(54) **Title:** SYSTEM AND METHOD FOR ACTIVE CANCELLATION OF PRESSURE PULSES

(57) **Abstract:** A respiration gas monitor device (100) includes a pump (110) connected to draw a flow of respired air, a pressure sensor (150, 160) is connected to measure an air pressure signal responsive to the flow of respired air, and a pressure transducer (180c). Electrical circuitry (170, 180) is operatively connected to measure flow across the pressure sensor. A gas component sensor (190, 192, 194) is arranged to monitor a target gas in the flow of respired air.

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SYSTEM AND METHOD FOR ACTIVE CANCELLATION OF PRESSURE PULSES

FIELD

The following relates generally to the monitoring arts, respiration arts, pressure pulsation monitoring arts, pressure pulsation cancellation arts, gaseous concentration measurement arts, and related arts.

BACKGROUND

In sidestream respiration gas monitors (RGMs), also known as diverting RGMs, a sample of respiration gas is drawn from a patient down a sample tube to a measuring area of the RGM (respiration gas monitor) where any of a variety of techniques can be used to measure the concentration of one or more components of the respiration gas including, but not limited to, carbon dioxide (CO_2), oxygen (O_2), nitrous oxide (N_2O), and halogenated agents such as halothane, enflurane, isoflurane, sevoflurane and desflurane. Patterns of variation in the concentrations of these gas components can have clinical significance in the treatment of patients. Accordingly, it is desired to provide a consistent, accurate temporal record of the monitored gas concentration to aid in the diagnosis and treatment of a variety of conditions. To this end, the manner of gas sampling can have a great influence on the performance and accuracy of an RGM.

Typically, a small diaphragm pump or similar air-moving device is used to create the gas flow from the patient to the measuring area. By the reciprocating nature of their operation, such pumps tend to move the sample gas in a pulsatile manner, producing significant pressure variation, i.e. ripple, in the sample line, especially in the vicinity of the pump. Other types of mechanical air pumps similarly tend to introduce a pressure ripple due to the cyclical nature of the pumping mechanism, usually at the cycle frequency or a multiple thereof, e.g. twice the cycle frequency. These pressure variations, depending upon their magnitude and frequency, can interfere with flow rate measurement and gas concentration measurement.

Two methods that have been used previously to deal with these pressure pulsation (i.e. ripple) include: (1) providing an air "reservoir" to absorb and attenuate the pulsation, effectively reducing the amplitude of the pulsations to manageable levels; and (2) low-pass filtering the

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pressure-drop measurement to attenuate the pulsation. Both of these methods have disadvantages. The reservoir approach, while effective, adds significant physical volume, which is disadvantageous where space is at a premium, and there is significant desire to reduce the physical volume of RGMs.

5   The low-pass filtering approach adds little physical volume, but does nothing to attenuate or eliminate the pressure pulsation in the gas sampling system. Since the pulsations can be very large compared to the pressure drop associated with flow, this creates a risk of pressure sensor saturation unless a sensor with a very wide pressure sensing range is employed. If the sensor saturates, the low-pass method produces an error in flow rate measurement, but selecting a wide-

10   range sensor (compared to the desired measurement) usually results in poor measurement accuracy unless a very expensive, high-accuracy sensor is chosen. Further, this technique permits the un-attenuated pressure pulsations to appear in the measurement area, producing errors in the measurement of gas concentrations.

        Improvements disclosed herein address the foregoing and other disadvantages of

15   respiratory gas monitoring systems, methods, and the like.

BRIEF SUMMARY

        In accordance with one illustrative example, a respiration gas monitor device includes a pump connected to draw a flow of respired air, a pressure sensor is connected to measure an air

20   pressure signal responsive to the flow of respired air, and a pressure transducer. Electrical circuitry is operatively connected to measure flow across the pressure sensor. A gas component sensor is arranged to monitor a target gas in the flow of respired air.

        In accordance with another illustrative example, a device for attenuating or eliminating pressure ripple in a respiration gas monitor is provided. The device includes a pump configured

25   to draw respired air from a measurement area, and a constrictor through which at least a portion of the respired air drawn by the pump moves. At least one pressure sensor is configured to measure a pressure value of air flowing through the constrictor. A ripple cancellation device is configured to attenuate or eliminate at least one pressure ripple in the respired air flowing through the constrictor.

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In accordance with another illustrative example, a respiratory gas monitoring method includes: drawing, with a pump, respired air through a measurement area, at least a portion of the respired air moving through a constrictor; measuring, with at least one pressure sensor, a pressure signal of air flowing through the constrictor; attenuating or eliminating, with a ripple cancellation device, at least one pressure ripple in the respired air flowing through the constrictor; and measuring, with a measurement device, a target gas in the flow of expired air.

One advantage resides in removing pressure pulsations in an air pressure signal.

Another advantage resides in measuring gases in air without pressure pulsations.

Another advantage resides in controlling flow in a pump by removing pressure pulsations.

Another advantage resides in measure concentrations of different gases in respired air.

Further advantages of the present disclosure will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description. It will be appreciated that a given embodiment may provide none, one, two, or more of these advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIGURE 1 diagrammatically illustrates a respiration gas monitor device according to one aspect.

FIGURE 2 is an exemplary flow chart of the calibration process of the device of FIGURE 1.

DETAILED DESCRIPTION

In RGMs, the respiration gas flow is typically regulated to a relatively constant rate to avoid temporal distortion of the gas concentration record (i.e., waveform). This flow regulation is often accomplished by introducing a constrictor (such as an orifice or a capillary tube) into the gas flow path and controlling the pump drive level is controlled to maintain a constant pressure drop across the constrictor. Since the pressure drop is a direct function of the flow rate, maintaining a constant pressure drop produces a constant flow rate. In the presence of pump-induced pressure

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pulsations, however, the amplitude of the pulsations in the pressure drop can be large, and may even exceed the magnitude of the flow-induced pressure drop, which can be problematic for accuracy of the flow rate measurement and control.

Another problem potentially introduced by pressure pulsations in the sample line is that the pressure pulsations appear on the gas sample in the measuring area of the RGM. The gas concentration measurements can be affected by the temperature and pressure of the gas in the measuring area, so any significant pressure pulsations can interfere with the accuracy of those measurements.

The following relates to an improvement in Respiration Gas Monitor (RGM) devices employing a sidestream (i.e. diverting) flow arrangement in which a pump is provided to draw sample gas from the main respiration circuit into a side stream feeding the RGM device. The pump produces a negative pressure (a "vacuum") that draws the flow into the side stream. A diaphragm pump is commonly used, which produces a constant or average negative pressure on which is superimposed a "ripple" pressure variation component. The average negative pressure can be on the order of 1 psi while the ripple may be comparable, e.g. 0.5 psi. Other types of pumps also operate using a cyclical pumping cycle that similarly typically introduces a pressure ripple. This ripple introduces pressure variations in the sampling chamber. Since the CO_2 or other gas measurement is pressure-dependent, the ripple can introduce respiration gas measurement errors.

The following describes improved RGM devices in which an audio transducer is provided to reduce or eliminate the pressure ripple introduced by the pump. In some illustrative embodiments, the transducer control circuit includes a differential pressure sensor to measure the pressure drop over a constrictor (i.e., orifice or capillary tube) and a high-pass or bandpass filter to filter the measured pressure to extract the ripple. The high-pass filtered signal is inverted and applied to drive the audio transducer to generate an opposing ripple that reduces or cancels the ripple produced by the pump. The transducer is thus used to provide a more uniform pressure output from the fluid pump.

There are many ways of sensing flow, including but not limited to: hot-wire, ultrasonic sensing by differential time delay, and measuring the pressure drop across an obstacle in the flow path, among others. The following describes the pressure drop/obstacle method, but other flow sensing techniques could be adapted. With the pressure drop/obstacle method of flow sensing, a

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"constrictor" device is used. The constrictor is essentially any obstacle placed in the flow path. The obstruction to flow produces a relative drop in pressure on the "lee" side of the obstacle when air (gas) passes by it. This difference in pressure is a function of flow. The pressure sensor measures the difference in pressure before and after the obstruction, thereby producing an electrical signal

5   responsive to and representative of airflow past the obstacle.

The most common constrictor type is an orifice. The orifice is very inexpensive, but has the disadvantage that it is highly nonlinear and highly sensitive to temperature and various gas properties. Another type of constrictor is a capillary tube, which is highly linear and much less sensitive to temperature and other sources of error. The capillary tube, used in this way, is

10   sometimes referred to as a "linear flow converter".

With reference now to FIGURE 1, a schematic illustration of a respiratory gas monitor (RGM) device **100** including components for attenuating or eliminating a pressure ripple. The RGM device **100** includes an air-moving device, such as a diaphragm pump **110**, connected to draw a flow of respired air by a patient. In a typical sidestream configuration, the respired air is

15   drawn from a nasal cannula, tracheal intubation, or other patient accessory. The RGM device **100** also includes a flow constrictor **140** through which at least a portion of the respired air drawn by the pump moves. The pump **110** is connected to draw a flow of respiration gas from a patient through a sample tube segment **120a** into a measurement area **130**. The air then flows to the constrictor **140**, which is disposed between the pump **110** and the measurement area **130**. The

20   pump **110** then receives the air from the constrictor **140**. Ultimately, the air drawn by the pump **110** may be discharged to the ambient air, optionally after passing through a scrubbing device (not shown). A sample tube segment **120b** provides connection of a differential pressure sensor **150** to measure differential pressure across the constrictor **140**, and connection of an optional gauge pressure sensor **160**. In some examples, the constrictor **140** can be a capillary tube or an orifice.

25   The device **100** also includes the at least one pressure sensor **150** connected to measure an air pressure signal responsive to the flow of respired air through the constrictor **140**. For example, the flow of respiration gas through the constrictor **140** creates a pressure drop across the constrictor. In this example, the pressure sensor **150** is a differential pressure sensor that measures the pressure decrease from the inlet to the outlet of the constrictor **140**. The pressure sensor **150** is configured

30   to measure this pressure drop and produce a differential pressure signal **175a** representative of the

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pressure drop across the constrictor **140**, (and hence representative of the rate of gas flow through the constrictor). In some examples, the pump **110** is connected to draw the flow of respired air through the constrictor **140** and the pressure sensor **150** is connected to measure the air pressure signal indicating a pressure change across the constrictor. The constrictor **140** and the pressure

5   sensor **150** serve to maintain a constant rate of airflow. A control mechanism, such as a pump controller (not shown) drives the pump **110** to maintain a constant pressure drop across the constrictor (as measured by the differential pressure sensor).The device **100** optionally further includes a gauge sensor **160** arranged to monitor pressure of the respired air. The gauge pressure sensor **160** is configured to measure the pressure at the outlet of the measurement area **130**, and

10   hence represents pressure of the respired air in the measurement area **130**. This gauge pressure measurement is optionally used in the calculation of the concentrations of the target gas (e.g. carbon dioxide in the case of the RGM device **100** being a capnometer) in the respiration gas sample present in the measurement area **130** at any given time. In the illustrative example, a target gas measurement device is an optical measurement device that includes an infrared light source

15   **190**, a light detector **192**, and a bandpass filter **194**. The infrared light source **190** is arranged to launch infrared light that is transmitted through the measurement area **130**, and more particularly through the flow of respired air through the measurement area **130**. The bandpass filter **194** is arranged to filter the infrared light to pass a wavelength absorbed by the target gas (that is, the bandpass filter **194** has a passband that encompasses an absorption line of the target gas, e.g. the

20   4.3 micron absorption line of carbon dioxide in the case of a capnometer). The light detector **192** is arranged to detect the infrared light after being transmitted through the flow of respired air and filtered by the bandpass filter **194**. The target gas concentration or partial pressure is computed, e.g. by a microprocessor or other electronic processor **196**, based on the detected infrared light intensity. A higher concentration of the target gas in the respired air produces more absorption and

25   hence a reduced transmitted and bandpass-filtered infrared light intensity. Optionally, the determination of the concentration or partial pressure of target gas takes into account known factors that can affect the measurement, such as the pressure of the respired air as measured by the gauge pressure sensor **160**, and/or a calibration infrared intensity measured in the absence of the respired air flow. The electronic processor **196** may also optionally compute a clinically significant value,

30   such as end-tidal carbon dioxide ($etCO_2$) in the case of the RGM device **100** implementing

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capnography. The target gas measurement and/or derived clinical value such as $etCO_2$ is displayed on an RGM display **198** (e.g. an LCD display showing the target gas concentration or partial pressure and/or the derived clinical quantity as a real-time numeric value, and/or as a trend line, or so forth). Additionally or alternatively, the data may be ported off the RGM device **100** via a wired or wireless communication link (not shown, e.g. a wired or wireless Ethernet link, a Bluetooth link, et cetera). The electronic processor **196** may also optionally perform various RGM device control functions, such as outputting the desired flow rate to the flow control mechanism **170**.

The illustrative optical target gas measurement device **190, 192, 194** is merely an illustrative example, and more generally any type of target gas measurement device may be employed to measure the concentration or partial pressure of the target gas in the respired air flowing through the measurement area **130**.

In some examples, the pump **110** is a reciprocating or cyclically operating device that moves air (i.e., respiration gas) in a pulsatile fashion, thereby producing significant pressure pulsations (i.e. pressure ripple) in the tubing segment **120c**. If these pressure pulsations are transmitted via the constrictor **140** and sample tube segment **120b** to the measurement area **130**, then they can lead to measurement error. The amplitude of the pulsations is likely to be reduced somewhat after passing through the tubing segments **120c, 120b** and the constrictor **140**, but this attenuation may not be enough to prevent a significant pulsation waveform to appear in measurements made by the gauge pressure sensor **160**. These pulsations can create errors in the measured concentrations of the components of the respiration gas sample present in the measurement area **130**.

The device **100** can also include electronic circuitry configured to control various operations thereof (e.g., flow control, pulse cancellation, and the like). To control flow operations, the electrical circuitry of the device **100** can include a flow control mechanism **170** with a comparator **170a**, a pump controller **170b**, and a pump driver **170c** arranged in a feedback control configuration. The comparator **170a** is configured to receive the differential pressure signal **175a** from the differential pressure sensor **150**. From this, the comparator **170a** is configured to subtract the differential pressure signal **175a** (i.e., the flow rate through the constrictor **140**) from a desired flow rate setpoint signal to produce or generate a flow rate error signal **175b** indicative of the difference between the desired flow rate and the actual flow rate. The pump controller **170b** is

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configured to amplify and process the flow rate error signal **175b** to produce or generate a pump control signal **175c**, which is used to driver a pump driver **170c**. The pump driver **170c** is configured to buffer the pump control signal **175c** to produce or generate a pump drive signal **175d**, which is transmitted to the pump **110** and used to drive the pump. If the differential pressure signal

5   **175a** indicates that the flow rate is less than the desired flow rate, the resultant error signal **170b** indicates that the flow rate should be increased by increasing the speed of the pump **110**. When this occurs, the pump driver **170c** is configured to increase the speed of the pump **110**. Conversely, if the differential pressure signal **175a** indicates that the flow rate is greater than the desired flow rate, the resultant error signal **170b** indicates that the flow rate should be decreased by decreasing

10   the speed of the pump **110**. When this occurs, the pump driver **170c** is configured to decrease the speed of the pump **110**. The pump controller **170b** is configured to control the pump **110** in a manner that will produce a stable, steady flow rate. Other types of feedback control of the pump **110** are contemplated. It is further contemplated to operate the pump **110** without feedback control, i.e. in open loop fashion.

15   As disclosed herein, a closed-loop control ripple cancellation device **180** is provided to cancel and thereby reduce or eliminate the pressure ripple introduced by the cyclical operation of the pump **110**. To provide pressure pulsation cancellation, the device **100** includes a pressure transducer **180c** (or other suitable device) which introduces a pressure ripple that is "opposite" that produced by the pump **110**, so as to cancel the pressure ripple of the pump **110**. The electronic

20   circuitry **180a**, **180b** is operatively connected to read the pressure sensor **150** and to drive the pressure transducer **180c** to inject ripple-canceling pressure pulses into flow of respired air to reduce or eliminate a pressure ripple in the flow of respired air. The ripple-canceling pressure pulses are determined by the electrical circuitry **180a**, **180b** from the air pressure signal measured by the pressure sensor **150**. In other contemplated embodiments, gauge pressure measured by the

25   gauge pressure sensor 160 is used, and those ripples are controlled instead. This may have an advantage in placing the ripple control driver closer to the capnography sensor. Cancellation of the pressure pulsations is accomplished with a closed-loop control ripple cancellation device **180** configured to attenuate or eliminate at least one pressure ripple in the respired air flowing through the constrictor **140**. The illustrative ripple cancellation device **180** includes a high-pass filter **180a**,

30   a controller **180b** and the audio transducer (or similar air moving device) **180c**. An AC component

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of the differential pressure signal **175a** measured by the differential pressure sensor **150** is representative of the pressure pulsations created by the pump **110**. The high-pass filter **180a** is configured to receive the pressure value from the pressure sensor **150** and separate out and isolate this AC component of the signal to generate such that a pulsation or ripple signal **185a** that

5   represents only those pulsations, without regard to a flow rate related component of the differential pressure signal **175a**. The cut-off frequency of the high-pass filter **180a** is chosen to pass the AC component corresponding to the pressure ripple. It will be appreciated that the high-pass filter **180a** may be replaced by a bandpass filter whose lower and upper cut-off frequencies are chosen such that the ripple signal is within the passband. On the other hand, the (lower) cut-off frequency

10   of the bandpass filter **180a** should be high enough to remove the DC pressure component, so that the output of the filter **180a** corresponds to the pressure ripple component alone. The controller **180b** is programmed or tuned to produce or generate a transducer drive signal **185b** from the ripple signal to drive the audio transducer **180c**. The audio transducer **180c** produces or generates an antiphase pressure waveform **185c** from the transducer drive signal **185b** that counteracts and

15   substantially nullifies the pressure pulsations (ripple) produced by the pump **110**, the goal of which being to produce minimal signal output from the high pass filter **180a**. The transducer **180c** is configured to apply the antiphase pressure waveform to air flowing from the constrictor **140** to the pump **110** to nullify the pulsations in the air. In some embodiments, the controller **180b** is a proportional-integral-derivative (PID) controller having proportional (P), integral (I), and

20   derivative (D) parameters. The PID controller may be implemented using analog circuitry (e.g. op amps) and/or digital circuitry, e.g. a microprocessor or microcontroller. The controller **180b** can also be some other type of feedback controller (e.g. a PI controller).

With reference now to FIGURE 2, the RGM device **100** is configured to perform a respiratory gas monitoring method **10**. At **12**, respired air is drawn, with the pump **110**, through

25   the measurement area **130**. At least a portion of the respired air moves through the constrictor **140**. At **14**, a pressure signal **175a** of air flowing through the constrictor **140** is measured with the at least one pressure sensor **150**.

At **16**, at least one pressure ripple in the respired air flowing through the constrictor **140** is attenuated or eliminated with the ripple cancellation device **180a, 180b, 180c**. The attenuation or

30   elimination includes separating, with the filter **180a**, an AC component of the pressure signal to

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generate a ripple signal **185a**. A transducer drive signal **185b** is generated from the ripple signal **185a** with the controller **180b**. An antiphase pressure waveform **185c** is generated from the transducer drive signal **185b** with the pressure transducer **180c**. The waveform **185c** is then applied by the transducers **180c** to air flowing from the constrictor **140** to the pump **110** to nullify

5   the pulsations in the air. It should be noted that as the antiphase pressure waveform **185c** cancels the pressure ripple produced by the pump **110** within the sample tube segment **120c**, this cancellation also removes the pressure ripple produced by the pump **110** for all points "upstream" of the sample tube segment **120c**, particularly in the constrictor **140** and the further-"upstream" measurement area **130**.

10   At **18**, a flow of the air is optionally controlled with the flow control mechanism **170a, 170b, 170c**. (Note that operations **16** and **18** are performed concurrently). To do so, the comparator **170a**, is configured to subtract the pressure signal from a desired flow rate setpoint signal **175a** to generate a flow rate error signal **175b**. The pump controller **170b** is configured to amplify and process the flow rate error signal **175b** to produce or generate a pump control signal **175c**, which

15   is used to drive a pump driver **170c**. The pump driver **170c** is configured to buffer the pump control signal **175c** to produce or generate a pump drive signal **175d**, which is transmitted to the pump **110** and used to drive the pump. When the differential pressure signal **175a** indicates that the flow rate is less than the desired flow rate, the pump driver **170c** is configured to increase the speed of the pump **110**. When the differential pressure signal **175a** indicates that the flow rate is

20   greater than the desired flow rate, the pump driver **170c** is configured to decrease the speed of the pump **110**.

At **20**, a target gas in the flow of expired air is measured with the gauge pressure sensor **160**. (Again, operation **20** is performed concurrently with operations **16, 18**).

Referring back to FIGURE 1, the electrical circuitry of the device **100** (e.g., the flow

25   control mechanism with a comparator **170a**, the pump controller **170b**, and the pump driver **170c**, the high-pass filter **180a**, and the controller **180b** and the electronic processor **196**) can be implemented as one or more microprocessors, microcontrollers, FPGA, or other digital device(s), and/or by analog circuitry.

It will be appreciated that the illustrative computational, data processing or data interfacing

30   components of the device **100** may be embodied as a non-transitory storage medium storing

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instructions executable by an electronic processor (e.g., the electronic processor **196**) to perform the disclosed operations. The non-transitory storage medium may, for example, comprise a hard disk drive, RAID, or other magnetic storage medium; a solid state drive, flash drive, electronically erasable read-only memory (EEROM) or other electronic memory; an optical disk or other optical

5   storage; various combinations thereof; or so forth.

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

10   equivalents thereof.

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CLAIMS:

1. A respiration gas monitor device **(100)**, comprising:

a pump **(110)** connected to draw a flow of respired air;

a pressure sensor **(150, 160)** connected to measure an air pressure signal responsive to the flow of respired air;

a pressure transducer **(180c)**;

electrical circuitry **(170, 180)** operatively connected to measure flow across the pressure sensor;

and

a gas component sensor **(190, 192, 194)** arranged to monitor a target gas in the flow of respired air.

2. The respiration gas monitor device according to claim 1, wherein the electrical circuity **(170, 180)** is operatively connected to read the pressure sensor and to drive the pressure transducer to inject ripple-canceling pressure pulses into flow of respired air to reduce or eliminate a pressure ripple in the flow of respired air wherein the ripple-canceling pressure pulses are determined by the electrical circuitry from the air pressure signal measured by the pressure sensor; and

wherein the electrical circuitry **(170, 180)** determines the ripple-canceling pressure pulses by operations including high-pass or bandpass filtering the air pressure signal measured by the pressure sensor **(150)**.

3. The respiration gas monitor device according to either one of claims 1 and 2, further comprising a constrictor **(140)** comprising a capillary tube or an orifice;

wherein the pump **(110)** is connected to draw the flow of respired air through the constrictor and the pressure sensor **(150)** is connected to measure the air pressure signal indicating a pressure change across the constrictor.

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4. The respiration gas monitor device according to any one of claims 1-3, wherein the electrical circuitry (**170, 180**) includes one of a proportional-integral-derivative (PID) controller and a microprocessor.

5. The respiration gas monitor according to any one of claims 1-4, wherein the gas component sensor includes:

an infrared light source (**190**) arranged to transmit infrared light through the flow of respired air;

a bandpass filter (**194**) arranged to filter the infrared light to pass a wavelength absorbed by the target gas, and

a light detector (**192**) arranged to detect the infrared light after being transmitted through the flow of respired air and filtered by the bandpass filter.

6. The respiration gas monitor according to any one of claims 1-5, wherein the pressure sensor (150, 160) is one of:

(i) a differential pressure sensor (150) connected to measure differential pressure across a constrictor (140) in a path of the flow of respired air; or

(ii) a gauge pressure sensor (160) connected to measure a gauge pressure of the flow of respired air.

7. A device (**100**) for attenuating or eliminating pressure ripple in a respiration gas monitor, the device comprising:

a pump (**110**) configured to draw respired air from a measurement area (**130**);

a constrictor (**140**) through which at least a portion of the respired air drawn by the pump moves;

at least one pressure sensor (**150, 160**) configured to measure a pressure value of air flowing through the constrictor; and

a ripple cancellation device (**180**) configured to attenuate or eliminate at least one pressure ripple in the respired air flowing through the constrictor.

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8. The device (**100**) according to claim 7, wherein the pulse cancellation device (**180**) includes:

a filter (**180a**) configured to receive the pressure value from the pressure sensor and to separate an AC component of the pressure signal to generate a ripple signal (**185a**);

a controller (**180b**) configured to generate a transducer drive signal (**185b**) from the ripple signal; and

a pressure transducer (**180c**) configured to produce an antiphase pressure waveform (**185c**) from the transducer drive signal, and to apply the antiphase pressure waveform to air flowing from the constrictor (**140**) to the pump (**110**) to nullify the pulsations in the air.

9. The device (**100**) according to either one of claims 7 and 8, wherein the at least one pressure sensor (**150**) is configured to measure a differential pressure signal of air (**175a**) flowing through the constrictor (**140**), the at least one pressure sensor including a differential pressure sensor disposed at each of an inlet and an outlet of the constrictor.

10. The device (**100**) according to claim 9, wherein

the differential pressure sensor (**150**) is configured to input the measured differential pressure signal (**175a**) to the filter (**180a**); and

the filter is configured to separate an AC component of the measured differential pressure signal to generate the ripple signal (**185a**).

11. The device (**100**) according to any one of claims 7-10, further including a gauge pressure sensor (**160**) configured to measure pressure values of air at an outlet of the constrictor (**140**); the measured pressure values being used by the respiration gas monitor to calculate concentrations of gases present in the measurement area (**130**).

12. The device (**100**) according to any one of claims 9-11, further including a flow control mechanism (**170**) configured to control flow of air from the pump (**110**), the flow control mechanism including:

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a comparator **(170a)** configured to receive the differential pressure signal **(175b)** from the differential pressure sensor **(150)**, and subtract the differential pressure signal from a desired flow rate setpoint signal to generate a flow rate error signal **(175b)**;

a pump controller **(170b)** configured to amplify and process the flow rate error signal to generate a pump control signal **(175c)**; and

a pump driver **(170c)** configured to buffer the pump control signal to generate a pump drive signal **(175d)**, and transmit the pump drive signal to the pump **(110)**.

13. The device **(100)** according to claim 12, wherein

the pump driver **(170c)** is configured to increase the speed of the pump **(110)** when the differential pressure signal **(175a)** is less than the desired flow rate setpoint signal, and.

the pump driver **(170c)** is configured to decrease the speed of the pump **(110)** when the differential pressure signal **(175a)** is greater than the desired flow rate setpoint signal.

14. The device **(100)** according to any one of claims 7-13, wherein the pump **(110)** is configured to draw air from a patient first through a measurement area **(130)** and then through the constrictor **(140)**, whereby the constrictor is disposed between the pump and measurement area.

15. The device **(100)** according to any one of claims 7-14, wherein the constrictor **(140)** is one of an orifice or a capillary tube.

16. A respiratory gas monitoring method **(10)**, comprising:

drawing, with a pump **(110)**, respired air through a measurement area **(130)**, at least a portion of the respired air moving through a constrictor **(140)**;

measuring, with at least one pressure sensor **(150, 160)**, a pressure signal **(175a)** of air flowing through the constrictor;

attenuating or eliminating, with a ripple cancellation device **(180)**, at least one pressure ripple in the respired air flowing through the constrictor; and

measuring, with a measurement device **(190, 192, 194)**, a target gas in the flow of expired air.

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17. The method (10) according to claim 16, wherein the measuring comprises:

launching infrared light through the measurement area (130) using an infrared light source (190);

filtering the launched infrared light using a bandpass filter (194) having a passband encompassing an absorption line of the target gas,; and

detecting the launched and filtered infrared light using a light detector (192).

18. The method (10) according to either one of claims 16 and 17, wherein the attenuating or eliminating, with a ripple cancellation device (180), at least one pressure ripple in the respired air flowing through the constrictor further includes:

separating, with a filter (180a), an AC component of the pressure signal to generate a ripple signal (185a);

generating, with a controller (180b), a transducer drive signal (185b) from the ripple signal; and

producing, with a pressure transducer (180c), an antiphase pressure waveform (185c) from the transducer drive signal, and apply the antiphase pressure waveform to air flowing from the constrictor (140) to the pump (10) to nullify the pulsations in the air.

19. The method (10) according to any one of claims 16-18, further including:

subtracting, with a comparator (170a) the pressure signal (175a) from a desired flow rate setpoint signal to generate a flow rate error signal (175b);
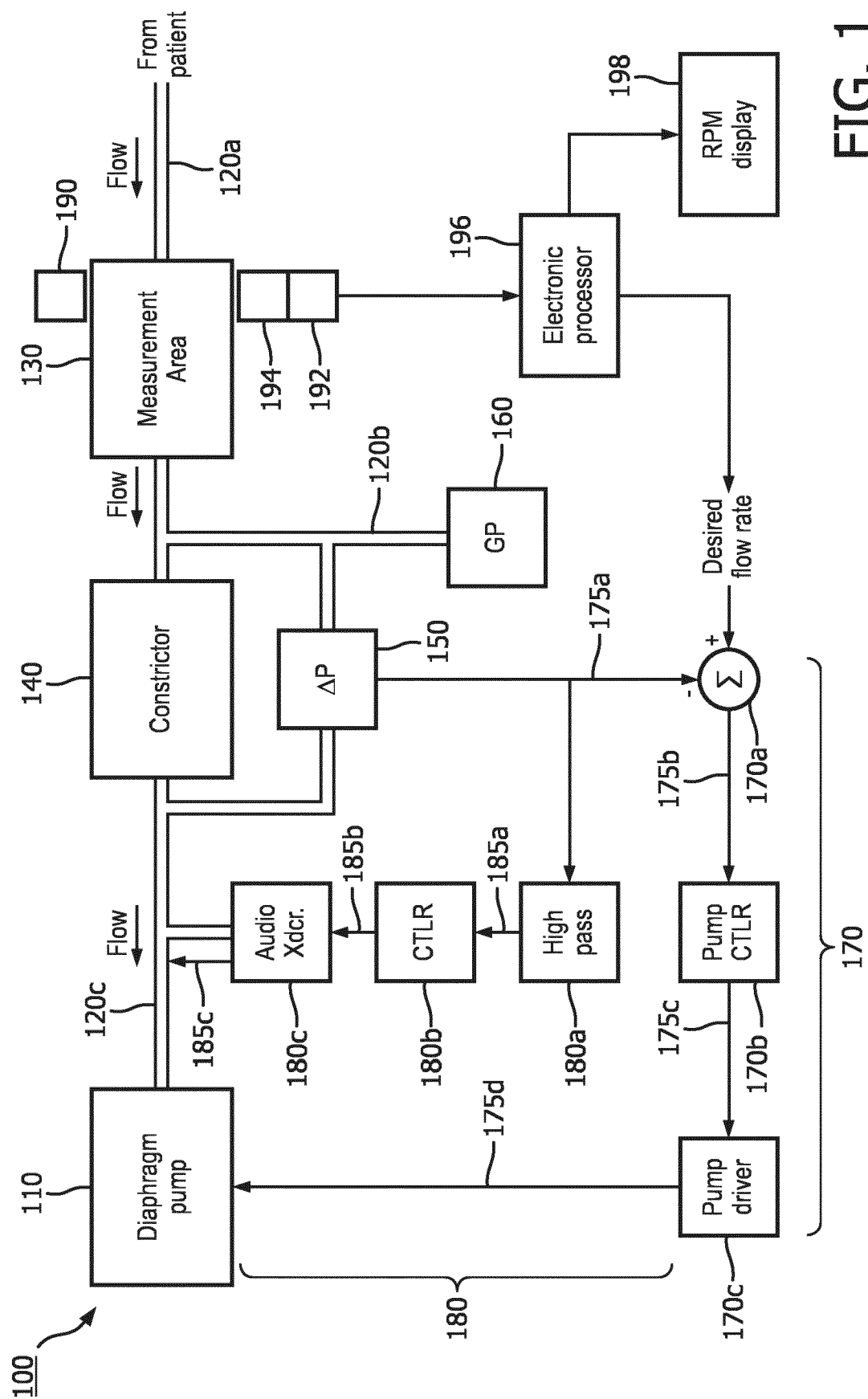
amplifying and processing, with a pump controller (170b), the flow rate error signal to generate a pump control signal (175c); and

buffering, with a pump driver (170c), the pump control signal to generate a pump drive signal (170d), and transmit the pump drive signal to the pump (110).

20. The method (10) according to claim 19, further including:

with the pump driver (170c), increasing the speed of the pump (110) when the pressure signal (175a) is less than the desired flow rate setpoint signal; and

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with the pump driver (**170c**), decreasing the speed of the pump (**110**) when the differential pressure signal (**175a**) is greater than the desired flow rate setpoint signal.
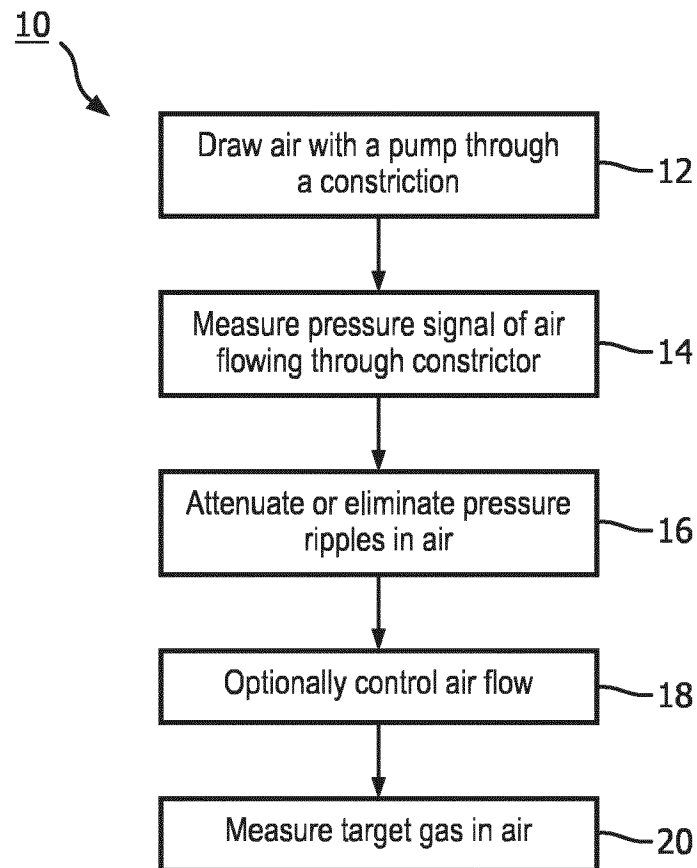
1/2

FIG. 1

FIG. 2

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B5/00   A61B5/08   A61B5/097
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2001/031224 A1 (LABUDA LAWRENCE L [US] ET AL) 18 October 2001 (2001-10-18)	1,3-7,9, 11-17, 19,20
A	paragraphs [0027], [0132] - [0135], [0159], [0188], [0192], [0194], [0196], [0198], [0200] figures 1, 25-27	2,8,10, 18

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[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 May 2018	25/05/2018

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

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INTERNATIONAL SEARCH REPORT

C(Continuation).   DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SHYAM SIVARAMAKRISHNAN ET AL: "Dynamic Model Inversion Techniques for Breath-by-Breath Measurement of Carbon Dioxide from Low Bandwidth Sensors", IEEE SENSORS JOURNAL, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 10, no. 10, 10 June 2010 (2010-06-10) , pages 1637-1646, XP011334806, ISSN: 1530-437X, DOI: 10.1109/JSEN.2010.2047942	1,7,16
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