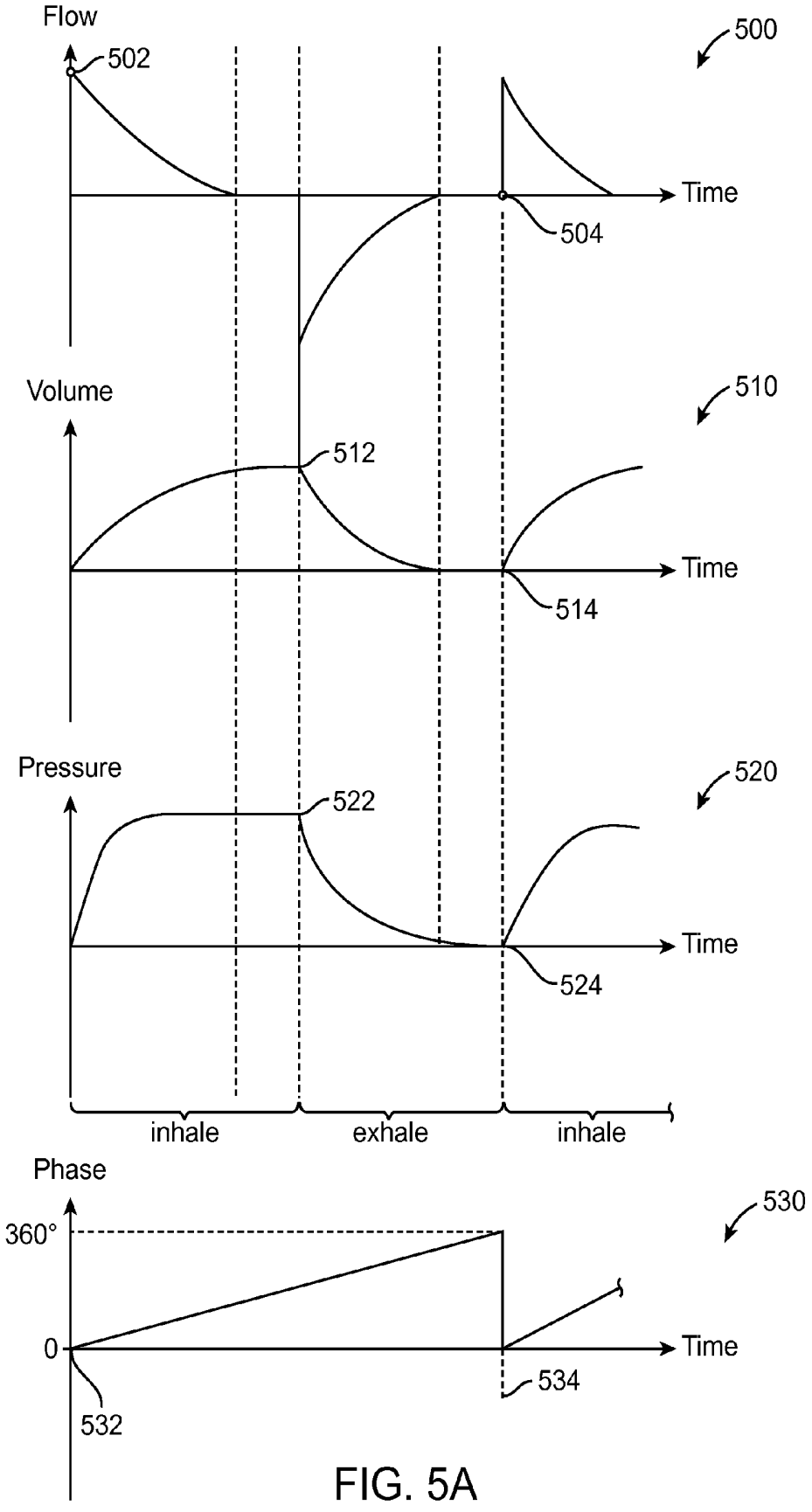
Flow
500
502
Time
504
Volume
510
512
Time
514
Pressure
520
522
Time
524
inhale
exhale
inhale
Phase
530
360°
0
Time
532
534

FIG. 5A

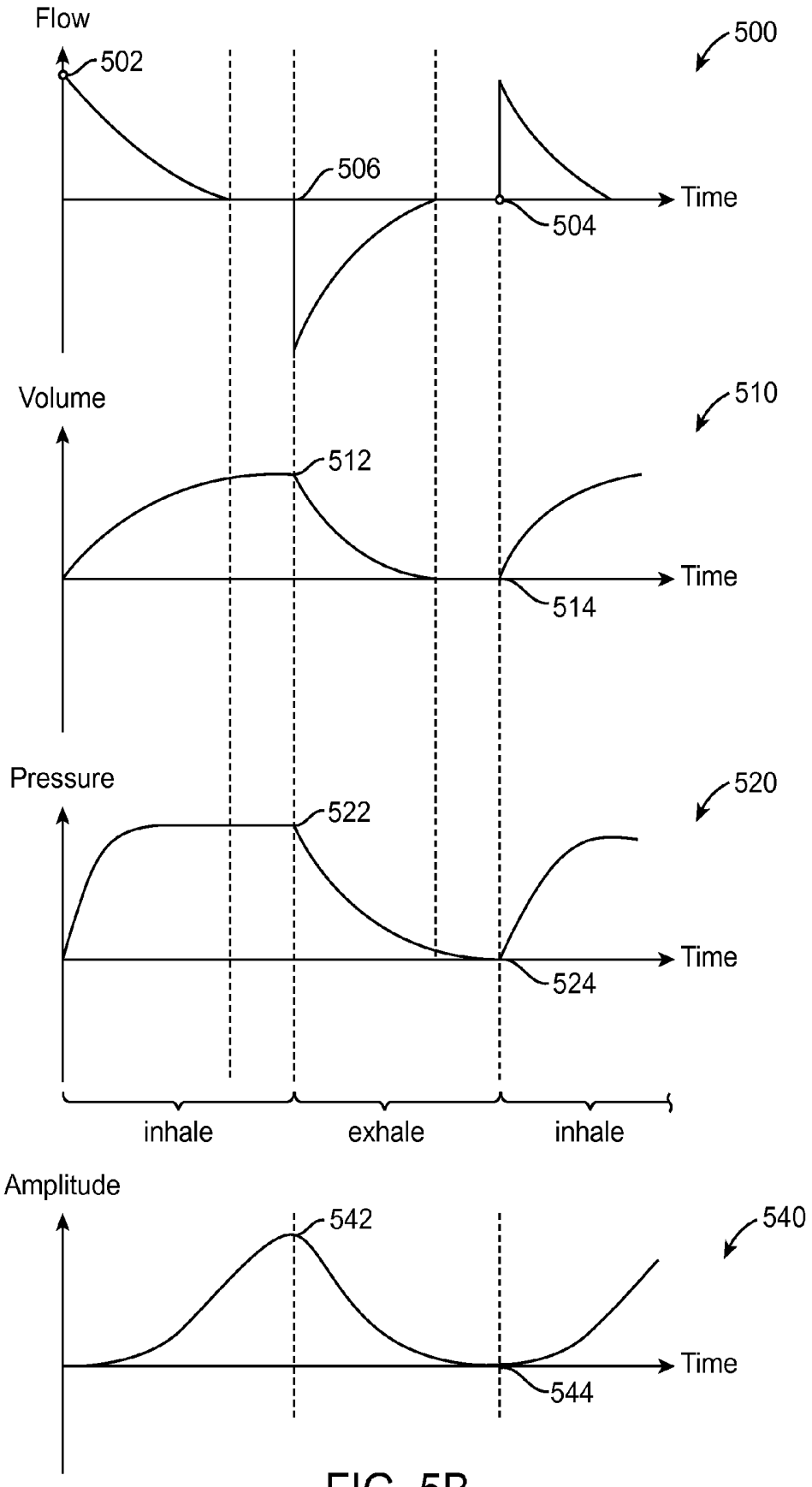
Flow
500
502
506
Time
504
Volume
510
512
Time
514
Pressure
520
522
Time
524
inhale
exhale
inhale
Amplitude
542
540
Time
544

FIG. 5B

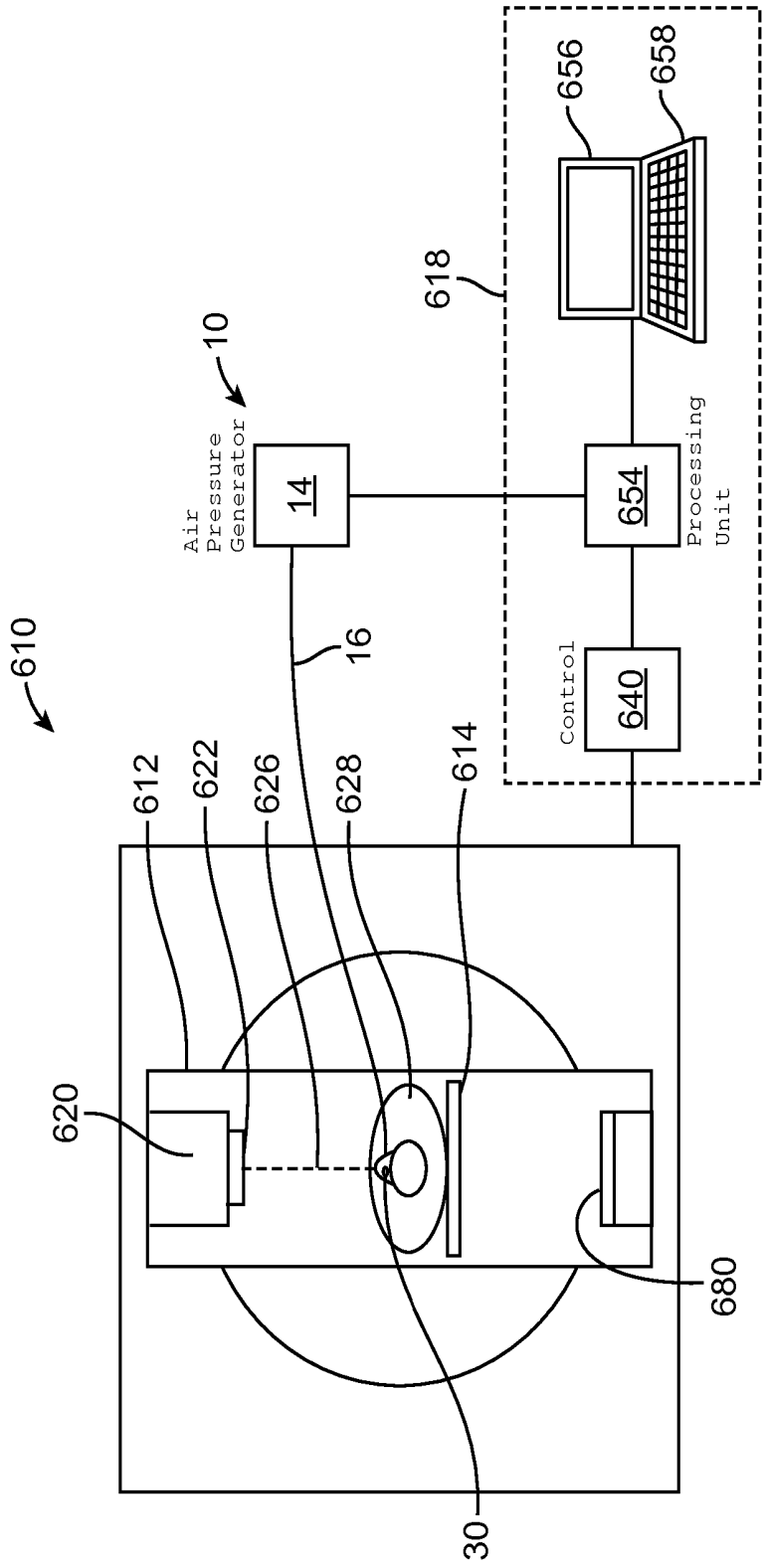
610
612
622
626
628
614
620
30
16
14
Air Pressure Generator
10
618
656
658
654
Processing Unit
640
Control
680

FIG. 6

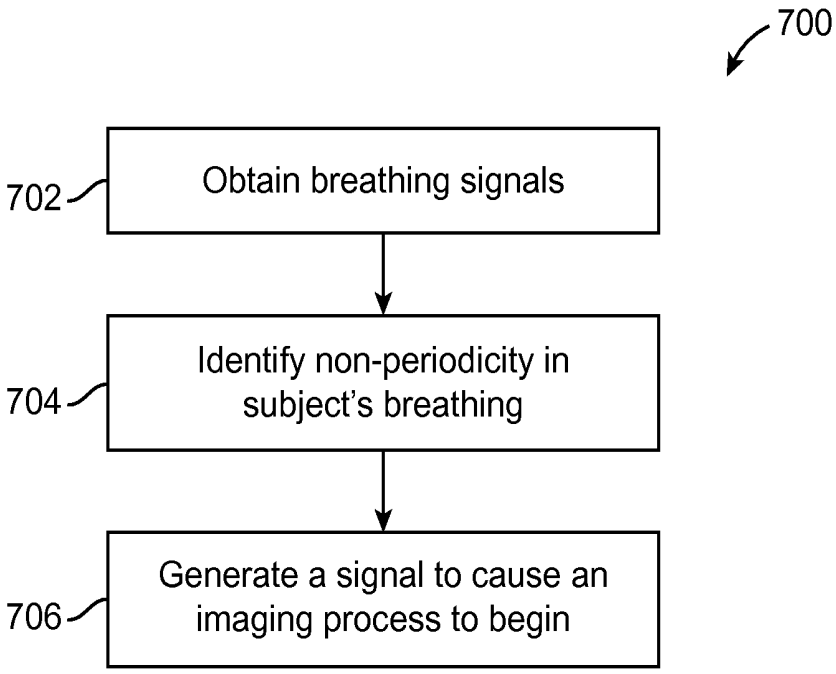
700
Obtain breathing signals
702
Identify non-periodicity in subject's breathing
704
Generate a signal to cause an imaging process to begin
706

FIG. 7

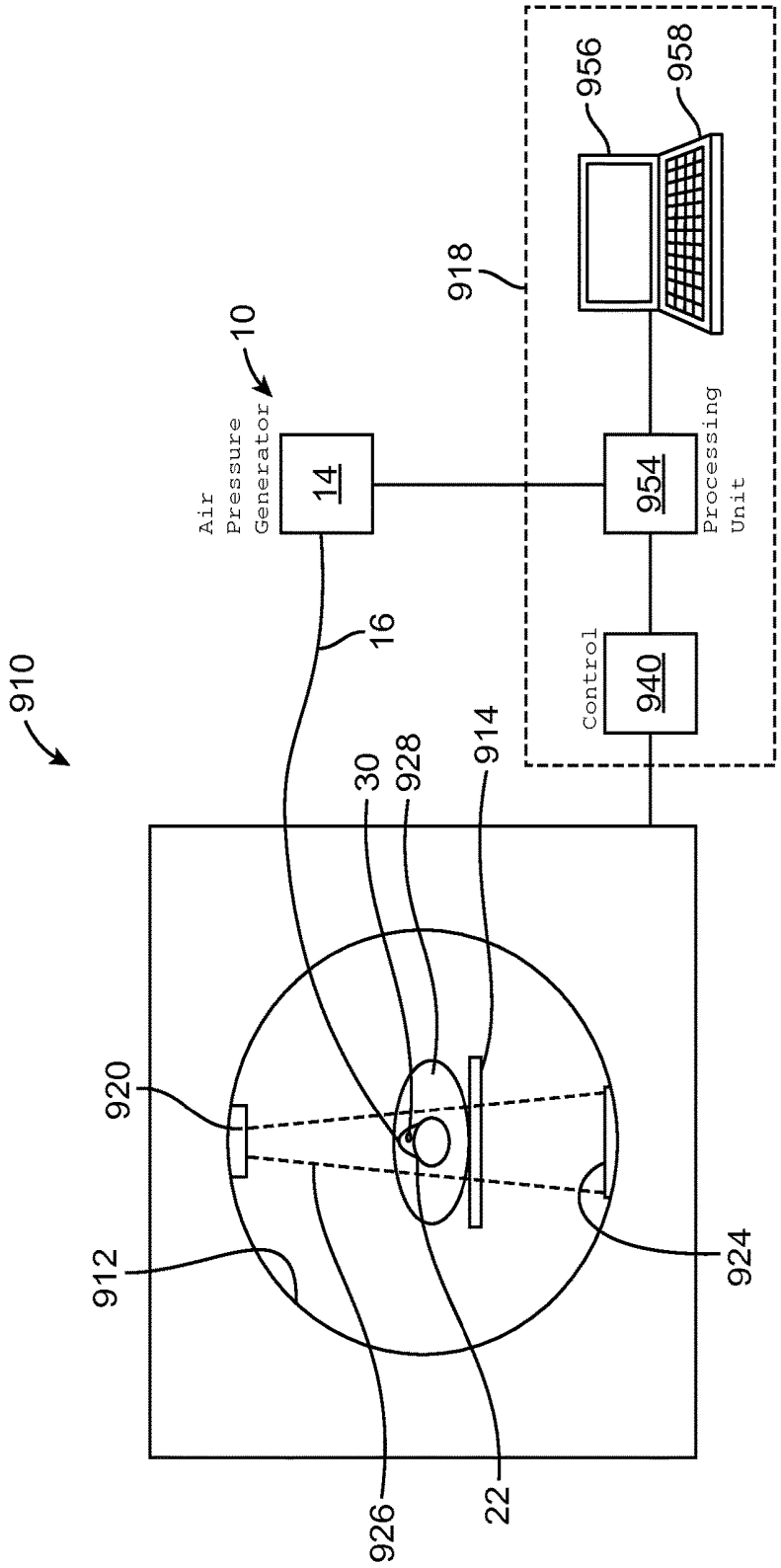
910
Air Pressure Generator
10
14
16
30
928
914
920
912
926
22
924
918
956
958
954
Processing Unit
Control
940

FIG. 8

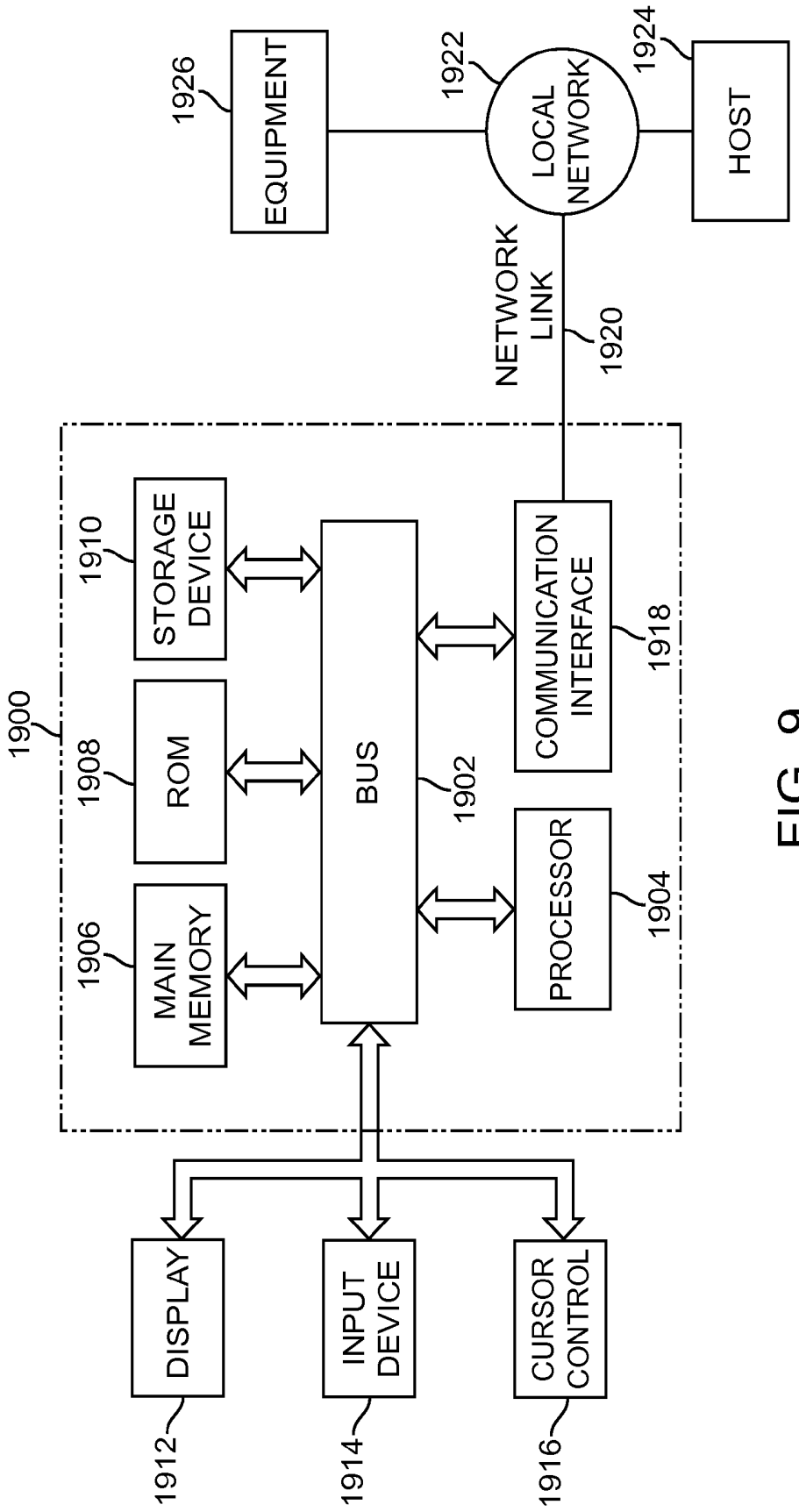
EQUIPMENT
1926
LOCAL NETWORK
1922
HOST
1924
NETWORK LINK
1920
1900
STORAGE DEVICE
1910
ROM
1908
MAIN MEMORY
1906
BUS
1902
COMMUNICATION INTERFACE
1918
PROCESSOR
1904
DISPLAY
1912
INPUT DEVICE
1914
CURSOR CONTROL
1916

FIG. 9

MEDICAL GATING USING POSITIVE AIRWAY PRESSURE DEVICES

FIELD

This application relates to systems and methods for obtaining breathing signals, and to systems and methods that use the breathing signals.

BACKGROUND

Radiation therapy has been employed to treat tumorous tissue. In radiation therapy, a high energy beam is applied from an external source towards the patient. The external source, which may be rotating (as in the case for arc therapy), produces a collimated beam of radiation that is directed into the patient to the target site. The dose and placement of the dose must be accurately controlled to ensure that the tumor receives sufficient radiation, and that damage to the surrounding healthy tissue is minimized.

Sometimes during a radiation therapy, the patient may be undergoing breathing motion. In such cases, it may be desirable to monitor the breathing motion of the patient during the treatment delivery session such that radiation may be properly delivered, or ceased to be delivered, to the target region. For example, if the patient's breathing becomes non-periodic (e.g., due to sudden movement such as coughing), then it may be desirable to stop a delivery of radiation.

Applicant of the subject application has determined that it would be desirable to provide a new device and method for obtaining breathing signals, and for determining treatment plans using the breathing signals. Applicant of the subject application has also determined that it would also be desirable to provide a new device and method for performing a medical procedure that accounts for a patient's breathing.

SUMMARY

In accordance with some embodiments, a medical apparatus includes: a breathing device comprising an air pressure generator for generating air pressure, a tube for delivering the air pressure to a patient, and a sensor configured to sense a characteristic associated with a breathing of the patient; and a processing unit configured to receive an output from the sensor, and generate a control signal for controlling a medical device based at least in part on the output from the sensor.

In accordance with other embodiments, a medical method includes: providing a breathing device, the breathing device comprising an air pressure generator for generating air pressure, a tube for delivering the air pressure to a patient, and a sensor; sensing a characteristic of a breathing of the patient using the sensor; and generating a control signal to control a medical device based at least in part on an output from the sensor.

In accordance with other embodiments, a medical apparatus includes: a breathing device configured to provide air pressure, the breathing device comprising an air pressure generator for generating the air pressure, and a tube for delivering the air pressure to a patient; wherein the breathing device comprises a sensor configured to sense a characteristic associated with a breathing of the patient at multiple time points during a breathing cycle of the patient; and a non-transitory medium for storing data associated with the sensed characteristic at the multiple time points.

In accordance with other embodiments, a medical method includes: providing a breathing device, the breathing device comprising an air pressure generator for generating air pressure, a tube for delivering the air pressure to a patient, and a sensor; sensing a characteristic associated with a breathing of the patient using the sensor at multiple time points during a respiratory cycle of the patient; and storing data associated with the sensed characteristic in a non-transitory medium.

Other and further aspects and features will be evident from reading the following detailed description of the embodiments, which are intended to illustrate, not limit, the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

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 typical embodiments and are not therefore to be considered limiting of its scope.

FIG. **1** illustrates a breathing monitoring system in accordance with some embodiments;

FIG. **2** illustrates a method of obtaining and processing breathing signals in accordance with some embodiments;

FIG. **3** illustrates the breathing monitoring system of FIG. **1**, particularly showing the system being used with a medical device in accordance with some embodiments;

FIG. **4** illustrates a method of using the breathing monitoring system of FIG. **1** to control a medical device in accordance with some embodiments;

FIG. **5**A illustrates different breathing characteristic graphs aligned with a corresponding breathing phase diagram in accordance with some embodiments;

FIG. **5**B illustrates different breathing characteristic graphs aligned with a corresponding breathing amplitude diagram in accordance with some embodiments;

FIG. **6** illustrates a radiation system that uses the breathing monitoring system of FIG. **1** in accordance with some embodiments;

FIG. **7** illustrates a method of triggering an imaging procedure in accordance with some embodiments;

FIG. **8** illustrates another radiation system that uses the breathing monitoring system of FIG. **1** in accordance with other embodiments; and

FIG. **9** is a block diagram of a computer system architecture, with which embodiments described herein may be implemented.

DESCRIPTION OF THE EMBODIMENTS

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.

FIG. **1** illustrates a breathing monitoring system **10** in accordance with some embodiments. The breathing monitoring system **10** includes a breathing device **12** having an air pressure generator **14** for generating air pressure, and a tube **16** for delivering the air pressure to a patient **18**. In the illustrated embodiments, the tube **16** has a first end **20** coupled to a facemask **22** worn by the patient **18**, and a second end **24** coupled to the air pressure generator **14**. As shown in the figure, the breathing monitoring system **10** also includes a sensor **30** configured to sense a characteristic associated with a breathing of the patient **18**. By means of non-limiting examples, the characteristic may be an airway pressure, an air flow, etc. In the illustrated embodiments, the sensor **30** is located at the facemask **22**. In other embodiments, the sensor **30** may be located anywhere along the length of the tube **16**. In further embodiments, the sensor **30** may be located at the air pressure generator **14**. In some embodiments, the sensor **30** may be a pressure sensor. In other embodiments, the sensor **30** may be an airflow sensor. In further embodiments, the sensor **30** may be any of other types of sensor that is configured to sense a characteristic associated with a breathing of the patient **18**.

It should be noted that as used in this specification, the term "sensor" is not limited to a component that senses a characteristic of a breathing performed by a patient, and may refer to any component that is capable of obtaining any parameter(s) that is associated with a breathing of a patient. For example, in some embodiments in which the sensor **30** is implemented at the air pressure generator **14**, the sensor **30** may be any component (such as a signal transmission device) that is capable of obtaining parameter(s) (such as preset pressures, preset airflow rate, etc.) used in the operation of the generator **14**. Also, in some embodiments, the sensor **30** may have multiple components. For example, in some embodiments, the sensor **30** may have a sensing component configured to sense a beginning of an inhale state (or an end of an exhale state), and/or an end of an inhale state (or a beginning of an exhale state), and another component (e.g., another sensing component) configured to obtain operation parameter(s) from the generator **14**. Similarly, the term "sense" or "sensing" is not necessarily limited to the act of sensing a characteristic of a breathing performed by a patient, and may refer to the act of obtaining parameter(s) used in the operation of the generator **14**.

In some embodiments, the breathing device **12** may be implemented using a BPAP machine. A BPAP machine may be configured to deliver positive air pressure cycling between two levels. The cycle times and/or pressure levels may be adjustable (through control(s), such as the user interface **40**) for optimal effect and comfort. In some embodiments, the BPAP machine may be configured to provide a controlled air leakage when supporting the patient's breathing through positive airway pressure. In other embodiments, the breathing device **12** may be implemented using a CPAP machine, which is configured to provide a constant positive airway pressure. In further embodiments, the breathing device **12** may be any positive airway pressure device that is configured to support a patient's breathing.

The air pressure generator **14** includes a processing unit **34** configured to generate a signal to activate a generator to thereby generate air pressure within the tube **16**. The facemask **22** is configured to provide a seal at the interface between the patient's face and the perimeter of the facemask **22** so that air pressure generated within the tube **16** is delivered into the airway of the patient **18**. The processing unit **34** of the generator **14** may include circuit. For example, the processing unit **34** may be one or more processors in some embodiments. The processing unit **34** may further include software running on the processor(s) in some embodiments. The processor may be a FPGA processor, an ASIC processor, a general purpose processor, or any of other types of processor.

The breathing monitoring system **10** also includes a user interface **40** having a screen **42** for displaying information to a user, and an input device **44** for allowing the user to input information, such as user commands. The user interface **40** is communicatively coupled to the air pressure generator **14**, so that information derived from signals from the air pressure generator **14** and/or from the sensor **30** may be displayed on the screen **42** for viewing by the user. In some embodiments, the input device **44** may be used to control the air pressure generator **14**, and/or to prescribe the manner in which the patient's breathing may be monitored. For example, in some embodiments, the input device **44** may be used to set the amount of airway pressure desired, sensitivity of the breathing device **12**, and/or to prescribe the sampling rate for the sensor **30**. The user interface **40** also includes a non-transitory medium **46** for storing information derived from the operation of the breathing device **12**. For example, the non-transitory medium **46** may be configured to store signals transmitted from the sensor **30**, and/or data derived from the signals transmitted from the sensor **30**. The non-transitory medium **46** may also store operating parameters that are used in the operation of the air pressure generator **14** in some embodiments.

In some embodiments, the user interface **40** may be implemented using a computer (such as a desktop or a laptop). In other embodiments, the user interface **40** may be implemented using a handheld device, such as an iPad, a tablet, an iPhone, a smart phone, etc. In either case, the user interface **40** will include processing unit therein for processing information. In other embodiments, the user interface **40** may be implemented as a part of the air pressure generator **14**. In such cases, the processing unit **34** of the air pressure generator **14** may also be considered the processing unit for the user interface **40**. As used in this specification, the term "processing unit" (such as the processing unit **34**) may refer to one or more processing units, which may reside in one component (e.g., the air pressure generator **14**, or in the user interface **40**), may reside in multiple respective components (e.g., the air pressure generator **14** and the user interface **40**), or may be communicatively coupled to one or more components (e.g., the air pressure generator **14**, the user interface **40**, etc.).

FIG. **2** illustrates a method **200** performed using the breathing monitoring system **10** of FIG. **1** in accordance with some embodiments. First, a breathing device is provided (Item **202**). The breathing device may be the breathing device **12**, which includes the air pressure generator **14** for generating air pressure, the tube **16** for delivering the air pressure to the patient **18**, the facemask **22**, and the sensor **30**. During use, the facemask **22** is placed over the patient's mouth, and the perimeter of the facemask **22** forms a seal with the patient's skin. An inhale sensor (not shown), which may be located at the facemask **22**, at the tube **20**, or at the air pressure generator **14**, is configured to sense an inhaling being performed by the patient **18**, and generate an inhale signal in response thereto. The inhale signal is transmitted to the air pressure generator **14**, which generates air pressure within the tube **16** in response to the inhale signal from the inhale sensor. The tube **16** supplies the air pressure to the airway of the patient **18**, thereby assisting the patient **18** in the breathing. In some embodiments, the inhale sensor for

sensing the inhaling of the patient **18** may be the sensor **30**, or another sensor that is different from the sensor **30**. The sensor for sensing the inhaling of the patient **18** may be an air flow sensor, a pressure sensor, or any of other types of sensor that is configured to sense a characteristic associated with an inhaling.

While the patient **18** is breathing, a characteristic associated with the breathing of the patient **18** is sensed using the sensor **30** at multiple time points during a respiratory cycle of the patient **18** (Item **204**). In some embodiments, the sensor **30** is a pressure sensor, and multiple pressure values are obtained at different respective time points during the respiratory cycle of the patient **18**. In other embodiments, the sensor **30** is an airflow sensor, and multiple airflow values are obtained at different respective time points during the respiratory cycle of the patient **18**. In further embodiments, the sensor **30** may be any of other types of sensor, and multiple characteristic values are obtained at different respective time points during the respiratory cycle of the patient **18**.

Next, the method **200** includes storing data associated with the sensed characteristic in a non-transitory medium (Item **206**). In some embodiments, the non-transitory medium may be the non-transitory medium **46** in the system **10** of FIG. **1**. In other embodiments, the non-transitory medium may be a storage device that is a part of the air pressure generator **14**. In further embodiments, the non-transitory medium may be communicatively coupled to the air pressure generator **14**, the sensor **30**, and/or the user interface **40**. Also, in some embodiments, the stored data may be values of the respective signals obtained from the sensor **30**. In other embodiments, the stored data may be data derived (e.g., through processing by the processing unit **34**) from the values of the signals obtained from the sensor **30**.

In some embodiments, the data stored may be airway pressure values and corresponding time points at which the respective airway pressure values are obtained. In other embodiments, the data stored may be airflow values and corresponding time points at which the respective airflow values are obtained. In further embodiments, the data stored may be other characteristic values and corresponding time points at which the respective characteristic values are obtained.

In other embodiments, instead of, or in addition to, storing the data in a non-transitory medium, the processing unit **34** may process signals (an example of breathing signals) from the sensor **30** to thereby monitor the breathing of the patient **20**. For example, the processing unit **34** may be configured to determine whether the patient **18** is breathing regularly based on the signals from the sensor **30**. In some embodiments, the signals from the sensor **30** and/or results of the processing of the sensor signals may be displayed on the monitor **42**, for allowing a user to view them.

Also, in some embodiments, if data obtained using the sensor **30** are stored, the data may be reviewed subsequently. For example, in some embodiments, the stored data may be analyzed (e.g., using a computer) to determine a treatment plan that considers a patient's breathing. By means of non-limiting examples, the treatment plan may be a radiation treatment plan, a proton treatment plan, or any of other types of treatment plan that may consider a patient's breathing during execution of the treatment. In some embodiments, when determining a treatment plan, treatment parameters may be determined using the computer, and may be stored in a non-transitory medium.

In other embodiments, the breathing monitoring system **10** may be used with a medical device. FIG. **3** illustrates the breathing monitoring system **10** of FIG. **1** that is used with a medical device **300**. In the illustrated embodiments, the medical device **300** is communicatively coupled to the airway pressure generator **14**. In other embodiments, the medical device **300** may be communicatively coupled to the sensor **30** (e.g., directly to the sensor **30**, or indirectly through another component, such as another processing unit) without going through the airway pressure generator **14**.

FIG. **4** illustrates a method **400** of controlling a medical device performed using the breathing monitoring system **10** of FIG. **1** in accordance with some embodiments. First, a breathing device is provided (Item **402**). The breathing device may be the breathing device **12**, which includes the air pressure generator **14** for generating air pressure, the tube **16** for delivering the air pressure to the patient **18**, the facemask **22**, and the sensor **30**. During use, the facemask **22** is placed over the patient's mouth, and the perimeter of the facemask **22** forms a seal with the patient's skin. An inhale sensor (not shown), which may be located at the facemask **22**, at the tube **20**, or at the air pressure generator **14**, is configured to sense an inhaling being performed by the patient **18**, and generate an inhale signal in response thereto. The inhale signal is transmitted to the air pressure generator **14**, which generates air pressure within the tube **16** in response to the inhale signal from the inhale sensor. The tube **16** supplies the air pressure to the airway of the patient **18**, thereby assisting the patient **18** in the breathing. In some embodiments, the inhale sensor for sensing an inhaling of the patient **18** may be the sensor **30**, or another sensor that is different from the sensor **30**. The sensor for sensing the inhaling of the patient **18** may be an air flow sensor, a pressure sensor, or any of other types of sensor that is configured to sense a characteristic associated with an inhaling.

While the patient **18** is breathing, a characteristic associated with the breathing of the patient **18** is sensed using the sensor **30** at multiple time points during a respiratory cycle of the patient **18** (Item **404**). In some embodiments, the sensor **30** is a pressure sensor, and multiple pressure values are obtained at different respective time points during the respiratory cycle of the patient **18**. In other embodiments, the sensor **30** is an airflow sensor, and multiple airflow values are obtained at different respective time points during the respiratory cycle of the patient **18**. In further embodiments, the sensor **30** may be any of other types of sensor, and multiple characteristic values are obtained at different respective time points during the respiratory cycle of the patient **18**.

Based on the sensed characteristic at one or more of the time points, the processing unit **34** and/or the processing unit **46** then generates a control signal to control the medical device **300** (Item **406**).

In some embodiments, the signals from the sensor **30** may be processed by the processing unit **34** to determine a corresponding breathing phases. In some embodiments, the sensor **30** may be a flow sensor, in which cases, the flow signals from the sensor **30** may be represented by the flow signal graph **500** shown in FIG. **5**A. The flow signals represent the amount or rate of air flow being supplied at different points in time. The flow signal graph **500** may be obtained by plotting values of sensor signals against time at which the sensor signals are obtained from the sensor **30**. In some embodiments, each of the flow signals in the flow diagram **500** may be obtained by sensing characteristic (e.g., airflow) due to a breathing performed by a patient. In other embodiments, part(s) of the flow diagram **500** may be

obtained using information (e.g., operation parameter(s)) from the generator **14**. For example, in some embodiments, the timing of when the various parts of the diagram **500** begin and end may be determined by sensing breathing characteristics, while the values (and therefore the shape) of the flow curve may be obtained from the generator **14** (e.g., they may be obtained directly from the generator **14**, or may be derived using information, such as operation parameter(s) obtained from the generator **14**). In some cases, the operation parameter may be a flow rate set in the generator **14**, which may correspond with the actual flow rate experienced by the patient.

As shown in the figure, a certain signal value **502** that is obtained when the patient is at a beginning of an inhale phase may be associated with a beginning **532** of a respiratory cycle in a phase diagram **530**, and a certain signal value **504** that is obtained when the patient is at an end of an exhale phase may be associated with an end **534** of the respiratory cycle in the phase diagram **530**. The phase of a physiological cycle represents a degree of completeness of a physiological cycle. In some embodiments, the phases of a respiratory cycle may be represented by a phase variable having values between 0° and 360°, like that shown in the phase diagram **530**. For example, a phase value of 0° (and 360°) may represent a beginning of an inhale state (or an end of an exhale 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 sensor value graph **500** at certain point in time, a corresponding phase value at the same point in time may be obtained. Thus, for each sensor signal, the processing unit can determine the corresponding phase of the respiratory cycle. In some embodiments, the determined phase may be considered an example of a breathing signal. In other embodiments, the sensor signal itself may be considered an example of a breathing signal. As shown in the figure, the phase values collectively form the phase diagram **530** that includes a plurality of data points, with each of the data points having a phase value and a time value.

In other embodiments, the processing unit **34** may be configured to determine lung volume during a respiratory cycle. As shown in the lung volume diagram **510** in FIG. **5**A, the lung volume may be determined by summing the area under the flow diagram over time. The lung volume has a peak **512** representing an end of an inhale state, and a minimum value **514** representing an end of an exhale state (or a beginning of an inhale state). Using the points **514** at different respective respiratory cycles, the phase diagram **530** may be determined by associating the points **514** with the 0° and 360° phase values at the different corresponding time points.

In further embodiments, the sensor **30** may be a pressure sensor for sensing pressure associated with an airway (which may be pressure in the tube **16**, pressure in the facemask **22**, or pressure in the airway of the patient). In such cases, the sensor **30** may provide sensed pressure values at different time points during a respiratory cycle. FIG. **5**A illustrates a pressure diagram **520** representing pressure values that may be provided by the sensor **30** at different respective time points. The pressure has a peak **522** representing an end of an inhale state, and a minimum value **524** representing an end of an exhale state (or a beginning of an inhale state). Using the points **524** at different respective respiratory cycles, the phase diagram **530** may be determined by associating the points **524** with the 0° and 360° phase values at the different corresponding time points.

In some embodiments, each of the pressure signals in the pressure diagram **520** may be obtained by sensing characteristic (e.g., pressure) due to a breathing performed by a patient. In other embodiments, part(s) of the pressure diagram **520** may be obtained using information (e.g., operation parameter(s)) from the generator **14**. For example, in some embodiments, the timing of when the various parts of the diagram **520** begin and end may be determined by sensing breathing characteristics, while the values (and therefore the shape) of the pressure curve may be obtained from the generator **14** (e.g., they may be obtained directly from the generator **14**, or may be derived using information, such as operation parameter(s) obtained from the generator **14**). In some cases, the operation parameter may be a pressure set in the generator **14**, which may correspond with the actual airflow pressure experienced by the patient.

In other embodiments, the processing unit **34** may determine breathing amplitude values that correspond with respective sensor signal values. In some embodiments, the sensor **30** may be a flow sensor, in which cases, the flow signals from the sensor **30** may be represented by the flow signal graph **500** shown in FIG. **5**B. The flow signals represent the amount or rate of air flow being supplied at different points in time. The flow signal graph **500** may be obtained by plotting values of sensor signals against time at which the sensor signals are obtained from the sensor **30**. As shown in the figure, a certain signal value **506** that is obtained when the patient is at an end of an inhale phase may be associated with an amplitude peak **542** in an amplitude diagram **540**, and a certain signal value **504** that is obtained when the patient is at an end of an exhale phase may be associated with a minimum amplitude value **544** in the amplitude diagram **540**. The amplitude values in the amplitude diagram **540** may represent breathing motion, such as a motion of a diaphragm, a motion of a chest, as the patient is breathing. As shown in the diagram, for each point in the sensor value graph **500** at certain point in time, a corresponding amplitude value at the same point in time may be obtained. Thus, for each sensor signal, the processing unit can determine the corresponding amplitude in the respiratory cycle. In some embodiments, the determined amplitude may be considered an example of a breathing signal. In other embodiments, the sensor signal itself may be considered an example of a breathing signal. As shown in the figure, the amplitude values collectively form the amplitude diagram **540** that includes a plurality of data points, with each of the data points having an amplitude value and a time value.

In other embodiments, the processing unit **34** may be configured to determine lung volume during a respiratory cycle. As shown in the lung volume diagram **510** in FIG. **5**B, the lung volume may be determined by summing the area under the flow diagram over time. The lung volume has a peak **512** representing an end of an inhale state, and a minimum value **514** representing an end of an exhale state (or a beginning of an inhale state). Using the points **512**, **514** at different respective respiratory cycles, the amplitude diagram **540** may be determined by associating the points **512**, **514** with the maximum and minimum values **542**, **544** at the different corresponding time points.

In further embodiments, the sensor **30** may be a pressure sensor for sensing pressure associated with an airway (which may be pressure in the tube **16**, pressure in the facemask **22**, or pressure in the airway of the patient). In such cases, the sensor **30** may provide sensed pressure values at different time points during a respiratory cycle. FIG. **5**B illustrates a pressure diagram **520** representing pressure values that may be provided by the sensor **30** at different respective time

points. The pressure has a peak **522** representing an end of an inhale state, and a minimum value **524** representing an end of an exhale state (or a beginning of an inhale state). Using the points **524** at different respective respiratory cycles, the amplitude diagram **540** may be determined by associating the points **522**, **524** with the maximum and minimum values **542**, **544** at the different corresponding time points.

In further embodiments, a device (such as a strain gauge, or a camera) for determining a breathing amplitude of the patient may be employed to determine breathing amplitudes as the patient is breathing. This is performed at the same time the sensor **30** is being used to sense breathing characteristic of the patient. Thus, for each sensor signal obtained using the sensor **30**, the processing unit **34** can determine the corresponding breathing amplitude (e.g., by looking up sensor signal and amplitude signal that are both obtained at the same time).

It should be noted that the flow diagram **500**, the volume diagram **510**, and the pressure diagram **520** are not limited to the examples shown in FIGS. **5**A-**5**B, and that these diagrams may have different shapes from those shown in the above examples. Also, in the above embodiments, the processing unit has been described as processing output from the sensor **30** to determine a metric (e.g., a phase, or an amplitude) of a breathing state. In other embodiments, the metric determined by the processing unit using output from the sensor **30** may be a flow (like that shown in the flow diagram **500**), a volume (like that shown in the volume diagram **510**), or a pressure (like that shown in the pressure diagram **520**). In further embodiments, the processing unit may be configured to process the output from the sensor **30** to determine other types of metric that represents a breathing state.

The breathing monitoring system **10** and the methods described previously may be used with a variety of medical devices, and in various different medical procedures. In some embodiments, the medical device **300** may be a radiation treatment machine. FIG. **6** illustrates a radiation system **610** that is used with the breathing monitoring system **10**. The system **610** is a treatment system that includes a gantry **612**, a patient support **614** for supporting a patient, and a control system **618** for controlling an operation of the gantry **612**. The gantry **612** is in a form of an arm. The system **610** also includes a radiation source **620** that projects a beam **626** of radiation towards a patient **628** while the patient **628** is supported on support **614**, and a collimator system **622** for controlling a delivery of the radiation beam **626**. The radiation source **620** can be configured to generate a cone beam, a fan beam, or other types of radiation beams in different embodiments.

In the illustrated embodiments, the radiation source **620** is a treatment radiation source for providing treatment energy. In other embodiments, in addition to being a treatment radiation source, the radiation source **620** can also be a diagnostic radiation source for providing diagnostic energy for imaging purpose. In such cases, the system **610** will include an imager, such as the imager **680**, located at an operative position relative to the source **620** (e.g., under the support **614**). In further embodiments, the radiation source **620** 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 **680** 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 **620** 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 **620** can be a diagnostic radiation source. In the illustrated embodiments, the radiation source **620** is coupled to the arm gantry **612**. Alternatively, the radiation source **620** may be located within a bore.

In the illustrated embodiments, the control system **618** includes a processing unit **654**, such as a processor, coupled to a control **640**. The control system **618** may also include a monitor **656** for displaying data and an input device **658**, such as a keyboard or a mouse, for inputting data. The operation of the radiation source **620** and the gantry **612** are controlled by the control **640**, which provides power and timing signals to the radiation source **620**, and controls a rotational speed and position of the gantry **612**, based on signals received from the processing unit **654**. Although the control **640** is shown as a separate component from the gantry **612** and the processing unit **654**, in alternative embodiments, the control **640** can be a part of the gantry **612** or the processor **654**. The processing unit **654** may be the processing unit **34** of the breathing monitoring system **10** of FIG. **1**, or a separate processing unit that is different from the processing units **34**. Also, in some embodiments, the screen **656** may be the screen **42** of the breathing monitoring system **10** of FIG. **1**, and the input device **658** may be the input device **44** of FIG. **1**. In other embodiments, the screen **656** and the input device **658** may be different from the screen **42** and the input device **44** of FIG. **1**.

In some embodiments, when using the system **610** of FIG. **6**, the radiation source **620** is rotated about the patient **628** to deliver treatment radiation from a plurality of gantry angles, for example, as in arc therapy. As treatment radiation is being delivered to the patient **628**, the breathing monitoring system **10** of FIG. **1** may be used to monitor the breathing of the patient **628**. In some embodiments, the processing unit **654** processes the signals from the sensor **30** to determine breathing states of the patient **628**, and then gates the delivery of the treatment radiation in real time based on the breathing states. For example, the processing unit **654** may process signals from the sensor **30** to determine respiratory amplitudes of the patient **628**, and then gates the delivery of the treatment radiation based on the respiratory amplitudes. In such cases, the processing unit **654** may cause the radiation source **620** to deliver radiation, or to stop a delivery of radiation, when the determined amplitude is within a prescribed amplitude range. In other embodiments, the processing unit **654** processes the signals from the camera to determine respiratory phases of the patient **628**, and then gates the delivery of the treatment radiation based on the respiratory phases. For example, the processing unit **654** may cause the radiation source **620** to deliver radiation, or to stop a delivery of radiation, when the determined phase is within a prescribed phase range. In further embodiments, the processing unit **654** processes the signals from the sensor **30** to detect non-periodicity, and then gates the delivery of the treatment radiation based on the detection of non-periodicity. In other embodiments, instead of, or in addition to, controlling the delivery of radiation, the

processing unit **654** may be configured to control the gantry **612** (e.g., stop, accelerate, or decelerate the gantry **612**), to operate the collimator system **622**, to position the patient support **614**, and/or to adjust a dose rate (e.g., increase a dose rate or decrease a dose rate), based on the sensor values obtained using the sensor **30** (e.g., based directly on the sensor values, based on amplitude and/or phase determined using the sensor value(s), based on detection of non-periodicity, etc.). Thus, the signals from the sensor **30** may be used to control one or more components of a radiation system in synchronization with a breathing of the patient **628**. In some embodiments, the adjustment of dose rate may involve controlling a collimator and/or a gantry to which the radiation source is mounted. Also, in some embodiments, the dose rate adjustment may be an adjustment of a rate of radiation exposure, a rate of image acquisition, or both. In further embodiments, based on signals from the sensor **30**, the processing unit may be configured to control an image process, such as an image data collection process, an image reconstruction process, a process for binning image data, etc.

During the treatment process, the processing unit **654** monitors the patient's **628** breathing, and correlates feature(s) of the breathing (such as sensor signals, breathing amplitudes, breathing phases, etc.) with positions of internal target region that is being irradiated by the radiation beam **626**. For example, based on signals received from the sensor **30**, the processing unit **654** then determines the phase/amplitude of the breathing cycle. The phase of the breathing cycle or the amplitude is then used by the processing unit **654** to determine a position of the internal target region based on a pre-established relationship between breathing phase/amplitude and position of internal target region. In some embodiments, the relationship between the breathing phase/amplitude and target position may be pre-determined by a physician during a treatment planning process. For example, during a treatment planning process, it may be determined that when a patient is at breathing phase=40° (or when a sensor value from the sensor **30** is 4.5), the corresponding position of the internal target region is at position X=45 mm, Y=23 mm, and Z=6 mm relative to the isocenter. This technique allows the treatment radiation system **610** to target delivery of radiation towards the target region based on breathing signals obtained by the system **10**. Thus, it has the benefit of obviating the need to continuously or periodically imaging the internal target region using X-ray imaging, which may be harmful to the patient due to its additional radiation dose.

In other method of using the system **10** with the radiation system **610**, the processing unit **654** is configured to detect non-periodicity in the patient's **628** breathing based on signals received form the sensor **30**. When the processing unit **654** determines that there is non-periodicity in the patient's **628** breathing, the processing unit **654** may generate a signal (e.g., a beam-stop signal) to cause the radiation source **620** to stop delivering radiation, and/or a signal to control a motion of the gantry **612** (e.g., to stop the gantry, decelerate the gantry **612**, or accelerate the gantry **612**).

In other embodiments, as an alternative, or in addition, to controlling component(s) of the radiation system **610**, if the radiation system **610** has imaging capability, the processing unit **654** may be configured to generate a signal to trigger an imaging process to image the internal target region when the processing unit **654** determines that there is non-periodicity in the patient's **628** breathing based on signals received from the sensor **30**. FIG. **7** illustrates a method **700** of triggering an imaging process in accordance with some embodiments. In the method **700**, the processing unit **654** obtains signals (breathing signals) from the sensor **30** (step **702**), and the processor **654** then analyzes the signals to identify a non-periodicity in a subject's breathing (step **704**).

When the processing unit **654** determines that there is non-periodicity in the patient's **628** breathing based on signals from the sensor **30**, the processing unit **654** then generates a signal to cause an image process to begin (**706**). In the illustrated embodiments, if the radiation system **610** has imaging capability (e.g., if the radiation system **610** has the imager **680**), the image process may be performed by the system **610**. For example, the radiation source **620** may deliver imaging radiation having diagnostic energy (e.g., in kv range), or radiation having treatment energy level (e.g., in MeV range) to generate one or more images of the internal region using the imager **680**. Alternatively, a separate imaging system may be used to generate the image(s) of the internal region. For example, the separate imaging system may be a CT system, an x-ray system, an ultrasound imaging device, a MRI system, a tomosynthesis imaging system, a PET system, a SPECT system, or any other system that is capable of obtaining an image of the internal target region. In further embodiments, the radiation system **610** may have two imagers (e.g., at 90° or another angle apart from each other). In such cases, the processing unit **654** may generate the signal to cause an image process to be performed using the two imagers.

In some embodiments, the image(s) of the internal target region is used by the processing unit **654** to verify the position of the target region, and/or to confirm the pre-established relationship between breathing feature (amplitude, phase, etc.) and target position. In other embodiments, the image of the internal target region may also be used by the processing unit **654** to verify the relationship between breathing feature and target position (e.g., external-internal correlation model). If a result of the verification process indicates that the model is inaccurate, the processing unit **654** may update (e.g., modify, recreate, etc.) the relationship between breathing feature and target position (e.g., external-internal correlation model) in the treatment plan, so that the updated relationship may be used by the system **610** to deliver additional radiation to the patient **628** (e.g., to control the radiation source, collimator, gantry, and/or patient support). Thus, in some embodiments, signals from the sensor **30** may be used to determine a treatment plan in real time during a treatment session. In other embodiments, the processing unit **654** may cause the radiation process to stop if the result of the verification process indicates that the model is inaccurate.

In other embodiments, the image(s) of the internal target region determined from the method **700** may be used by the processing unit **654** to determine the position of the internal target region using stereo imaging technique. In stereo imaging technique, a set of reference images are first obtained. The reference images may be obtained before the treatment process begins. Each of the reference images is obtained when the internal target region is at a certain position, and therefore, each reference image is associated with a certain position of the target region. In some embodiments, the reference images may be generated using a CT system by rotating the radiation source of the CT system at different gantry angles while the target is undergoing motion. Thus, the reference images are obtained at different times. In other embodiments, if the system **610** has imaging capability, the reference images may be generated using the system **610**. In some embodiments, after the image (input image) from the method **700** is obtained, the processing unit **654** then selects one or more reference images from the

reference image set that spatially correspond with the input image. In one technique, the processing unit **654** determines a projection line that extends between the source that generates the input image and the target image in the image frame. The processing unit **654** also determines a plurality of projection lines for respective reference images, wherein each projection line extends between the source and the target image in the corresponding reference image. The processing unit **654** then determines, for each projection line, an epipolar distance that is between the projection line of the input image and the projection line for the corresponding reference image. The epipolar distance is measured in a direction that is perpendicular to both the projection line of the input image and the projection line of the reference image. In some embodiments, the processing unit **654** is configured to select a reference image that spatially corresponds with the input image by comparing the epipolar distances with a prescribed threshold. If the epipolar distance for a reference image is below the prescribed threshold, then it may be determined that the target's position when the input image is generated (during method **700**) corresponds (e.g., is the same relative to certain arbitrary coordinate system) with the target's position when the reference image is generated. In such cases, the processing unit **654** then selects such reference image for determining the position of the target region. In some embodiments, the position of the midpoint at the epipolar line between the projection line of the input image and the projection line of the selected reference image may be used as the position of the target. Stereo imaging technique has been described in U.S. patent application Ser. No. 12/211,686, filed on Sep. 16, 2008, the entire disclosure of which is expressly incorporated by reference herein.

It should be noted that using detected non-periodicity of patient's breathing to trigger an imaging of internal region is advantageous because it obviates the need to periodically image the internal region for verification of the position of the internal region and for verification of the relationship between breathing and target positions. Periodic imaging of internal region is not desirable because it complicates the treatment procedure. Also, in the case in which radiation is used to image internal region, periodic imaging using radiation is also not desirable because it increases the radiation dosage to the patient **628**.

In further embodiments, instead of using the breathing monitoring system **10** with a device that has treatment capability, the breathing monitoring system **10** may be used with an imaging device. FIG. **8** illustrates a computed tomography system **910** that is used with the breathing monitoring system **10** in accordance with some embodiments. The system **910** includes a gantry **912**, and a support **914** for supporting a patient **928**. The gantry **912** includes an x-ray source **920** that projects a beam **926** of x-rays towards a detector **924** on an opposite side of the gantry **912** while the patient **928** is positioned at least partially between the x-ray source **920** and the detector **924**. By means of non-limiting examples, the beam of x-rays can be a cone beam or a fan beam. The detector **924** has a plurality of sensor elements configured for sensing a x-ray that passes through the patient **928**. Each sensor element generates an electrical signal representative of an intensity of the x-ray beam as it passes through the patient **928**.

The system **910** also includes a control system **918**. In the illustrated embodiments, the control system **918** includes a processing unit **954**, such as a computer processor, coupled to a control **940**. The control system **918** may also include a monitor **956** for displaying data and an input device **958**, such as a keyboard or a mouse, for inputting data. The operation of the radiation source **920** and the gantry **912** are controlled by the control **940**, which provides power and timing signals to the radiation source **920**, and controls a rotational speed and position of the gantry **912**, based on signals received from the processing unit **954**. Although the control **940** is shown as a separate component from the gantry **912** and the processing unit **954**, in alternative embodiments, the control **940** can be a part of the gantry **912** or the processing unit **954**. The processing unit **954** may be the processing unit **34**, or a separate processing unit that is different from the processing units **34**. Also, in some embodiments, the screen **956** may be the screen **42**, and the input device **958** may be the input device **44** of FIG. **1**. In other embodiments, the screen **956** and the input device **958** may be different from the screen **42** and the input device **44** of FIG. **1**.

It should be noted that the system **910** is not limited to the configuration described above, and that the system **910** may have other configurations in other embodiments. For example, in other embodiments, the system **910** may have a different shape. In other embodiments, the radiation source **920** of the system **910** may have different ranges of motions and/or degrees of freedom. For example, in other embodiments, the radiation source **920** may be rotatable about the patient **928** completely through a 360° range, or partially through a range that is less than 360°. Also, in other embodiments, the radiation source **920** is translatable relative to the patient **928**. Further, the radiation source **920** is not limited to delivering diagnostic energy in the form of x-ray, and may deliver treatment energy for treating a patient.

During a scan to acquire x-ray projection data (i.e., CT image data), the gantry **912** rotates about the patient **928** at different gantry angles, so that the radiation source **920** and the imager **924** may be used to obtain images at different gantry angles. As the system **910** is operated to obtain images at different gantry angles, the patient **928** is breathing. Thus, the resulting images at different gantry angles may correspond to different phases of a breathing cycle for the patient **928**. After the scan is completed, the projection images at different gantry angles are stored, e.g., in a memory (such as a non-transitory medium), and the projection images are processed to sort the images so that images at different gantry angles that correspond to a same phase of a breathing cycle are binned (e.g., associated with each other). The binned images for a specific phase of a respiratory cycle can then be used to generate a reconstructed three-dimensional CT image for that phase.

In some embodiments, when using the system **910** of FIG. **9**, the radiation source **920** is rotated about the patient **928** to deliver diagnostic (imaging) radiation from a plurality of gantry angles. As radiation is being delivered to the patient **928**, the breathing monitoring system **10** of FIG. **1** may be used to obtain the breathing signals for binning the images. For example, as images are being obtained using the system **910** to obtain projection images at different gantry angles, the signal values from the sensor **30** of the breathing monitoring system **10** are stored in the non-transitory medium. The signal values may be stored together with their corresponding time points at which the signal values are obtained. After or during the imaging session, the signal values may be processed by the processing unit **954** to determine corresponding phases for the signal values. For example, when a projection image is obtained at a certain gantry angle, the sensor **30** may sense a breathing characteristic having a value of "34", and the processing unit **954**

may determine that such sensor signal value has a corresponding phase value of 15°. Also, a respiratory cycle may be divided into 6 phase bins—i.e., bin **1** for phases 0°-60°, bin **2** for phases 60°-120°, bin **3** for phases 120°-180°, bin **4** for phases 180°-240°, bin **5** for phases 240°-300°, and bin **6** for phases 300°-360°. In the above example, the projection image (that is obtained when the signal value of 34 having the corresponding phase value of 15° is obtained) is then binned into bin **1** because it cover phases 0°-60°. Thus, the breathing monitoring system **10** may be used to bin images (during an image session, or after an image session). After the images are binned into different phase bins, images that are within the same phase bin may then be used to reconstruct a CT image for that phase bin. In some embodiments, the reconstructed CT images for the different phase bins may be displayed in a sequence to form a video. In other example, the number of bins may be more than six or less than six.

In some embodiments, in addition to, or instead of, using the breathing monitoring system **10** to determine breathing signals for binning projection images, the breathing monitoring system **10** may be used to control the imaging device. For example, in some embodiments, the processing unit **954** processes the signals from the sensor **30** to determine breathing amplitudes of the patient **928**, and then gates the delivery of the imaging radiation based on the amplitudes. For example, the processing unit **954** may cause the radiation source **920** to deliver radiation, or to stop a delivery of radiation, when the determined amplitude is within a prescribed amplitude range. In other embodiments, the processing unit **954** processes the signals from the sensor **30** to determine respiratory phases of the patient **928**, and then gates the delivery of the radiation based on the respiratory phases. For example, the processing unit **954** may cause the radiation source **920** to deliver radiation, or to stop a delivery of radiation, when the determined phase is within a prescribed phase range. In other embodiments, instead of, or in addition to, controlling the delivery of radiation, the processing unit **954** may be configured to control the gantry **912** (e.g., stop, accelerate, or decelerate the gantry **912**), and/or to position the patient support **914**, based on the determined amplitude and/or phase.

In other embodiments of a method of using the system **10** with the radiation system **910**, the processing unit **954** is configured to detect non-periodicity in the patient's **928** breathing based on signals received from the sensor **30**. When the processing unit **954** determines that there is non-periodicity in the patient's **928** breathing, the processing unit **954** may generate a signal (e.g., a beam-stop signal) to cause the radiation source **920** to stop delivering radiation, a signal to control a motion of the gantry **912** (e.g., to stop the gantry, decelerate the gantry **912**, or accelerate the gantry **912**), and/or a signal to position the patient support **914**.

As illustrated in the above embodiments, the breathing monitoring system **10** is advantageous because it may reduce a total amount of radiation dose delivered to the patient by considering breathing of the patient in the delivery of radiation. Also, in some embodiments, the breathing monitoring system **10** and methods described herein may be used to synchronize patient's respirations with a diagnostic imaging procedure to thereby reduce or eliminate motion artifact characteristics in various imaging techniques, including but not limited to CT, MRI, PET, SPECT, PET-CT, etc.

It should be noted that the breathing monitoring system **10** is not limited to being used with a radiation delivery device, and may be used with other medical devices, which may or may not be configured to deliver radiation.

Also, in one or more embodiments, the breathing monitoring system **10** may be configured to detect an end of inspiration (or beginning of exhalation) by using a sensor (e.g., pressure sensor, flow sensor, etc.) to detect resistance to filling. For example, if the sensor value has reached certain limit (e.g., the sensed pressure value may reach a maximum limit, or the sensed flow value in the inhale direction may reach a minimum limit), then the processing unit in the breathing monitoring system **10** may determine that the patient has reached an end of inspiration. In such cases, the system **10** may reduce the airflow/pressure to allow elastic recoil of the chest for expiration. Similarly, the system **10** may be configured to detect an end of exhalation (or beginning of inspiration) by using the sensor. For example, if the sensor value has reached certain limit (e.g., the sensed pressure value may reach a minimum limit, or the sensed flow value in the exhale direction may reach a minimum limit), then the processing unit in the breathing monitoring system **10** may determine that the patient has reached an end of exhalation. In such cases, the system **10** may increase airflow/pressure to provide support for inspiration. In some embodiments, the various limits for determining end of inspiration, beginning of exhalation, beginning of inspiration, and end of exhalation may be predetermined and set in the system **10**. In other embodiments, one or more of the limits may be selectively set by a user of the system **10**. Also, in one or more embodiments, the amount of airflow or pressure provided by the system **10** to support an inhalation, and/or the amount of airflow or pressure provided by the system **10** to support an exhalation, may be fixed in the system **10** or selectively set by a user of the system **10**. It should be noted that the breathing monitoring system **10** is not limited to the examples of the functions described herein, and that other types of breathing system **10** may be used in other embodiments.

In addition, in some embodiments, the system **10** may be used to semi-control the patient's breathing so that the patient's breathing occurs in a predictable manner during an imaging procedure and/or a treatment procedure. For example, in some embodiments, the timing for initiating an inhale phase and/or an exhale phase may be determined by the patient, but the rest of the breathing pattern (e.g., speed of exhaling, speed of inhaling, etc.) may be achieved at least partially using the breathing monitoring system **10**. For example, in some embodiments, a breathing cycle period, period length for inhalation, period length for exhalation, or any combination of the foregoing, may be entered or set in the breathing monitoring system **10**. In such cases, the system **10** may be configured to provide different amount of airflow/pressure at different time points to achieve certain exhaling and/or inhaling speed based on any of the above information. In other embodiments, the system **10** may be configured to provide more control for the patient's breathing. For example, in other embodiments, the system **10** may be configured to determine when inhalation begins and/or ends, and when exhalation begins and/or ends. In further embodiments, the system **10** may be configured to allow the patient to control most of his/her breathing. In such cases, the system **10** may provide airway pressure support based on the patient's breathing pattern throughout the breathing cycle. In still further embodiments, the system **10** may be configured to control most or all of the patient's breathing. For example, in some embodiments, the system **10** may be configured to take over the breathing function of the patient and control a timing of the inhale phase for the patient. In

some embodiments, the system **10** may also control a timing of the exhale phase. Also, in some embodiments, when the system **10** takes over the control of most or all of the patient's breathing, the patient may be intubated with one end of the tube **16** inserted into the mouth of the patient.

Furthermore, in one or more embodiments, the breathing monitoring system **10** may be used by patient who may or may not need any positive airway pressure support. For example, while patient who has breathing condition may benefit from the use of the breathing monitoring system **10** because it provides positive airway pressure for the patient, patient who does not have any breathing condition may also use the system **10**. Also, in some embodiments, the breathing monitoring system **10** may provide air flow having a regular amount of oxygen concentration. In other embodiments, the breathing monitoring system **10** may be configured to provide airflow with an increased amount of oxygen concentration. For example, in some embodiments, a tank of concentrated oxygen may be fluidly coupled to the tube **16**, so that when airflow/air pressure is created in the tube **16** by the breathing device, air with an increased amount of oxygen will be delivered to the patient. Thus, as used in this specification, the term "air", or similar terms (such as "airflow", "air pressure", etc.) is not limited to gas having a normal amount of oxygen concentration, but may also refer to any gas having any amount of oxygen concentration.

Computer System Architecture

FIG. **9** is a block diagram that illustrates an embodiment of a computer system **1900** upon which an embodiment of the invention may be implemented. Computer system **1900** includes a bus **1902** or other communication mechanism for communicating information, and a processor **1904** coupled with the bus **1902** for processing information. The processor **1904** may be an example of the processing unit **34** of FIG. **1**, or another processor that is used to perform various functions described herein. In some cases, the computer system **1900** may be used to implement the processor **14** (or other processors described herein). The computer system **1900** also includes a main memory **1906**, such as a random access memory (RAM) or other dynamic storage device, coupled to the bus **1902** for storing information and instructions to be executed by the processor **1904**. The main memory **1906** also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor **1904**. The computer system **1900** further includes a read only memory (ROM) **1908** or other static storage device coupled to the bus **1902** for storing static information and instructions for the processor **1904**. A data storage device **1910**, such as a magnetic disk or optical disk, is provided and coupled to the bus **1902** for storing information and instructions.

The computer system **1900** may be coupled via the bus **1902** to a display **1912**, such as a cathode ray tube (CRT) or a flat panel, for displaying information to a user. An input device **1914**, including alphanumeric and other keys, is coupled to the bus **1902** for communicating information and command selections to processor **1904**. Another type of user input device is cursor control **1916**, such as a mouse, a trackball, or cursor direction keys for communicating direction information and command selections to processor **1904** and for controlling cursor movement on display **1912**. 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.

The computer system **1900** may be used for performing various functions (e.g., calculation) in accordance with the embodiments described herein. According to one embodiment, such use is provided by computer system **1900** in response to processor **1904** executing one or more sequences of one or more instructions contained in the main memory **1906**. Such instructions may be read into the main memory **1906** from another computer-readable medium, such as storage device **1910**. Execution of the sequences of instructions contained in the main memory **1906** causes the processor **1904** 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 **1906**. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement the invention. Thus, embodiments of the invention are not limited to any specific combination of hardware circuitry and software.

The term "computer-readable medium" as used herein refers to any medium that participates in providing instructions to the processor **1904** 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 **1910**. A non-volatile medium may be considered as an example of a non-transitory medium. Volatile media includes dynamic memory, such as the main memory **1906**. A volatile medium may be considered as another example of a non-transitory medium. Transmission media includes coaxial cables, copper wire and fiber optics, including the wires that comprise the bus **1902**. Transmission media can also take the form of acoustic or light waves, such as those generated during radio wave and infrared data communications.

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.

Various forms of computer-readable media may be involved in carrying one or more sequences of one or more instructions to the processor **1904** 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 computer system **1900** 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 **1902** can receive the data carried in the infrared signal and place the data on the bus **1902**. The bus **1902** carries the data to the main memory **1906**, from which the processor **1904** retrieves and executes the instructions. The instructions received by the main memory **1906** may optionally be stored on the storage device **1910** either before or after execution by the processor **1904**.

The computer system **1900** also includes a communication interface **1918** coupled to the bus **1902**. The communication interface **1918** provides a two-way data communication coupling to a network link **1920** that is connected to a local network **1922**. For example, the communication interface **1918** 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 **1918** may be a local area network (LAN) card to provide a data commu-

nication connection to a compatible LAN. Wireless links may also be implemented. In any such implementation, the communication interface **1918** sends and receives electrical, electromagnetic or optical signals that carry data streams representing various types of information.

The network link **1920** typically provides data communication through one or more networks to other devices. For example, the network link **1920** may provide a connection through local network **1922** to a host computer **1924** or to equipment **1926** such as a radiation beam source or a switch operatively coupled to a radiation beam source. The data streams transported over the network link **1920** can comprise electrical, electromagnetic or optical signals. The signals through the various networks and the signals on the network link **1920** and through the communication interface **1918**, which carry data to and from the computer system **1900**, are exemplary forms of carrier waves transporting the information. The computer system **1900** can send messages and receive data, including program code, through the network(s), the network link **1920**, and the communication interface **1918**.

Although particular embodiments of the present inventions 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 departing 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.

What is claimed:

1. A medical apparatus, comprising:

a breathing device comprising an air pressure generator for generating air pressure, a facemask defining a space, a tube for delivering the air pressure to the space defined by the facemask for a patient, and a sensor configured to sense a characteristic of a breathing of the patient; and

a processing unit configured to receive an output from the sensor, the output comprising multiple sensor values at different respective time points, wherein the processing unit is further configured to determine metric values using the sensor values, and generate a control signal for controlling a medical device based at least in part on at least one of the metric values, wherein each of the metric values represents a degree of completeness of a breathing cycle.

2. The medical apparatus of claim **1**, wherein the breathing device comprises a BPAP machine.

3. The medical apparatus of claim **1**, wherein the breathing device comprises a CPAP machine.

4. The medical apparatus of claim **1**, wherein the sensor comprises a pressure sensor or an airflow sensor.

5. The medical apparatus of claim **1**, wherein the processing unit comprises a processor.

6. The medical apparatus of claim **1**, wherein the medical device comprises a radiation machine, and the processing unit is configured to generate the control signal to control the radiation machine.

7. The medical apparatus of claim **6**, wherein the radiation machine is configured to deliver diagnostic radiation for imaging the patient.

8. The medical apparatus of claim **6**, wherein the radiation machine is configured to deliver treatment radiation for treating the patient.

9. The medical apparatus of claim **6**, wherein the control signal is configured to control the medical device to perform one or more of: turning on a radiation beam, turning off the radiation beam, rotating a gantry of the radiation machine, operating a collimator, operating a patient support, and adjusting a dose rate.

10. The medical apparatus of claim **1**, wherein the medical device comprises a collimator, and the processing unit is configured to generate the control signal to control the collimator in synchronization with the breathing of the patient.

11. The medical apparatus of claim **1**, wherein the medical device comprises an imaging device, and the processing unit is configured to generate the control signal to activate the imaging device.

12. The medical apparatus of claim **11**, wherein the imaging device comprises a CT machine, a PET machine, a PET-CT machine, or a MRI machine.

13. The medical apparatus of claim **1**, wherein the processing unit is configured to generate the control signal in real time to control the medical device.

14. The medical apparatus of claim **1**, wherein the processing unit is also configured to obtain information from a device that is configured to determine a position of a part of the patient, and to correlate the position of the part of the patient with the sensed characteristic.

15. The medical apparatus of claim **14**, wherein the position determined by the device is associated with a breathing motion of the patient.

16. The medical apparatus of claim **14**, wherein the device that is configured to determine the position comprises a breathing monitoring device.

17. The medical apparatus of claim **1**, wherein the air pressure generator is configured to generate the air pressure in response to a respiratory activity of the patient.

18. A medical method, comprising:

providing a breathing device, the breathing device comprising an air pressure generator for generating air pressure, a facemask defining a space, a tube for delivering the air pressure to the space defined by the facemask for a patient, and a sensor;

sensing a characteristic of a breathing of the patient using the sensor;

receiving, by a processing unit, an output from the sensor, the output comprising multiple sensor values at different respective time points;

determining, by the processing unit, metric values using the sensor values, wherein each of the metric values represents a degree of completeness of a breathing cycle; and

generating a control signal to control a medical device based at least in part on at least one of the metric values, wherein the control signal is generated by the processing unit.

19. The medical method of claim **18**, wherein the breathing device comprises a BPAP machine.

20. The medical method of claim **18**, wherein the breathing device comprises a CPAP machine.

21. The medical method of claim **18**, wherein sensor comprises a pressure sensor or an airflow sensor.

22. The medical method of claim **18**, wherein the medical device comprises a radiation machine, and the control signal is generated to control the radiation machine.

23. The medical method of claim **22**, wherein the radiation machine is configured to deliver diagnostic radiation for imaging the patient.

24. The medical method of claim 22, wherein the radiation machine is configured to deliver treatment radiation for treating the patient.

25. The medical method of claim 22, wherein the control signal is configured to control the medical device to perform one or more of: turning on a radiation beam, turning off the radiation beam, rotating a gantry of the radiation machine, operating a collimator, operating a patient support, and adjusting a dose rate.

26. The medical method of claim 18, wherein the medical device comprises a collimator, and the control signal is generated to control the collimator in synchronization with the breathing of the patient.

27. The medical method of claim 18, wherein the medical device comprises an imaging device, and the control signal is generated to activate the imaging device.

28. The medical method of claim 27, wherein the imaging device comprises a CT machine, a PET machine, a PET-CT machine, or a MRI machine.

29. The medical method of claim 18, wherein the control signal is generated in real time to control the medical device.

30. The medical method of claim 18, further comprising:

obtaining information from a device that is configured to determine a position of a part of the patient; and

correlating the position of the part of the patient with the sensed characteristic.

31. The medical method of claim 18, wherein the air pressure generator is configured to generate the air pressure in response to a respiratory activity of the patient.

32. A medical apparatus, comprising:

a breathing device configured to provide air pressure, the breathing device comprising an air pressure generator for generating the air pressure, a facemask defining a space, and a tube for delivering the air pressure to the space defined by the facemask for a patient;

wherein the breathing device comprises a sensor configured to sense a characteristic associated with a breathing of the patient;

a processing unit configured to receive an output from the sensor, the output comprising multiple sensor values at different respective time points, wherein the processing unit is further configured to determine metric values using the sensor values, and generate a control signal to control a medical device based at least in part on at least one of the metric values, wherein each of the metric values represents a degree of completeness of a breathing cycle, and wherein the medical device is configured to provide a medical benefit that is different from that of the breathing device; and

a non-transitory medium for storing data associated with the sensed characteristic at the multiple time points.

33. The medical apparatus of claim 32, wherein the breathing device comprises a BPAP machine.

34. The medical apparatus of claim 32, wherein the breathing device comprises a CPAP machine.

35. The medical apparatus of claim 32, wherein the sensor comprises a pressure sensor or an airflow sensor.

36. The medical apparatus of claim 32, wherein the sensor is configured to sense airway pressure or airflow as the characteristic; and

wherein the data comprises:

airway pressure values or airflow values provided from the sensor, and

time points corresponding to the respective airway pressure values or airflow values.

37. The medical apparatus of claim 32, wherein the medical device comprises a radiation machine, and the processing unit is configured to generate the control signal to control the radiation machine.

38. The medical apparatus of claim 37, wherein the radiation machine is configured to deliver diagnostic radiation for imaging the patient.

39. The medical apparatus of claim 37, wherein the radiation machine is configured to deliver treatment radiation for treating the patient.

40. The medical apparatus of claim 37, wherein the control signal is configured to control the medical device to perform one or more of: turning on a radiation beam, turning off the radiation beam, rotating a gantry of the radiation machine, operating a collimator, operating a patient support, and adjusting a dose rate.

41. The medical apparatus of claim 32, wherein the processing unit is configured to generate the control signal in real time to control the medical device.

42. The medical apparatus of claim 32, further comprising a treatment planning unit configured to determine a parameter of a treatment plan using the data associated with the sensed characteristic, wherein the treatment plan is configured for use by the medical device.

43. The medical apparatus of claim 32, wherein the processing unit is also configured to obtain information from a device that is configured to determine a position of a part of the patient, and to correlate the position of the part of the patient with the sensed characteristic.

44. The medical apparatus of claim 43, wherein the position determined by the device is associated with a breathing motion of the patient.

45. The medical apparatus of claim 43, wherein the device that is configured to determine the position comprises a breathing monitoring device.

46. The medical apparatus of claim 32, wherein the air pressure generator is configured to generate the air pressure in response to a respiratory activity of the patient.

47. A medical method, comprising:

providing a breathing device, the breathing device comprising an air pressure generator for generating air pressure, a facemask defining a space, a tube for delivering the air pressure to the space defined by the facemask for a patient, and a sensor;

sensing a characteristic associated with a breathing of the patient using the sensor;

receiving, by a processing unit, an output from the sensor, the output comprising multiple sensor values at different respective time points;

determining, by the processing unit, metric values using the sensor values, wherein each of the metric values represents a degree of completeness of a breathing cycle; and

generating a control signal to control a medical device based at least in part on at least one of the metric values, wherein the medical device is configured to provide a medical benefit that is different from that of the breathing device, and wherein the control signal is generated by the processing unit; and

storing data associated with the sensed characteristic in a non-transitory medium.

48. The medical method of claim 47, wherein the breathing device comprises a BPAP machine.

49. The medical method of claim 47, wherein the breathing device comprises a CPAP machine.

50. The medical method of claim 47, wherein the sensor comprises a pressure sensor or an airflow sensor.

51. The medical method of claim 47, wherein the data comprises:

airway pressure values or airflow values provided from the sensor, and

time points corresponding to the respective airway pressure values or airflow values.

52. The medical method of claim **47**, further comprising determining a parameter of a treatment plan using the stored data, wherein the treatment plan is configured for use by the medical device.

53. The medical method of claim **52**, wherein the treatment plan comprises a radiation treatment plan.

54. The medical method of claim **47**, wherein the medical device comprises a radiation machine.

55. The medical method of claim **54**, wherein the radiation machine comprises a radiation diagnostic machine.

56. The medical method of claim **54**, wherein the radiation machine comprises a radiation treatment machine.

57. The medical method of claim **54**, wherein the act of controlling the medical device comprises one or more of: turning on a radiation beam, turning off the radiation beam, rotating a gantry of the radiation machine, operating a collimator, operating a patient support, and adjusting a dose rate.

58. The medical method of claim **47**, further comprising:

obtaining information from a device that is configured to determine a position of a part of the patient; and

correlating the position of the part of the patient with the sensed characteristic.

59. The medical method of claim **47**, wherein the air pressure generator is configured to generate the air pressure in response to a respiratory activity of the patient.

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专利名称(译)	使用正气道压力装置进行医疗门控		
公开(公告)号	US10159446	公开(公告)日	2018-12-25
申请号	US13/603200	申请日	2012-09-04
[标]申请(专利权)人(译)	DICKERSON葛雷格一个		
申请(专利权)人(译)	迪克森GREGG A.		
当前申请(专利权)人(译)	迪克森GREGG A.		
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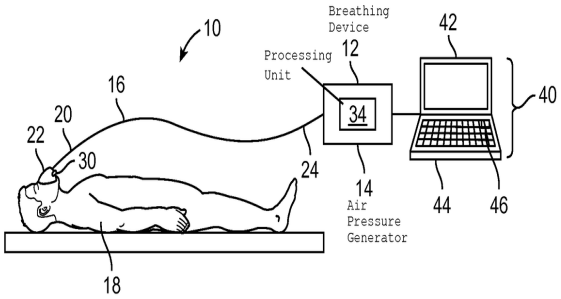
一种医疗设备，包括：呼吸装置，包括用于产生气压的气压发生器，用于将气压输送到患者的管，以及被配置为感测与患者的呼吸相关的特性的传感器;处理单元，被配置为从传感器接收输出，并且至少部分地基于来自传感器的输出生成用于控制医疗设备的控制信号。