



- (51) International Patent Classification:  
A61B 5/00 (2006.01) A61M 16/08 (2006.01)  
A61B 5/083 (2006.01)
- (21) International Application Number:  
PCT/IL2018/050183
- (22) International Filing Date:  
19 February 2018 (19.02.2018)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
62/461,121 20 February 2017 (20.02.2017) US
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

(54) Title: SYSTEMS AND METHODS FOR CONCOMITANT CO<sub>2</sub> SAMPLING AND O<sub>2</sub> DELIVERY

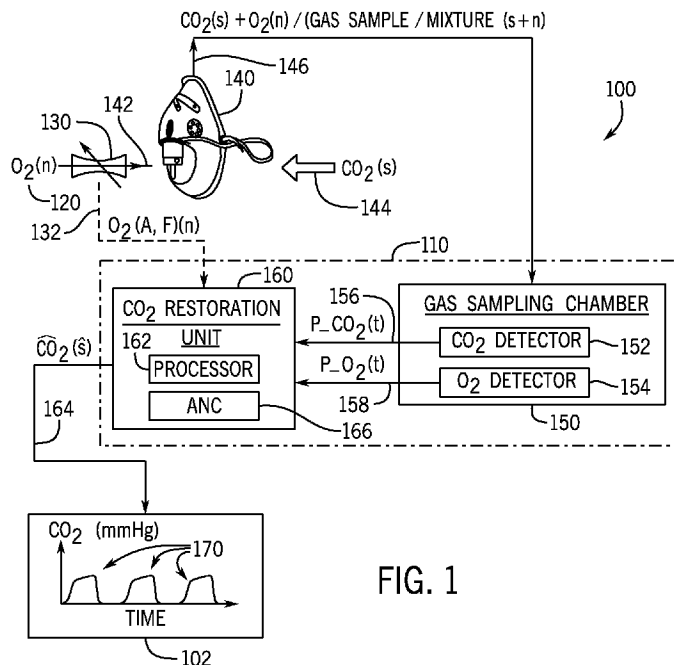


FIG. 1

(57) Abstract: A CO<sub>2</sub> monitoring system (100) provides oxygen (O<sub>2</sub>) (120, 230) to a subject's mask (140) with known characteristics. The CO<sub>2</sub> monitoring system (100) receives, from the mask (140), gas samples (146) including exhaled CO<sub>2</sub> (144) diluted by O<sub>2</sub> (120, 230). The CO<sub>2</sub> monitoring system (100) uses an adaptive noise canceller (166, 400) to cancel the diluting O<sub>2</sub> (120, 230) by using the known characteristics of the O<sub>2</sub> (120, 230) provided to the mask (140), the result of which process is restoration of the original concentration level of the CO<sub>2</sub> (144) as exhaled by the subject into the mask (140).

WO 2018/150431 A1

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,  
KM, ML, MR, NE, SN, TD, TG).

**Published:**

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

## **SYSTEMS AND METHODS FOR CONCOMITANT CO<sub>2</sub> SAMPLING AND O<sub>2</sub> DELIVERY**

### **CROSS-REFERENCE TO RELATED APPLICATION**

[0001] This application claims the benefit of U.S. Provisional Application No. 62/461,121, filed February 20, 2017, the content of which is incorporated herein by reference in its entirety for all purposes.

### **TECHNICAL FIELD**

[0002] The present disclosure generally relates to capnography systems for sampling carbon dioxide (CO<sub>2</sub>) that is exhaled by a subject, and more specifically to methods and systems that enable reliable measuring of exhaled CO<sub>2</sub> despite dilution of the exhaled CO<sub>2</sub> by oxygen that is concomitantly provided to the subject.

### **BACKGROUND**

[0003] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present techniques, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

[0004] A human respiratory cycle includes a sequence of events during which a subject inhales and exhales a given volume of air through the respiratory system. The respiratory system includes the lungs that, during breathing, take in oxygen and expel CO<sub>2</sub>, a waste gas. An exchange of oxygen and CO<sub>2</sub> in the lungs can be evaluated, for example, by measuring oxygen saturation level in the blood and concentration of exhaled CO<sub>2</sub>. After CO<sub>2</sub> is exhaled, another respiratory cycle begins with the next breath.

[0005] Normal levels of both blood oxygen saturation and concentration level of exhaled CO<sub>2</sub> can attest to the healthiness of the subject's respiratory system. For example, if

one's blood oxygen saturation level is normal, there may still be respiratory dysfunction which is, or caused due, for example, to inability of body cells to use oxygen that is absorbed in the blood. In general, the higher the incompetence of body cells to exploit oxygen (and the more incompetent cells there are), the lower the concentration of the CO<sub>2</sub> that the subject exhales.

[0006] Face (respiration) masks for subjects suffering from, prone to, or susceptible to, breathing problems typically include an oxygen port for delivering oxygen to a subject at a designated rate, and a CO<sub>2</sub> port for drawing CO<sub>2</sub> samples of CO<sub>2</sub> exhaled by the subject. Conventional masks that include the two ports have drawbacks. One drawback is that the sampled CO<sub>2</sub> is diluted by oxygen that is delivered to the subject continuously. Diluting the CO<sub>2</sub> gas by the oxygen (or by any other gas for that matter) decreases the concentration level (the partial pressure) of the CO<sub>2</sub> sample, causing the CO<sub>2</sub> measurement to be below capnography standards and leading to inaccurate, or incorrect, CO<sub>2</sub> concentration measurement and, potentially, to wrong conclusions that may be reached by the caring medical staff regarding the true respiratory condition of the subject. As a result of this, the CO<sub>2</sub> sampling port is typically located in the face mask adjacent to the oral/nasal openings, making the wearability of the face mask uncomfortable to the patient.

[0007] While sampling CO<sub>2</sub> and delivering oxygen are beneficial, there are some drawbacks which are associated with the concomitant use of the two functions (e.g., in terms of CO<sub>2</sub> dilution). It would be, therefore, beneficial to have methods and systems that would facilitate both reliable measurement and analysis of CO<sub>2</sub> samples (e.g., enable accurate measurement of end-tidal CO<sub>2</sub> (EtCO<sub>2</sub>) values) with high confidence (e.g.,  $\pm 4$  mmHg), and concomitant delivery of oxygen at required oxygen flow rates, for example at oxygen flow rates of up to 10 liters per minute (LPM), without compromising the CO<sub>2</sub> measurement reliability.

### **SUMMARY**

[0008] A CO<sub>2</sub> monitoring system provides oxygen to a subject's mask with known characteristics, and the CO<sub>2</sub> monitoring system receives, from the mask, gas samples

including exhaled CO<sub>2</sub> that is diluted by oxygen, and uses an adaptive noise canceller, or other methods, to cancel the diluting oxygen by using the known characteristics of the oxygen that is provided to the mask, the result of which process is restoration of the original concentration level of the CO<sub>2</sub> as (originally) exhaled by the subject into the mask.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0009] Various exemplary embodiments are illustrated in the accompanying figures with the intent that these examples not be restrictive. It will be appreciated that for simplicity and clarity of the illustration, elements shown in the figures referenced below are not necessarily drawn to scale. Also, where considered appropriate, reference numerals may be repeated among the figures to indicate like, corresponding or analogous elements. Of the accompanying figures:

[00010] FIG. 1 shows a CO<sub>2</sub> monitoring system, according to an embodiment of the present disclosure;

[00011] FIG. 2 shows a comparative graph, in accordance with an embodiment of the present disclosure;

[00012] FIG. 3 depicts an oxygen flow re-shaper, according to an embodiment of the present disclosure;

[00013] FIG. 4 shows a CO<sub>2</sub>/O<sub>2</sub> detector, according to an embodiment of the present disclosure;

[00014] FIG. 5 schematically illustrates an adaptive noise canceller (“ANC”), according to an embodiment of the present disclosure; and

[00015] FIG. 6 is a flow diagram of a method of restoring exhaled carbon dioxide concentration level using the CO<sub>2</sub> monitoring system of FIG. 1, according to an embodiment of the present disclosure.

### **DETAILED DESCRIPTION**

[00016] The description that follows provides various details of exemplary embodiments. However, this description is not intended to limit the scope of the claims but instead to explain various principles of the disclosure and the manner of practicing it. Additionally, in an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but may nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure. Further, the current embodiments may be implemented by one or more computer-processors that implement one or more machine-readable instructions stored on a tangible, non-transitory, machine-readable medium and/or by specialized circuitry designed to implement the discussed features.

[00017] The design of face masks (respiration masks) has generally been focused on the mechanical separation between oxygen flow and exhaled carbon dioxide (CO<sub>2</sub>) in order to reduce the dilution of the exhaled CO<sub>2</sub> by oxygen (O<sub>2</sub>). For example, certain masks include internal gas flow 'diversion' or 'separation' means (e.g., scoop, tubes, etc.) to divert one of the gas flows (e.g., exhaled CO<sub>2</sub> flow) in order to reduce the CO<sub>2</sub> dilution effect.

[00018] The present systems and methods enable use of a simplified ('basic') face mask, which may not include such means. Instead, exhaled CO<sub>2</sub> and O<sub>2</sub> that is provided to the mask are allowed to mix in the mask (e.g., the exhaled CO<sub>2</sub> is allowed to be diluted by O<sub>2</sub>), but characteristics of the O<sub>2</sub> entering the mask (e.g., oxygen flow rate, pressure, amplitude, frequency, etc.) are known before it enters the mask. For example, the characteristics of the O<sub>2</sub> may be preset or measured in real-time before the O<sub>2</sub> enters the mask. By knowing the characteristics of the O<sub>2</sub> before it enters the mask, the oxygen 'noise' that dilutes the CO<sub>2</sub>

samples may be decreased and, thus, the diluted CO<sub>2</sub> measurements (e.g., in terms of shape and amplitude) may be restored.

**[00019]** In a mixture of gases, each gas has a partial pressure, which is the hypothetical pressure of that gas if it alone occupied the entire volume of the original mixture at the same temperature. The total pressure of an ideal gas mixture is the sum of the partial pressures of each individual gas admixture in the gas mixture. The relationship between the volume of an individual gas ( $x$ ) in a gas mixture and the gas partial pressure is shown below:

$$\frac{V_x}{V_{tot}} = \frac{p_x}{p_{tot}} = \frac{n_x}{n_{tot}}$$

where  $V_x$  is the partial volume of the individual gas component ( $x$ ),  $V_{tot}$  is the total volume of the gas mixture,  $p_x$  is the partial pressure of gas  $x$ ,  $p_{tot}$  is the total pressure of the gas mixture,  $n_x$  is the amount of substance of gas  $x$ , and  $n_{tot}$  is the total amount of substance in the gas mixture.

**[00020]** A concentration level of a first gas admixture in a two-gas mixture and a concentration level of a second gas admixture in the two-gas mixture are interrelated because, with a total pressure of the gas mixture assumed to be fixed, the greater the concentration of one gas admixture, the lower the concentration of the other gas admixture. The relationship between concentration ( $C$ ) of an ideal gas in a gas mixture and partial pressure ( $P$ ) of the ideal gas is given in the following formula:

$$P_A = C_A R T_A$$

where  $C_A (=n/V)$  is a gas concentration (in moles per liter) at time  $A$ ,  $n$  is number of moles of the solute,  $V$  is volume of the gas in liters,  $R$  is a gas constant, and  $T$  is temperature at time  $A$ .

**[00021]** This property of gases facilitates restoration of the concentration level of an oxygen-diluted exhaled CO<sub>2</sub>. That is, by knowing a relationship between known characteristics (e.g., frequency and/or amplitude) of the O<sub>2</sub> originally provided to a respiration mask and measured characteristics of oxygen admixture in the CO<sub>2</sub>/O<sub>2</sub> gas mixture, the measured concentration of the CO<sub>2</sub> admixture in the gas mixture may be restored to a value that is identical or similar to the CO<sub>2</sub> concentration level as (originally) exhaled by a subject. For example, the more the oxygen admixture in the CO<sub>2</sub>/O<sub>2</sub> gas resembles the O<sub>2</sub> originally provided to a respiration mask, the lesser the extent by which the CO<sub>2</sub> concentration level has to be adjusted, or modified, in order to restore the original concentration level of the exhaled CO<sub>2</sub>. On the other hand, the lesser the resemblance between the oxygen admixture in the CO<sub>2</sub>/O<sub>2</sub> gas and the O<sub>2</sub> originally provided to a respiration mask, the greater the extent by which the CO<sub>2</sub> concentration level has to be adjusted or modified in order to restore the original CO<sub>2</sub> concentration level. That is, if the oxygen admixture significantly differs from the O<sub>2</sub> that is originally provided to the mask, this indicates that the oxygen admixture in the CO<sub>2</sub>/O<sub>2</sub> gas mixture has been impacted by CO<sub>2</sub> having a relatively high concentration level. Therefore, restoring the exhaled CO<sub>2</sub> level may require a significant adjustment, or modification, of the measured CO<sub>2</sub> level.

**[00022]** Adaptive Noise Cancellers (ANCs) are known in the field of signal processing. Adaptive noise cancelling is an alternative method of estimating signals that are corrupted by additive noise or interference. An adaptive noise canceller uses a “primary” input containing the corrupted signal (in our case CO<sub>2</sub> signal that is corrupted by diluting O<sub>2</sub>), and a “reference” input containing noise (in our case diluting O<sub>2</sub>) correlated in some unknown way with the noise in the primary input. The reference input is adaptively filtered and subtracted from the primary input to obtain a signal estimate. When the reference input is free of signal noise and certain other conditions are met, noise in the primary input can be essentially eliminated without signal distortion. Some embodiments of the present disclosure use an ANC. Other embodiments may use alternative noise cancellation and signal estimation methods.

[00023] FIG. 1 shows a carbon dioxide (CO<sub>2</sub>) monitoring system **100** according to an example embodiment. Carbon dioxide monitoring system **100** may include a CO<sub>2</sub> measuring and restoration (“**CMR**”) unit **110**, an oxygen source **120**, an oxygen flow re-shaper (OFR) **130**, and a respiration (oxygen) mask **140**. The oxygen flow re-shaper **130** may receive O<sub>2</sub> from the oxygen source **120**, for example at a known, or predetermined, flow rate and may output an input oxygen flow **142** to the mask **140** in the form of, for example, high-frequency oxygen pulses (high-frequency oxygen flow). The oxygen flow re-shaper **130** may be configured to receive an oxygen flow from the oxygen source **120**, and to control, adjust or modify characteristics of the inflow oxygen such that the oxygen flow re-shaper **130** outputs, for the mask **140**, an input oxygen flow **142** that is useful both for the patient breathing it and for the oxygen signal cancellation process.

[00024] Exhaled CO<sub>2</sub> flow **144** is also provided to the mask **140** during respiration. The mask **140**, therefore, receives both high-frequency oxygen (e.g., the input oxygen flow **142**) and the exhaled CO<sub>2</sub> **144**, and, therefore, the exhaled CO<sub>2</sub> **144** is diluted, in the mask **140**, by high-frequency input oxygen flow **142**.

[00025] The carbon dioxide measuring and restoration unit **110** measures CO<sub>2</sub> concentration, or CO<sub>2</sub> partial pressure, as diluted by oxygen, and restores the oxygen-diluted CO<sub>2</sub> to the original concentration of the exhaled CO<sub>2</sub> **144**. Restoration of the concentration of the exhaled CO<sub>2</sub> **144** may include, for example, restoration of the shape, frequency, and magnitude of the concentration level of the exhaled CO<sub>2</sub>. The carbon dioxide measuring and restoration unit **110** may include a gas sampling chamber (“**GSC**”) **150** for receiving or drawing (for example continually or periodically) the gas samples **146** from the mask **140**. The carbon dioxide measuring and restoration unit **110** may also include a CO<sub>2</sub> restoration unit (“**CRU**”) **160** for restoring the CO<sub>2</sub> measurements. The term “restoration,” as used herein, is intended to denote adjustment or modification of a measured (detected) CO<sub>2</sub> concentration level to a value that genuinely represents, indicates, or resembles a concentration level of the originally (non-diluted) exhaled CO<sub>2</sub>. The amount of CO<sub>2</sub> concentration adjustment or modification may be determined based on the oxygen **142** provided to the mask **140**, and also based on measured characteristics (e.g., concentration

level) of the oxygen admixture. The gas samples **146** that the GSC **150** receives, or draws, from the mask **140** include a gas mixture that includes diluted CO<sub>2</sub> and the diluting oxygen. The gas mixture is expressed herein as CO<sub>2</sub> (s)+O<sub>2</sub>(n), where (s) denotes a “signal” (or data) that represents the diluted (impaired) CO<sub>2</sub> signal whose original (non-diluted) concentration level is to be restored, and (n) denotes oxygen admixture (“noise”) causing the CO<sub>2</sub> dilution. The O<sub>2</sub> in the mask **140**, hence in the GSC **150**, is, in turn, diluted by CO<sub>2</sub>, but it is of no clinical interest because O<sub>2</sub> is provided to the mask **140** in a way that enables the subject wearing the mask **140** to breathe as efficiently as possible. In addition, knowing characteristics (e.g., concentration level) of the oxygen admixture vis-à-vis characteristics of the O<sub>2</sub> provided to the mask **140** facilitates determination of the concentration level of the CO<sub>2</sub> admixture in each gas sample.

[00026] In some embodiments, the GSC **150** may include two, separate, gas cells – one gas cell for detecting exhaled CO<sub>2</sub> samples and another gas cell for detecting O<sub>2</sub> samples. Each gas cell may include, or have associated with it, a respective gas detector. The embodiments disclosed herein include detecting a CO<sub>2</sub> and O<sub>2</sub> admixture, and using characteristics of the O<sub>2</sub> provided to the mask **140** to both cancel the O<sub>2</sub> ‘component’ in the CO<sub>2</sub>/O<sub>2</sub> gas mixture and restoring characteristics of the originally (non-diluted) exhaled CO<sub>2</sub>. Therefore, using two, separate, gas cells to detect CO<sub>2</sub> and O<sub>2</sub> may include dealing with ‘out-of-phase’ and ‘out-of-synchronization’ measurement issues with regard to the detection of the two gases. For example, if the two-cell measurement option is used, the two gas samples (one in the CO<sub>2</sub> cell, the other in the O<sub>2</sub> cell) should be kept under the same physical conditions (e.g., in terms of pressure, a size of the gas sample, a flow rate, and a temperature) and/or be measured simultaneously. This may be useful because, for example, a concentration of gas in a gas mixture is measured by its partial pressure, and to obtain reliable results, CO<sub>2</sub> restoration requires that the two partial pressures (one of the CO<sub>2</sub>, another of the O<sub>2</sub>) be related to (e.g., measured in) the same gas sample and at the same time.

[00027] In our case, measuring concentration of CO<sub>2</sub> in a CO<sub>2</sub>/O<sub>2</sub> gas sample includes measuring the partial pressure of CO<sub>2</sub> in the CO<sub>2</sub>/O<sub>2</sub> gas sample, and measuring concentration of O<sub>2</sub> includes measuring the partial pressure of O<sub>2</sub> in the CO<sub>2</sub>/O<sub>2</sub> gas sample.

Therefore, measuring CO<sub>2</sub> and O<sub>2</sub> in separate gas samples may skew the CO<sub>2</sub> and O<sub>2</sub> readings and, thus, result in unreliable restoration of the non-diluted concentration level of the exhaled CO<sub>2</sub>. Therefore, preferably, the GSC **120** may, in some embodiments, include one, common, gas cell that is designed to facilitate simultaneous detection of both the CO<sub>2</sub> admixture (sample) and the O<sub>2</sub> admixture (sample) in the same gas sample.

[00028] The GSC **150** may include a CO<sub>2</sub> detector **152** and an oxygen detector **154**. The carbon dioxide detector **152** and the O<sub>2</sub> detector **154** may be configured such that they can detect CO<sub>2</sub> and O<sub>2</sub>, respectively, in the same gas cell (hence in the same gas sample) at the same time, which is beneficial for the oxygen ‘noise’ cancellation and CO<sub>2</sub>’s concentration level restoration process. Each detector **152**, **154** may output, in real-time, an analog signal that represents a concentration level (e.g., expressed as partial pressure) of the respective gas. For example, the CO<sub>2</sub> detector **152** may generate an output **156** that includes an analog signal  $P_{co2}(t)$  that represents the partial pressure of the CO<sub>2</sub> in the CO<sub>2</sub>/O<sub>2</sub> gas sample, and the O<sub>2</sub> detector **154** may generate an output **158** that includes an analog signal  $P_{o2}(t)$  that represents the partial pressure of O<sub>2</sub> in the CO<sub>2</sub>/O<sub>2</sub> gas sample. Rather than outputting analog signals, the CO<sub>2</sub> detector **152** and the O<sub>2</sub> detector **154** may output digital data that represent the partial pressure of CO<sub>2</sub> in the CO<sub>2</sub>/O<sub>2</sub> gas sample and the partial pressure of O<sub>2</sub> in the CO<sub>2</sub>/O<sub>2</sub> gas sample., respectively

[00029] The CRU **160** may receive signals  $P_{co2}(t)$  and  $P_{o2}(t)$ . In addition, the CRU **160** may receive a signal (or data) **132**,  $O2(A,F)$  that represents characteristics of the high-frequency O<sub>2</sub> that is provided to the mask **140**.  $A$  in  $O2(A,F)$  represents amplitude of the O<sub>2</sub>,  $F$  in  $O2(A,F)$  represents the frequency of the O<sub>2</sub>. The term “high-frequency oxygen,” as used herein, is intended to denote O<sub>2</sub> that is provided to the mask **140** at high frequency. The term “high-frequency,” as used herein, is intended to denote a frequency that is sufficiently high to facilitate distinction between oxygen admixture in the oxygen-diluted CO<sub>2</sub> mixture and the CO<sub>2</sub> admixture in the oxygen-diluted CO<sub>2</sub> mixture by means of an ANC (e.g., the ANC **166**) or by digital signal processing, and the like. The frequency at which O<sub>2</sub> may be provided to the mask **140** may be selected based on the normal respiration rate (breathes per minute, “BPM”), which is between 12 and 25 BPM. Accordingly, the O<sub>2</sub> that is provided to the mask

**140** at a frequency which is, for example, at least ten times the average BPM may be regarded as high-frequency oxygen. For example, the O<sub>2</sub> that is provided to the mask **140** at a rate of, for example, 300 times per minute may be regarded as high-frequency oxygen. Generally, the more efficient (e.g., the more ‘sensitive’) the ANC, digital signal processing (DSP), etc., is in terms of detection of the O<sub>2</sub> signal/data in the oxygen-diluted CO<sub>2</sub> signal/data, the lower the “high-frequency” can be. In some examples, the frequency at which O<sub>2</sub> is provided to a mask may be within the range of 5Hz to 10Hz. As should be appreciated, other frequency ranges may also be used.

[00030] The CRU **160** may include a processor **162** and an adaptive noise canceller (“ANC”) **166**. ANC **166** may receive signals **156** and **158** that respectively represent the partial pressure of the measured CO<sub>2</sub> and O<sub>2</sub>. In addition, the ANC **166** may receive the signal **132**. The processor **162** may initially calculate a coefficient matrix for of the ANC **166**, and the ANC **166** may apply the coefficient matrix to the signals **156**, **158**, and **132**. The ANC **166** may generate an output **164** that includes a signal  $\widehat{CO}_2(\hat{s})$  that represents a restored CO<sub>2</sub> concentration level, and the processor **162** may iteratively recalculate the coefficient matrix for or of the ANC **166** in order for the ANC **166** to minimize, in each iteration, an error value that represents a difference between characteristics of the high-frequency oxygen (per the signal **132**) and characteristics of the O<sub>2</sub> admixture as measured by the O<sub>2</sub> detector **154**.

[00031] The ANC **166** may iteratively minimize the error value, for example, until the error value is smaller than a predetermined threshold value. In general, the smaller the error value, the closer the CO<sub>2</sub> concentration level, which is represented by the ANC’s output signal  $\widehat{CO}_2(\hat{s})$  at **164** to the sought for concentration level of the exhaled CO<sub>2</sub> **144**. The Signal  $\widehat{CO}_2(\hat{s})$  **164** may be displayed on a computer display **102**. The display **102** shows, at **170**, restored (non-diluted) CO<sub>2</sub> concentration (in mmHg) during three respiration cycles.

[00032] In some embodiments, a system for monitoring a concentration level of the exhaled CO<sub>2</sub> may include a GSC identical or similar to the GSC **150**, which receives gas samples from a mask identical or similar to **140** attached to a face of a subject. Each gas sample may include an oxygen admixture that originates from an input oxygen flow, such as

input oxygen flow **142**, provided to the mask, and, in addition, CO<sub>2</sub> that is exhaled by the subject into the mask. The system may also include a CO<sub>2</sub> detector identical or similar to the CO<sub>2</sub> detector **152** to detect a concentration level of CO<sub>2</sub> in the gas sample, and an oxygen detector identical or similar to the oxygen detector **154** to detect a concentration level of oxygen admixture in the gas sample. The system may also include a CRU identical or similar to the CRU **160** to restore a concentration level of the CO<sub>2</sub> exhaled (**144**) by the subject based on characteristics of the input oxygen flow (e.g., the input oxygen flow **142**) and the concentration level of the oxygen admixture detected in the gas sample. The system may also include a computer display (e.g., the computer display **102**) to display a signal (e.g., the signal **170**) that represents the restored concentration level of the exhaled CO<sub>2</sub> (e.g., CO<sub>2</sub> **144**).

[00033] The CO<sub>2</sub> detector (e.g., the detector **152**) and the oxygen detector (e.g., the detector **154**) may respectively be configured to simultaneously detect CO<sub>2</sub> and oxygen in a same gas sample. For example, if the gas sample flows in a first direction, one detector may be disposed (oriented) in a second direction that is at a first angle relative to the first direction, and the other detector may be disposed (oriented) in a third direction that is at a second angle relative to the first and second directions. The first and second angles may be 90 degrees. Other angles may be selected for the first angle, the second angle, or both angles.

[00034] FIG. 2 shows a graph that demonstrates the dilution effect of the high-frequency input oxygen flow **142** on the exhaled CO<sub>2</sub> **144**. The graph shows a CO<sub>2</sub> signal **180** (measured in pressure units, mmHg) after it is impaired by the diluting high-frequency input oxygen flow **190**. As shown in FIG. 2, the high-frequency oxygen flow **190**, having a pulse frequency  $F$  ( $F=1/T$ ), is shown superimposed on the CO<sub>2</sub> signal **180**. Another effect of the diluting oxygen on the CO<sub>2</sub> measurements is, per the description herein with regard to gases partial pressure, that the magnitude of the CO<sub>2</sub> is generally lower than it should be (e.g., lower than the amplitude of the exhaled CO<sub>2</sub> at the subject's nostrils), due to the dilution effect of input oxygen flow **190**.

[00035] FIG. 3 schematically illustrates an oxygen flow re-shaper (OFR) **200**, according to an embodiment of the present disclosure. The OFR **200** may include a tube **210** through which oxygen can flow from an oxygen source to an oxygen mask (e.g., the mask **140**), and a toothed wheel, which is schematically shown at **220**, to control the oxygen gas dynamics in the tube **210**. The tube **210** includes an oxygen intake portion into which oxygen **230** flows at a constant flow rate, and an oxygen outlet portion from which high-frequency oxygen **240** flows out to an oxygen mask (e.g., to the mask **140**). The toothed wheel **220** is designed in terms of, for example, number, size, shape and angular spacing of the teeth, such that O<sub>2</sub> flowing through the tube **210** causes the toothed wheel **220** to rotate around a rotation axis **250** of the toothed wheel **220**, to thereby generate the high-frequency oxygen flow **240**. During rotation of the toothed wheel **220** the toothed wheel **220** introduces a cycling resistance to the oxygen flow that results in the cyclically changing oxygen flow. Rotation axis **250** of the toothed wheel **220** is perpendicular to a longitudinal axis **260** of the tube **210** (to the direction of the oxygen flow in the tube **210**).

[00036] FIG. 4 is a schematic CO<sub>2</sub>/O<sub>2</sub> detector **300**, according to an example embodiment. The CO<sub>2</sub>/O<sub>2</sub> detector **300** includes a gas sampling cell (GSC) **310** through which gas sample **320** flows. The CO<sub>2</sub>/O<sub>2</sub> detector **300** also includes a CO<sub>2</sub> detector and an O<sub>2</sub> detector. The CO<sub>2</sub>/O<sub>2</sub> detector **300** enables simultaneous measurement of the CO<sub>2</sub> and O<sub>2</sub> admixtures in the same gas sample (e.g., in the same gas mixture), which, as described herein, is beneficial to the CO<sub>2</sub> restoration process.

[00037] The CO<sub>2</sub> detector may include an infrared (IR) lamp **330** to irradiate IR light (e.g., with 4,300nm wavelength) into and through the GSC **310**, and an IR light sensor **340** to sense IR light that passes through the GSC **310** (e.g., through the gas sample). The higher the CO<sub>2</sub> concentration, or partial pressure, in the gas mixture (gas sample) in the GSC **310**, the lower the intensity of the IR light that impinges on the IR light sensor **340**.

[00038] The O<sub>2</sub> detector may include a laser source **350** to emit a laser beam (e.g., with 760-765nm wavelength) into and through the GSC **310**, and a laser sensor **360** to sense the laser light that passes through the GSC **310**. The higher the O<sub>2</sub> concentration, or partial

pressure, in the gas mixture (gas sample) in the GSC **310**, the lower the intensity of the laser light that impinges on the laser sensor **360**. The O<sub>2</sub> detector may also include a reference laser sensor **370** (e.g., to increase the O<sub>2</sub> detection accuracy) and a semi-transparent mirror **380** that enables some of the laser light originating from the laser source **350** to pass through it, towards (the main) laser sensor **360**, but it also deflects a portion of the laser light to the reference laser sensor **370**.

[00039] The carbon dioxide detector **152** and the oxygen detector **154** may respectively be assembled onto the GSC **310** to enable detection of the CO<sub>2</sub> and O<sub>2</sub> in the same gas sample at the same time. Each measured CO<sub>2</sub> concentration value, thus, has a conjugated oxygen measured concentration value. For example, if gas (air) sample **320** flows in direction **302**, the CO<sub>2</sub> detector **330** and the CO<sub>2</sub> sensor **340** may be disposed on opposite sides of the GSC **310** and form a line **304** (a 'CO<sub>2</sub> measuring line or axis') that may be, for example, perpendicular to gas (air) flow direction **302**. The oxygen detector **350** and the O<sub>2</sub> sensor **360** may also be disposed on opposite sides of the GSC **310** and form a line **306** (e.g., an 'oxygen measuring line or axis') that may be, for example, perpendicular to the gas (air) flow direction **302** and to the CO<sub>2</sub> measuring line **304**. The CO<sub>2</sub> measuring line **304** and the oxygen measuring line **306** may form a plane that may be perpendicular to, or be at other angles, relative to the gas flow direction **302**. The angles between CO<sub>2</sub> measuring line **304**, the O<sub>2</sub> measuring line **306**, and the gas (air) flow direction **302** may be 90 degrees, though other angles may be selected.

[00040] FIG. 5 shows an adaptive noise canceller (ANC) **400**, according to an embodiment of the present disclosure. The ANC **160** of FIG. 1 may operate in a similar way as the ANC **400**. The ANC **400** includes a primary input **410** and a reference input **420**. The primary input **410** receives a signal  $s$  from a signal source that is corrupted by the presence of noise  $n$ . The signal  $s$  and the noise  $n$  are uncorrelated. The reference input **420** receives a noise  $n0$  that is uncorrelated with the signal  $s$ , but is correlated in some way with the noise  $n$ . The noise  $n0$  (at **420**) passes through an adaptive filter **430** to produce an output  $\hat{n}$  (at **440**) that is a close estimate of the input noise  $n$  in the primary input **410**. The noise estimate  $\hat{n}$

(440) is subtracted (at 450) from the corrupted signal  $(s+n)$  410 to produce an estimate  $\hat{s}$  (460), which is the output of the ANC 400.

[00041] In noise canceling systems, a practical objective is to produce a system output  $\hat{s} = (s+n) - \hat{n}$  that is a best fit (e.g., in the least squares sense) to the signal  $s$ . This objective is accomplished by feeding the system output  $\hat{s}$  back to the adaptive filter, and adjusting the filter by using, for example, a least mean square (LMS) adaptive algorithm that minimizes the total system output power. In other words, the system output can serve as an error signal for the adaptive process.

[00042] For the ANC 400, the signal power of the signal  $\hat{s}$  ( $\hat{s}=s+n-\hat{n}$ ) is given in the following equation:

$$\hat{s}^2 = s^2 + 2s(n - \hat{n}) + (n - \hat{n})^2$$

Taking expectation of both sides and realizing that  $s$  is uncorrelated with  $n$  and  $\hat{n}$ ,

$$E[\hat{s}^2] = E[s^2] + 2E[s(n - \hat{n})] + E(n - \hat{n})^2$$

Since the filter is adjusted to minimize  $E[\hat{s}^2]$ , the signal power itself  $E[s^2]$  is unaffected by the minimization process. That is:

$$\min E[\hat{s}^2] = E[s^2] + \min E(n - \hat{n})^2]$$

Thus, when the filter is adjusted to minimize the output noise power  $E[\hat{s}^2]$ , the output noise power  $(n - \hat{n})^2$  is also minimized. Since the signal in the output remains constant, minimizing the total output power maximizes the output signal-to noise ratio. Since  $(\hat{s}-s) = (n-\hat{n})$ , this is equivalent to causing the output  $\hat{s}$  to be a best least squares estimate of the signal  $s$ .

[00043] By analogy, according to some embodiments of the present disclosure, the corrupted signal  $(s+n)$  at the primary input **410** of the ANC **400** denotes the impaired (diluted) CO<sub>2</sub> admixture in a gas mixture or sample, and the noise signal  $n$  at the reference input **420** of the ANC **400** denotes a signal, or data, that represents characteristics of the high-frequency oxygen flow that dilutes the CO<sub>2</sub> in the mask. First data, which represents both the CO<sub>2</sub> and the oxygen admixture in the gas sample, may be provided to the input **410** (a “first input”) of the ANC **400**, and, at the same time, second data, which represents characteristics of the input oxygen flow, may be provided to the input **420** (a “second input”) of the ANC **400**. The ANC **400** may use the first and the second data to cancel, in real-time, the oxygen noise signal that represents the oxygen admixture in the gas samples, and, while cancelling the oxygen noise signal, to output the restored concentration level of the CO<sub>2</sub> exhaled by the subject. As described herein in connection with gas partial pressure in a gas mixture, given a constant pressure of a two-gas mixture, the lesser the partial pressure of one gas admixture, the greater the partial pressure of the other gas admixture. Therefore, the greater the cancellation of the signal that represents the oxygen admixture in a gas sample/mixture is, the greater the partial pressure of the CO<sub>2</sub> admixture would be. The maximum concentration level to which the CO<sub>2</sub> can reach (e.g., can be restored to) as a result of the oxygen cancellation process is the exhaled CO<sub>2</sub>'s original concentration level (e.g., the concentration level of the exhaled CO<sub>2</sub> before it is diluted by oxygen in the mask).

[00044] As seen above, the adaptive noise canceller works on the principle of correlation cancellation (e.g., the ANC output contains the primary input signals, with the component, whose correlated estimate is available at the reference input, removed). Therefore, the ANC is capable of removing (from the corrupted signal) only noises which are correlated with the noises at the reference input.

[00045] FIG.6 shows a method of restoring exhaled carbon dioxide concentration level, according to an embodiment of the present disclosure. FIG. 6 is described below in association with FIG. 1. In step 510, the input oxygen flow 142 is provided to the mask 140 attached to a subject. Characteristics of the input oxygen flow 142 may be known. For example, characteristics of the input oxygen flow 142 may be predetermined, for example by presetting parameter(s) of the input oxygen flow (e.g., frequency, amplitude, flow rate, etc.) and maintaining the preset parameter(s) throughout the entire CO<sub>2</sub> monitoring procedure. Additionally or alternatively, the characteristics of the input oxygen flow 142 may be determined by measuring them in real-time as oxygen continues to be provided to the mask 140. Steps 520 through 550, which are described below, may be performed by the CMR unit 110 (or by a similar system) that may be part of the CO<sub>2</sub> monitoring system 100 (or part of a similar system).

[00046] In step 520, the CMR unit 110, which monitors carbon dioxide exhaled by the subject during a respiration cycle (in, for example, a series of consecutive respiration cycles), receives or draws gas sample(s), shown at 146, from the mask 140. Each gas sample (a gas mixture) may include a CO<sub>2</sub> sample and, in addition, an O<sub>2</sub> admixture sample that originates from, and is characteristically (characteristic-wise) related to, the input oxygen flow 142. The CMR unit 110 may receive or draw gas samples from the mask 140 continuously, or periodically (e.g., according to a predetermined interval), or intermittently, or once in a while.

[00047] In step 530, the CMR unit 110 may simultaneously detect a concentration level of the CO<sub>2</sub> sample and a concentration level of the O<sub>2</sub> admixture sample in each gas sample 146. In step 540, the CMR unit 110 may restore (e.g., estimate) a concentration level of the

CO<sub>2</sub> sample exhaled by the subject during the respiration cycle, based on characteristics of the input O<sub>2</sub> flow **142** existing at the time when (that is, to be in temporal synchronization with the time at which) the concentration level of the CO<sub>2</sub> sample and the concentration level of the O<sub>2</sub> sample are detected by the GSC **150**, and also based on the concentration level of the O<sub>2</sub> admixture detected in the same gas sample. The same restoration process may be repeated **560** for subsequent respiration cycles.

[00048] In step **550**, the CMR unit **110** may output **164**, to a computer system, a signal or data that represents the restored (e.g., estimated non-diluted) concentration level of exhaled CO<sub>2</sub> concentration for the respiration cycle, and, if required, for subsequent respiration cycles. The computer may process the signal or data that represents the restored concentration level of exhaled CO<sub>2</sub> concentration and, based on the processing, the computer may introduce clinical data that is related to the restored concentration level of exhaled CO<sub>2</sub>. The computer may additionally or alternatively display the concentration level of the exhaled CO<sub>2</sub> **170** on the computer display **102** over time. The steps described above may similarly be repeated **560** for subsequent gas samples **146** in a same respiration cycle, and, if required, the steps described above may similarly be repeated **560** for subsequent respiration cycles.

[00049] Restoring the concentration level of CO<sub>2</sub> sample **144** exhaled by the subject during a respiration cycle may include modification of the concentration level of the CO<sub>2</sub> sample that the GSC **150** detects in the gas sample/mixture **146**. Restoring the concentration level of exhaled CO<sub>2</sub> **144** may include determining and using characteristics of the input oxygen flow **142**. Determining the characteristics of the input oxygen flow **142** may include setting, or predetermining, characteristics (e.g., a parameter) of the input oxygen flow **142** and maintaining the predetermined characteristics of the input oxygen flow **142** while exhaled CO<sub>2</sub> is being monitored (e.g., measured). Determining the characteristics of the input oxygen flow **142** may include measuring a parameter of the input oxygen flow **142**. The parameter of the input oxygen flow **142** may be selected from a group consisting of: a frequency at which the input oxygen flow is provided to the mask **140**, and an amplitude of the input oxygen flow **142**. Both the frequency and amplitude parameters may be used, rather than using one of the frequency or amplitude parameter.

[00050] Detecting the concentration level of the CO<sub>2</sub> sample and the concentration level of the oxygen admixture in the gas sample **146** may include: (i) providing the gas sample **146**, or a portion of the gas sample **146**, to the GSC **150**, and (ii) simultaneously detecting both the concentration level of the CO<sub>2</sub> and the oxygen admixture in the gas sample **146** contained in the GSC **150**.

[00051] Restoring the concentration level of the exhaled CO<sub>2</sub> **144** may include cancelling an oxygen 'noise' signal representing the oxygen admixture in the gas sample **146**. Cancelling the oxygen noise signal or data may be effected by the ANC **166**. Using the ANC **166** may include changing a set of coefficients of the ANC **166**. The set of coefficients of the ANC **166** may be changed based on a signal or data at the output of the ANC **166**.

[00052] Cancelling the oxygen noise signal by the ANC **166** may include: (i) providing first data (at **410**) representing a superposition of the CO<sub>2</sub> and oxygen admixture in the gas sample **146** to a first input **410** (e.g., a "primary" input) of the ANC **166**; (ii) providing second data (at **420**) representing the characteristics of the input oxygen flow **142** to a second input **420** (e.g., a "reference" input) of the ANC **166**; and (iii) using (based on) the first and second data, adjusting the set of coefficients of the ANC **166** so as to cause the ANC **166** to restore a concentration level of the CO<sub>2</sub> exhaled by the subject, and to output the restored concentration level of the CO<sub>2</sub> exhaled by the subject.

[00053] The methods described herein may further include a step of calibration of the CMR unit **110**. The calibration process may include: (i) providing to the mask **140** only the input oxygen flow **142** and detecting an oxygen dispersion (concentration) level in the gas sample, and/or providing to the mask **142** only the exhaled CO<sub>2</sub> **144** and detecting CO<sub>2</sub> concentration level in the gas sample in order to estimate a CO<sub>2</sub> rebreathing; and (iii) setting parameters of the input oxygen flow **142** based on the oxygen dispersion level and/or based on the estimated CO<sub>2</sub> rebreathing.

[00054] Various aspects of the various embodiments disclosed herein are combinable with other embodiments disclosed herein. Although portions of the discussions herein may relate to a particular method of restoring CO<sub>2</sub> level of exhaled CO<sub>2</sub>, embodiments of the

disclosure are not limited in this regard, and may include, for example, using various digital signal processing (“DSP”) algorithms or techniques, etc.

**[00055]** Although portions of the discussions herein may relate to a particular type of ANC, the present disclosure is not limited in this regard, and may include other types of ANCs, or the like. Those skilled in the art of signal processing will understand how to implement the ANC to restore the genuine concentration level of exhaled CO<sub>2</sub>, and will readily appreciate that numerous changes, variations, and modifications, for example to the ANC and to the CO<sub>2</sub>/O<sub>2</sub> common sampling cell and to CO<sub>2</sub>/O<sub>2</sub> detectors, can be made without departing from the scope of the disclosure.

**CLAIMS**

1. A method of restoring an exhaled carbon dioxide (CO<sub>2</sub>) concentration level, comprising:
  - providing an input oxygen flow to a mask attached to a subject;
  - using, a CO<sub>2</sub> monitoring system configured to monitor CO<sub>2</sub> exhaled by the subject into the mask during a respiration cycle, to perform the steps of:
    - drawing, from the mask, a gas sample including exhaled CO<sub>2</sub> and oxygen (O<sub>2</sub>) admixture originating from the input oxygen flow;
    - detecting, in the gas sample, a concentration level for the CO<sub>2</sub> and for the O<sub>2</sub> admixture; and
    - restoring a concentration level of the CO<sub>2</sub> as exhaled by the subject during the respiration cycle based on characteristics of the input oxygen flow and the concentration level of the oxygen admixture detected in the gas sample; and
    - displaying, on a computer display, for the respiration cycle, a signal representing the restored concentration level of the exhaled CO<sub>2</sub>.
2. The method of claim 1, wherein restoring the concentration level of the CO<sub>2</sub> exhaled by the subject during the respiration cycle comprises modifying the concentration level of the CO<sub>2</sub> detected in the gas sample.
3. The method of claim 1, wherein detecting the concentration level of the CO<sub>2</sub> and the concentration level of the O<sub>2</sub> admixture in the gas sample comprises: providing the gas sample, or a portion of the gas sample, to a common gas sampling chamber, and simultaneously detecting both the concentration level of the CO<sub>2</sub> and O<sub>2</sub> admixture in the gas sample contained in the common gas sampling chamber.
4. The method of claim 1, wherein restoring the concentration level of the exhaled CO<sub>2</sub> comprises determining the characteristics of the input oxygen flow.

5. The method of claim 4, wherein determining the characteristics of the input oxygen flow comprises setting a parameter of the input oxygen flow and maintaining the predetermined parameter of the input oxygen flow, wherein the parameter comprises a frequency at which the input oxygen flow is provided to the mask, and amplitude of the input oxygen flow, or a combination thereof.

6. The method of claim 4, wherein determining the characteristics of the input oxygen flow comprises measuring a parameter of the input oxygen flow, wherein the parameter comprises a frequency at which the input oxygen flow is provided to the mask, an amplitude of the input oxygen flow, or a combination thereof.

7. The method of claim 1, wherein restoring the concentration level of the exhaled CO<sub>2</sub> comprises cancelling an oxygen noise signal representative of the O<sub>2</sub> admixture in the gas sample.

8. The method of claim 7, wherein cancelling the oxygen noise signal comprises using an adaptive noise canceller.

9. The method of claim 8, wherein using the adaptive noise canceller comprises changing coefficients of the adaptive noise canceller based on a signal or data output by the adaptive noise canceller.

10. The method of claim 9, wherein cancelling the oxygen noise signal comprises:

providing first data representing both the CO<sub>2</sub> and the O<sub>2</sub> admixture in the gas sample to a first input of the adaptive noise canceller;

providing second data representing characteristics of the input oxygen flow to a second input of the adaptive noise canceller; and

cancelling the oxygen noise signal that represents the O<sub>2</sub> admixture in the gas sample by using the first and second data.

11. The method of claim 10, comprising calibrating the CO<sub>2</sub> monitoring system, the calibrating comprising: providing to the mask only an initial input oxygen flow and detecting

an oxygen dispersion level in a respective gas sample and/or providing to the mask only exhaled CO<sub>2</sub> and detecting an initial CO<sub>2</sub> concentration level in a respective gas sample in order to estimate CO<sub>2</sub> rebreathing; and setting parameters of the input oxygen flow based on the oxygen dispersion level and/or based on the estimated CO<sub>2</sub> rebreathing.

12. A system configured to monitor an exhaled carbon dioxide (CO<sub>2</sub>) concentration level, comprising:

a gas sampling chamber configured to receive a gas sample from a mask attached to a face of a subject, the gas sample including an oxygen (O<sub>2</sub>) admixture originating from an input oxygen flow provided to the mask and CO<sub>2</sub> exhaled by the subject into the mask;

a CO<sub>2</sub> detector configured to detect a concentration level of CO<sub>2</sub> in the gas sample;

an O<sub>2</sub> detector configured to detect a concentration level of O<sub>2</sub> admixture in the gas sample;

a CO<sub>2</sub> restoration unit configured to determine a restored concentration level of the CO<sub>2</sub> exhaled by the subject based on characteristics of the input O<sub>2</sub> flow and the concentration level of the O<sub>2</sub> admixture detected in the gas sample; and

a computer display configured to display a signal representing the exhaled CO<sub>2</sub> with the restored concentration level.

13. The system of claim 12, wherein the CO<sub>2</sub> detector and the O<sub>2</sub> detector are, respectively, configured to simultaneously detect CO<sub>2</sub> and O<sub>2</sub> in a same gas sample.

14. The system of claim 12, wherein the CO<sub>2</sub> restoration unit comprises an adaptive noise canceller.

15. The system of claim 12, comprising an O<sub>2</sub> flow re-shaper configured to receive an O<sub>2</sub> flow from an O<sub>2</sub> source and to control characteristics of the inflow O<sub>2</sub> so as to output to the mask the input oxygen flow.

16. The system of claim 12, comprising the mask.

17. A system configured to monitor a non-diluted concentration level of carbon dioxide (CO<sub>2</sub>), comprising:

a gas sampling chamber configured to receive a dilute CO<sub>2</sub> gas sample from a mask attached to a face of a subject, wherein the dilute CO<sub>2</sub> gas sample comprises a mixture of an oxygen (O<sub>2</sub>) admixture and CO<sub>2</sub>, and wherein the CO<sub>2</sub> is exhaled by the subject during a respiration cycle;

a CO<sub>2</sub> detector disposed within the gas sampling chamber and configured to detect CO<sub>2</sub> in the dilute CO<sub>2</sub> gas sample;

an O<sub>2</sub> detector disposed within the gas sampling chamber and configured to detect the O<sub>2</sub> admixture in the dilute CO<sub>2</sub> gas sample; and

a CO<sub>2</sub> restoration unit comprising a processor configured to monitor a concentration level of the CO<sub>2</sub> and a concentration level of the O<sub>2</sub> admixture in the dilute CO<sub>2</sub> gas sample and to determine the non-diluted concentration level of CO<sub>2</sub> as exhaled by the subject during the respiration cycle based on characteristics of a flow of O<sub>2</sub> into the mask and the concentration level of O<sub>2</sub> admixture detected in the dilute CO<sub>2</sub> gas sample.

18. The system of claim 17, wherein the processor is configured to modify the concentration level of the CO<sub>2</sub> detected in the dilute CO<sub>2</sub> gas sample to determine the non-diluted concentration level of CO<sub>2</sub>.

19. The system of claim 17, comprising an adaptive noise canceller configured to cancel an oxygen noise signal representative of the O<sub>2</sub> admixture in the dilute CO<sub>2</sub> gas sample to determine the non-diluted concentration level of the CO<sub>2</sub>.

20. The system of claim 17, wherein the characteristics of the flow of O<sub>2</sub> comprises measuring a parameter of the flow, the parameter comprises a frequency at which the flow of O<sub>2</sub> is provided to the mask, an amplitude of the flow of O<sub>2</sub>, or a combination thereof.

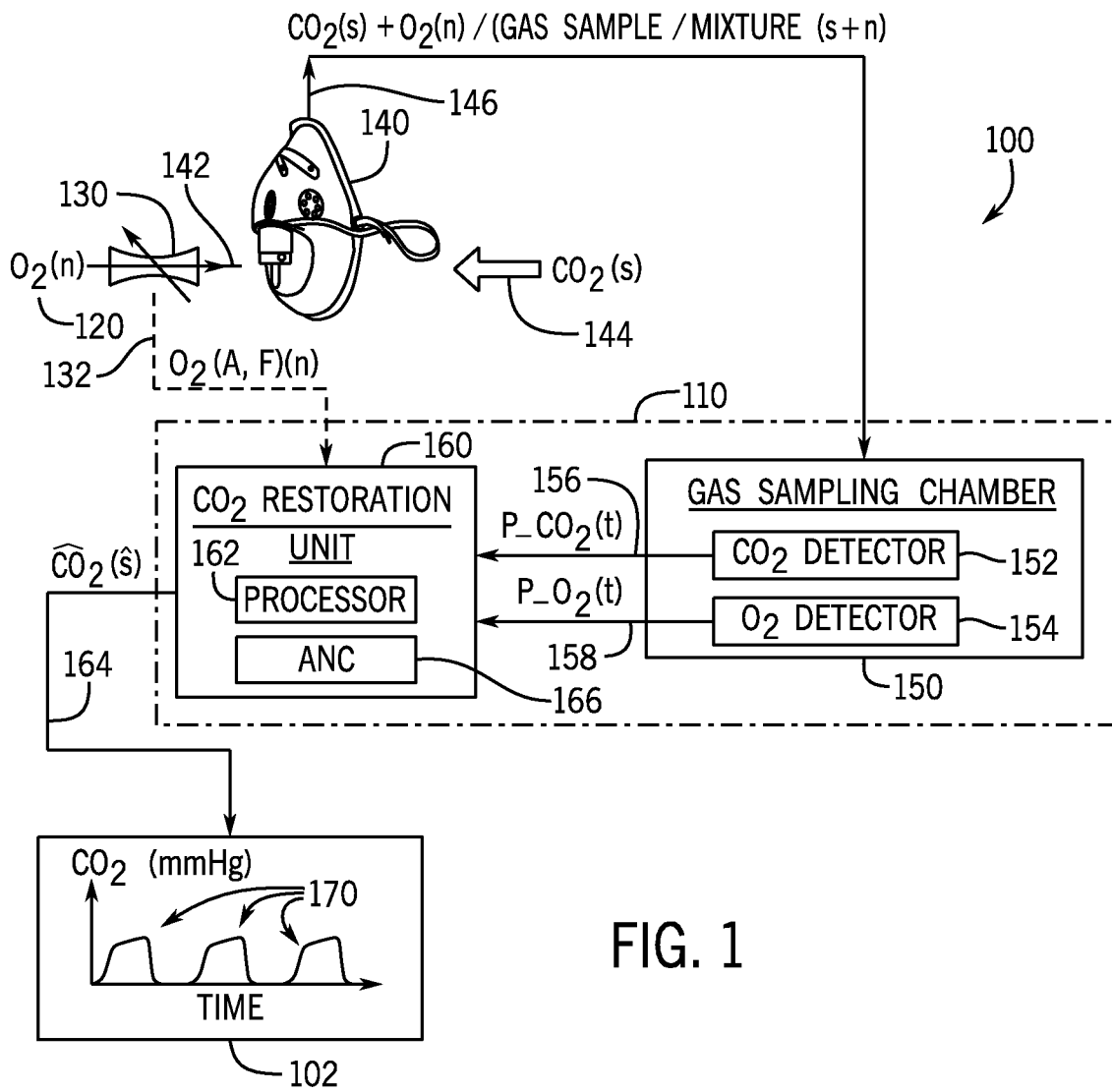


FIG. 1

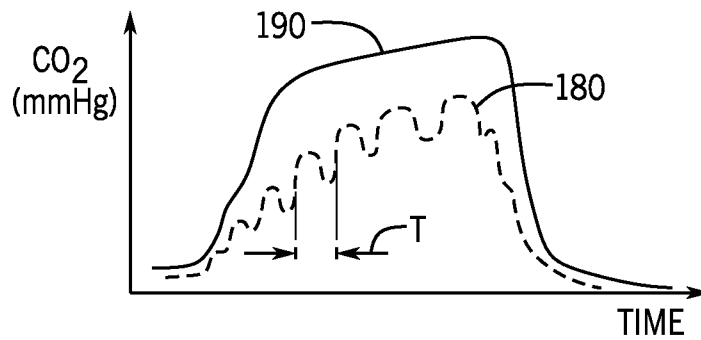


FIG. 2

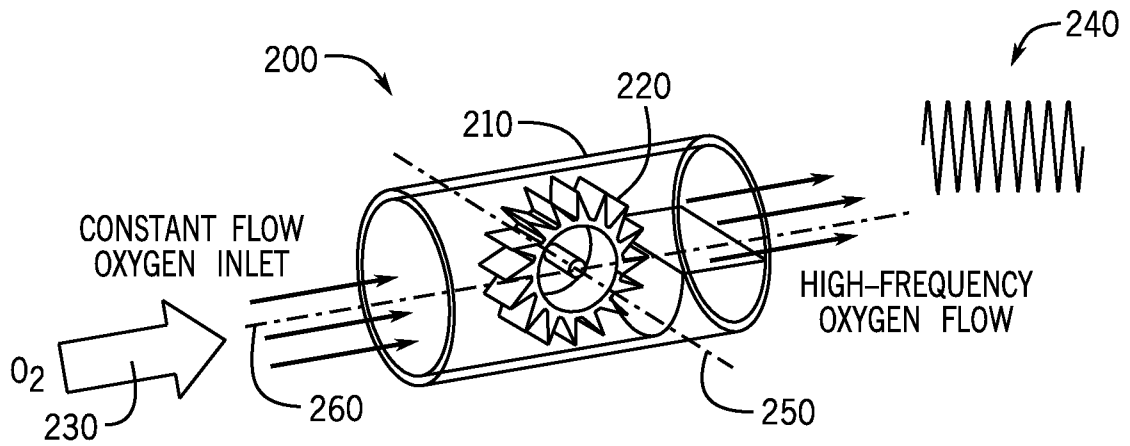


FIG. 3

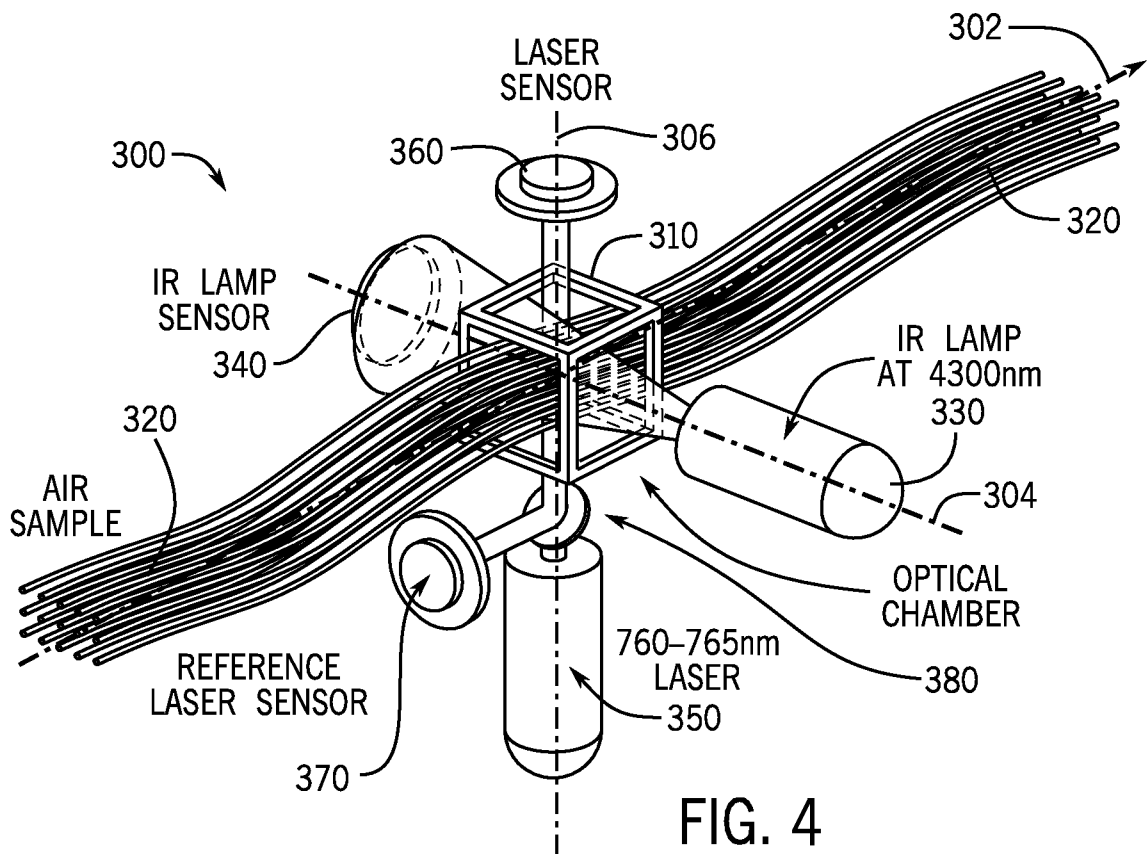


FIG. 4

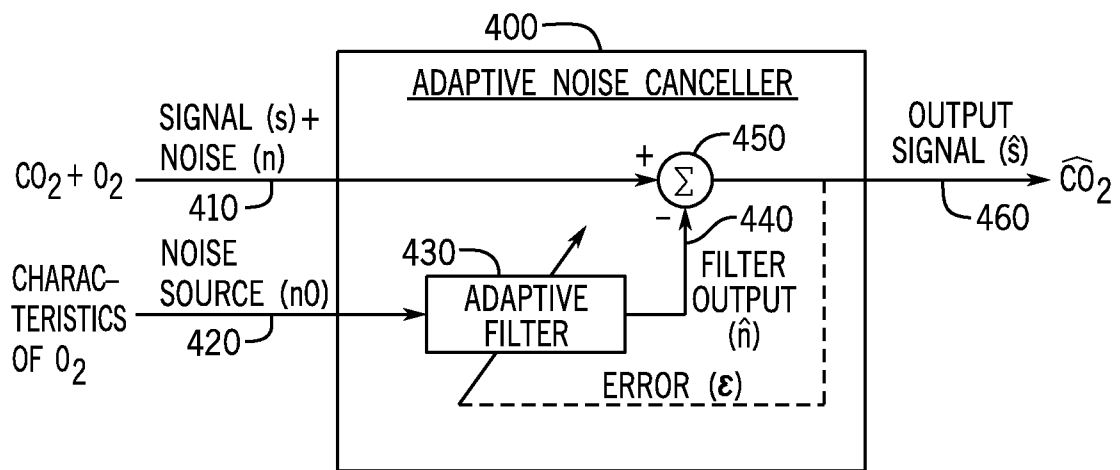


FIG. 5

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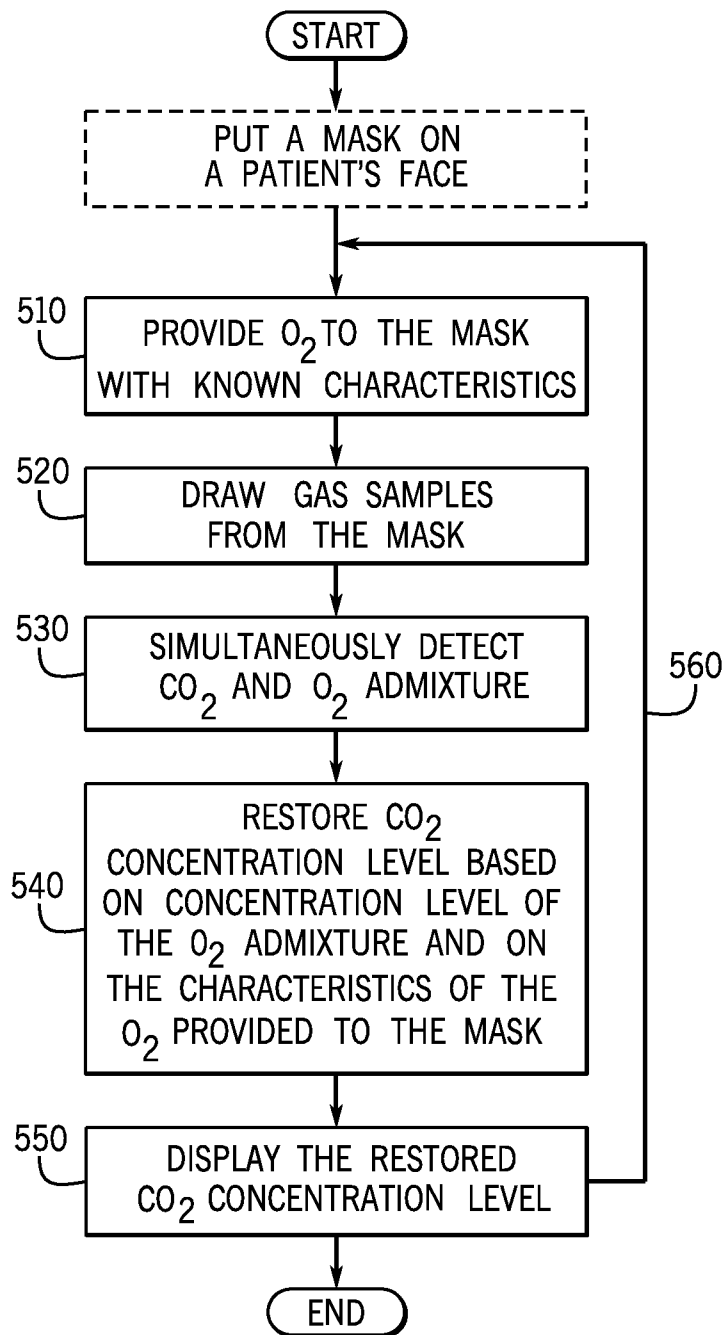


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No  
PCT/IL2018/050183

A. CLASSIFICATION OF SUBJECT MATTER  
INV. A61B5/00 A61B5/083 A61M16/08  
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 A61M

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/035035 A1 (FISHER & PAYKEL HEALTHCARE LTD [NZ]) 10 March 2016 (2016-03-10) paragraphs [0009], [0085], [0086], [0091], [0097], [0098], [0102], [0104], [0112]; figures 1,2,4 -----	1-20
A	WO 2016/108127 A1 (KONINKL PHILIPS NV [NL]) 7 July 2016 (2016-07-07) page 1, line 5 - line 6 page 22, line 20 - line 23 page 27, line 2 - line 3 page 10, line 1 - line 3 -----	1-20
A	US 7 376 453 B1 (DIAB MOHAMED K [US] ET AL) 20 May 2008 (2008-05-20) column 1, lines 17-22,50-53 column 2, line 4 - line 13 -----	1-20

Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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

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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search  16 May 2018	Date of mailing of the international search report  25/05/2018
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/IL2018/050183
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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专利名称(译)	同时进行CO <sub>2</sub> 采样和O <sub>2</sub> 输送的系统和方法		
公开(公告)号	<a href="#">EP3606406A1</a>	公开(公告)日	2020-02-12
申请号	EP2018709801	申请日	2018-02-19
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IPC分类号	A61B5/00 A61B5/083 A61M16/08		
CPC分类号	A61B5/0833 A61B5/0836 A61B5/7214 A61B5/725 A61M16/085 A61M2016/1025 A61M2202/0208 A61M2205/702 A61M2230/432 A61M2202/0007 A61M16/12 A61M2016/103		
优先权	62/461121 2017-02-20 US		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

CO<sub>2</sub>监视系统以已知的特征向受试者的口罩提供氧气 ( O<sub>2</sub> )。 CO<sub>2</sub>监控系统从面罩接收气体样本，其中包括被O<sub>2</sub>稀释的呼出CO<sub>2</sub>。 CO<sub>2</sub>监控系统使用自适应噪声消除器，通过利用提供给面罩的O<sub>2</sub>的已知特性来消除稀释的O<sub>2</sub>，其结果是恢复了受试者呼出到面罩中的原始CO<sub>2</sub>浓度水平。

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