



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
17.03.2021 Bulletin 2021/11

(51) Int Cl.:
A62B 18/00 (2006.01)

(21) Application number: **19197180.3**

(22) Date of filing: **13.09.2019**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

- **KELLY, Declan Patrick**
5656 AE Eindhoven (NL)
- **ZHANG, Claire**
5656 AE Eindhoven (NL)
- **CHEN, Weizhong**
5656 AE Eindhoven (NL)
- **SHI, Jun**
5656 AE Eindhoven (NL)

(71) Applicant: **Koninklijke Philips N.V.**
5656 AG Eindhoven (NL)

(74) Representative: **de Haan, Poul Erik**
Philips International B.V.
Philips Intellectual Property & Standards
High Tech Campus 5
5656 AE Eindhoven (NL)

(72) Inventors:
• **SU, William**
5656 AE Eindhoven (NL)

(54) **A BREATHING ANALYSIS MASK AND BREATHING ANALYSIS METHOD**

(57) A pollution mask with a filter and fan monitors a rotation speed of the fan and a pressure between the mask air chamber and the ambient surroundings. Breathing flow volume information is then obtained from these monitored parameters, and breathing flow volume infor-

mation is provided to a user of the mask. This mask functions both as a pollution mask, and an analysis system from providing breathing flow volume information, for example for personal health and/or fitness monitoring.

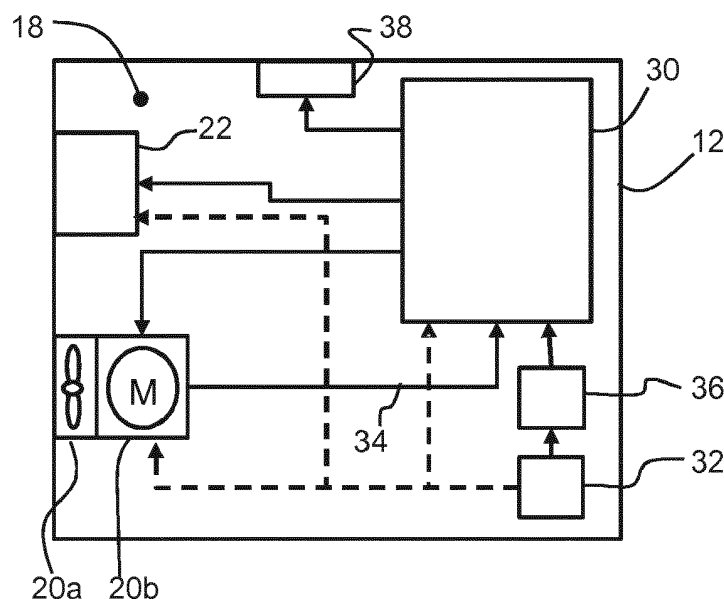


FIG. 2

Description

FIELD OF THE INVENTION

[0001] The invention relates to breathing analysis, for example to determine breathing volume information such as an oxygen uptake value or maximum oxygen uptake value (VO₂max). In particular, it relates to implementation of the breathing analysis using a mask, for providing filtered air to the wearer of the mask, with the flow assisted by a fan.

BACKGROUND OF THE INVENTION

[0002] The World Health Organization (WHO) estimates that 4 million people die from air pollution every year. Part of this problem is the outdoor air quality in cities. The worst in class are Indian cities like Delhi that have an annual pollution level more than 10 times the recommended level. Well known is Beijing with an annual average 8.5 times the recommended safe levels. However, even in European cities like London, Paris and Berlin, the levels are higher than recommended by the WHO.

[0003] Since this problem will not improve significantly on a short time scale, the only way to deal with this problem is to wear a mask which provides cleaner air by filtration. To improve comfort and effectiveness one or two fans can be added to the mask. These fans are switched on during use and are typically used at a constant voltage. For efficiency and longevity reasons these are normally electrically commutated brushless DC fans.

[0004] The benefit to the wearer of using a powered mask is that the lungs are relieved of the slight strain caused by inhalation against the resistance of the filters in a conventional non-powered mask.

[0005] Furthermore, in a conventional non-powered mask, inhalation also causes a slight negative pressure within the mask which leads to leakage of the contaminants into the mask, which leakage could prove dangerous if these are toxic substances. A powered mask delivers a steady stream of air to the face and may for example provide a slight positive pressure, which may be determined by the resistance of an exhale valve, to ensure that any leakage is outward rather than inward.

[0006] There are several advantages if the fan operation or speed is regulated. This can be used to improve comfort by more appropriate ventilation during the inhalation and exhalation sequence or it can be used to improve the electrical efficiency. The latter translates into longer battery life or increased ventilation. Both of these aspects need improvement in current designs.

[0007] To regulate the fan speed, the pressure inside the mask can be measured and both pressure as well as pressure variation can be used to control the fan.

[0008] For example, the pressure inside a mask can be measured by a pressure sensor and the fan speed can be varied in dependence on the sensor measurements. A pressure sensor is costly so it would be desirable to provide an alternative method of monitoring pressure inside a mask.

[0009] WO 2018/215225 discloses a mask in which a rotation speed of the fan is used as a proxy for pressure measurement. A pressure or a pressure change is determined based on the rotation speed of the fan. Using this pressure information, the breathing pattern of the user can be tracked.

[0010] With increasing awareness of the issue of air pollution discussed above, an increasing number of people wear masks during exercise. In pollution seasons, people still wish to take part in outdoor sports, and hence a pollution mask provides an attractive option during exercise.

[0011] An indication of fitness level is also of interest to people who exercise regularly. It is known that the VO₂max (maximum oxygen uptake value) indicator can reflect the fitness level.

[0012] It would therefore be of interest to enable a sports mask to be provide breathing volume and breathing flow rate information such as oxygen uptake (VO₂) information.

[0013] A basic VO₂ measurement relates to the volume of oxygen consumption during exercise. The particular value VO₂max is the maximum oxygen consumption measured during incremental exercise. It is a special case of the VO₂ measurement and is widely used as a health indicator. Normally, in order to measure VO₂ or VO₂max, a graded exercise test must be conducted on a treadmill or cycle ergometer. The user also needs to wear a mask with a long tube, with the tube connected to a remote analysis system for further breathing ventilation, and oxygen and carbon dioxide concentration analysis of the inhaled and exhaled air. This is an inconvenient and high cost test, and so it is typically used only for clinical and athletics testing.

[0014] It would be desirable to be able to provide breathing volume information, such as a VO₂max indication, using a filtration mask, as is increasingly commonly worn during exercise.

SUMMARY OF THE INVENTION

[0015] The invention is defined by the claims.

[0016] According to examples in accordance with an aspect of the invention, there is provided a pollution mask comprising:

an outer wall for, when the mask is worn, defining air chamber between the outer wall and the face of the user;
 a filter which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;
 a fan for drawing air from outside the air chamber into the air chamber and/or drawing air from inside the air chamber to the outside;
 a means for determining a rotation speed of the fan;
 means for determining a pressure between the air chamber and the ambient surroundings;
 a controller which is adapted to analyze the rotation speed of the fan over time and the pressure over time thereby to determine breathing flow information; and
 an output for providing the breathing flow information to the user.

[0017] The invention relates to a pollution mask. By this is meant a device which has the primary purpose of filtering ambient air to be breathed by the user. The mask does not perform any form of patient treatment. In particular, the pressure levels and flows resulting from the fan operation are intended solely to assist in providing comfort (by influencing the temperature or relative humidity in the air chamber) and/or to assist in providing a flow across a filter without requiring significant additional breathing effort by the user. The mask does not provide overall breathing assistance compared to a condition in which the user does not wear the mask.

[0018] This mask functions both as a pollution mask, as explained above, and also when worn during exercise, an analysis system from providing breathing flow information. This provides a user with information relating to their personal health and/or fitness. This information can be achieved without adding significant complexity to the mask. The rotation speed of the fan and/or the pressure measurement are to identify breathing cycles (i.e. inhalation and exhalation cycles) and flow rates. The breathing flow information is derived without a direct flow measurement. It is instead derived from pressure values (and known characteristics of the structure of the mask), and these pressure values may themselves in turn be derived from fan rotation information as explained below.

[0019] The breathing flow information may be an instantaneous oxygen uptake rate, or an average over a preceding period, or a maximum reached during a predetermined period, or a combination of these.

[0020] The controller for example also controls the fan speed. It may for example control the fan in synchronism with the breathing cycles of the user, in order to save power. It may for example turn off during inhalation.

[0021] The means for determining a pressure between the air chamber and the ambient surroundings may be implemented by the controller, which is adapted to derive a pressure between the air chamber and the ambient surroundings from the rotation speed of the fan, such that the fan speed is used as a proxy of pressure measurement.

[0022] In this way the fan speed (for a fan which drives air into the chamber and/or expels it from the chamber) is used as a proxy of pressure measurement. To measure the fan speed, the fan itself may be used so that no additional sensors are required. The chamber may be closed in normal use, so that pressure fluctuations in the chamber have an influence on the load conditions of the fan and hence alter the fan electrical characteristics. This avoids the need for a separate pressure sensor.

[0023] The means for determining a pressure between the air chamber and the ambient surroundings may however instead comprise a cavity pressure sensor or a differential pressure sensor.

[0024] In one example, the fan is driven by an electronically commutated brushless motor, and the means for determining rotation speed comprises an internal sensor of the motor. The internal sensor is already provided in such motors to enable rotation of the motor. The motor may even have an output port on which the internal sensor output is provided. Thus, there is a port which carries a signal suitable for determining the rotation speed.

[0025] Alternatively, the means for determining the rotation speed may comprise a circuit for detecting a ripple on the electrical supply to a motor which drives the fan. The ripple results from switching current through the motor coils, which cause induced changes in the supply voltage as a result of the finite impedance of the input voltage source.

[0026] The fan may be a two-wire fan and the circuit for detecting a ripple comprises a high pass filter. The additional circuitry needed for a motor which does not already have a suitable fan speed output can be kept to a minimum.

[0027] The controller may be adapted to:

derive a filter flow rate through the filter based on the pressure and on filter permeability characteristics of the filter;
 derive a fan flow rate from the fan rotation speed; and
 derive a breathing flow rate based on a sum of, or difference between, the filter flow rate and the fan flow rate.

[0028] The permeability characteristics may be known in advance and taken into account in the algorithm implemented by the controller. For example, filter permeability information can be calibrated at the production line. For instance, after

filter manufacture, the filter permeability can be measured by a flow rate and pressure measurement device. Permeability information can then be written into a memory of the controller for use by the algorithm run by the controller.

[0029] By combining information about the fan flow rate (from the fan speed) and the filter flow rate (from the pressure difference across the filter), the breathing flow from the user, e.g. through the nose, can be determined.

[0030] The controller is preferably adapted to determine the timing of inhaling and exhaling from the pressure (e.g. proxy pressure), and to derive the breathing flow rate during inhalation or exhalation. A breathing flow volume can then be derived from the breathing flow rate over the time of a breathing inhalation or exhalation.

[0031] The controller preferably then derives a VO₂ measure from the breathing flow volume and breathing rate. In a preferred example, a maximum VO₂ level is recorded over a time period and provided to the output as the breathing flow information. This time period may be a fixed time duration or it may be a variable time period during which a particular exercise task is being conducted, such as a run or cycle.

[0032] The filter forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber. This provides a compact arrangement which avoids the need for flow transport passageways. It means the user is able to breathe in through the filter. The filter may have multiple layers. For example, an outer layer may form the body of the mask (for example a fabric layer), and an inner layer may be for removing finer pollutants. The inner layer may then be removable for cleaning or replacement, but both layers may together be considered to constitute the filter, in that air is able to pass through the structure and the structure performs a filtering function.

[0033] The filter thus preferably comprises an outer wall of the air chamber and optionally one or more further filter layers. This provides a particularly compact arrangement and enables a large filter area, because the mask body performs the filtering function. The ambient air is thus provided directly to the user, when the user breathes in, through the filter.

[0034] The fan may be only for drawing air from inside the air chamber to the outside. In this way, it may at the same time promote a supply of fresh filtered air to the air chamber even during exhalation, which improves user comfort. In this case, the pressure in the air chamber may be below the outside (atmospheric) pressure at all times so that fresh air is always supplied to the face.

[0035] The volume of the air chamber is for example less than 250cm³. Thus, it is a compact mask suitable for use during exercise, without physical connection to other analytical equipment.

[0036] The invention also provides a non-therapeutic method of controlling a pollution mask, the method comprising:

- drawing air into and/or out of an air chamber of the mask using a fan which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;
- determining a rotation speed of the fan;
- determining a pressure between the air chamber and the ambient surroundings;
- analyzing the rotation speed of the fan over time and the pressure over time thereby to determine breathing flow information; and
- providing the breathing flow information to a user as an output.

[0037] The pollution mask is not a mask for delivering therapy to a patient,

[0038] The method may comprise determining a pressure between the air chamber and the ambient surroundings from the rotation speed of the fan, such that the fan speed is used as a proxy of pressure measurement.

[0039] The method may comprise:

- deriving a filter flow rate through the filter based on the pressure and on filter permeability characteristics of the filter;
- deriving a fan flow rate from the fan rotation speed;
- deriving a breathing flow rate based on a sum of, or difference between, the filter flow rate and the fan flow rate;
- deriving a breathing flow volume from the breathing flow rate over the time of a breathing inhalation or exhalation; and
- deriving a VO₂ measure from the breathing flow volume and breathing rate.

[0040] Note that for the VO₂ calculation, information is preferably obtained about the body mass of the user. A pre-defined table may then provide a mapping between the breathing flow volume and rate and the VO₂ measure by taking account of this body mass information. The body mass information may include information relating to age, gender and weight. This information may be input by the user through an app running on an external device (e.g. smartphone) with which the mask communicates.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] Examples of the invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 shows a face mask which may be used to provide breathing flow information;

Figure 2 shows one example of the components of the pressure monitoring system;

Figure 3A shows a rotation signal during inhalation and during exhalation and Figure 3B shows how a fan rotation speed varies over time; and

Figure 4 shows a circuit for controlling the current through one of the stators of a brushless DC motor;

Figures 5A and 5B show flow conditions and are used to explain the processing carried out by the mask; and

Figure 6 shows a mask control method.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0042] The invention will be described with reference to the Figures.

[0043] It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the apparatus, systems and methods, are intended for purposes of illustration only and are not intended to limit the scope of the invention. These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention will become better understood from the following description, appended claims, and accompanying drawings. It should be understood that the Figures are merely schematic and are not drawn to scale. It should also be understood that the same reference numerals are used throughout the Figures to indicate the same or similar parts.

[0044] The invention provides a pollution mask with a filter and fan monitors a rotation speed of the fan and a pressure between the mask air chamber and the ambient surroundings. Breathing flow information is then obtained from these monitored parameters, and breathing flow information (such as an oxygen uptake rate) is provided to a user of the mask. This mask functions both as a pollution mask, and an analysis system from providing breathing flow information, for example for personal health and/or fitness monitoring.

[0045] Figure 1 shows a face mask with automatic fan speed control.

[0046] A subject 10 is shown wearing a face mask 12 which covers the nose and mouth of the subject. The purpose of the mask is to filter air before it is breathed in the subject. For this purpose, the mask body itself acts as an air filter 16. Air is drawn in to an air chamber 18 formed by the mask by inhalation. During inhalation, an outlet valve 22 such as a check valve is closed due to the low pressure in the air chamber 18.

[0047] The filter 16 may be formed only by the body of the mask, or else there may be multiple layers. For example, the mask body may comprise an external cover formed from a porous textile material, which functions as a pre-filter. Inside the external cover, a finer filter layer is reversibly attached to the external cover. The finer filter layer may then be removed for cleaning and replacement, whereas the external cover may for example be cleaned by wiping. The external cover also performs a filtering function, for example protecting the finer filter from large debris (e.g. mud), whereas the finer filter performs the filtering of fine particulate matter. There may be more than two layers. Together, the multiple layers function as the overall filter of the mask.

[0048] When the subject breathes out, air is exhausted through the outlet valve 22. This valve is opened to enable easy exhalation, but is closed during inhalation. A fan 20 assists in the removal of air through the outlet valve 22. Preferably, more air is removed than exhaled so that additional air is supplied to the face. This increases comfort due to lowering relative humidity and cooling. During inhalation, by closing the valve, it is prevented that unfiltered air is drawn in. The timing of the outlet valve 22 is thus dependent on the breathing cycle of the subject. The outlet valve may be a simple passive check valve operated by the pressure difference across the filter 16. However, it may instead be an electronically controlled valve.

[0049] There will be a varied pressure inside the chamber if the mask is worn and the user is breathing. In particular the chamber is closed by the face of the user. The pressure inside the closed chamber when the mask is worn will also vary as a function of the breathing cycle of the subject. When the subject breathes out, there will be a slight pressure increase and when the subject breathes in there will be a slight pressure reduction.

[0050] If the fan is driven with a constant drive level (i.e. voltage), the different prevailing pressure will manifest itself as a different load to the fan, since there is a different pressure drop across the fan. This altered load will then result in a different fan speed. The rotation speed of the fan may thus be used as a proxy for a measurement of pressure across the fan. This is a preferred implementation because it uses fewer sensors.

[0051] However, the concept of the invention may be implemented with pressure sensors for obtaining the breathing characteristics.

[0052] For a known pressure (e.g. atmospheric pressure) at one side of the fan, the pressure monitoring enables determination of a pressure, or at least a pressure change, on the other side of the fan. This other side is for example a closed chamber which thus has a pressure different to atmospheric pressure.

[0053] The pressure variation, as detected based on monitoring the fan rotation speed, may be used to obtain information about the breathing of the user. In particular, a first value may represent the depth of breathing and a second value may represent the rate of breathing.

[0054] The means for determining a rotation speed may comprise an already existing output signal from the fan motor

or a separate simple sensing circuit may be provided as an additional part of the fan. However, in either case the fan itself is used so that no additional sensors are required.

[0055] Figure 2 shows one example of the components of the system. The same components as in Figure 1 are given the same reference numbers.

[0056] In addition to the components shown in Figure 1, Figure 2 shows a controller 30, a local battery 32 and a means 36 for determining the fan rotation speed. It shows an output 38 for providing output information to the user. It could be an integrated display, but more preferably it is a wireless communications transmitter (or transceiver) for sending data to a remote device such as a smartphone, which can then be used as the final user interface for providing data to the user, and optionally for receiving control commands from the user for relaying to the controller 30.

[0057] The smartphone may also be used for inputting user information to create a user profile. The user profile includes at least the age, weight and gender of the user, since these may be used to convert between a breathing volume and an oxygen uptake level, as explained further below.

[0058] The fan 20 comprises a fan blade 20a and a fan motor 20b. In one example, the fan motor 20b is an electronically commutated brushless motor, and the means for determining rotation speed comprises an internal sensor of the motor. Electronically commutated brushless DC fans have internal sensors that measure the position of the rotor and switch the current through the coils in such a way that the rotor rotates. The internal sensor is thus already provided in such motors to enable feedback control of the motor speed.

[0059] The motor may have an output port on which the internal sensor output 34 is provided. Thus, there is a port which carries a signal suitable for determining the rotation speed.

[0060] Alternatively, the means for determining the rotation speed may comprise a circuit 36 for detecting a ripple on the electrical supply to the motor 20b. The ripple results from switching current through the motor coils, which cause induced changes in the supply voltage as a result of the finite impedance on the battery 32. The circuit 36 for example comprises a high pass filter so that only the signals in the frequency band of the fan rotation are processed. This provides an extremely simple additional circuit, and of much lower cost than a conventional pressure sensor.

[0061] This means the motor can be of any design, including a two-wire fan with no in-built sensor output terminal. It will also work with a DC motor with brushes.

[0062] If the outlet valve 22 is an electronically switched valve, the respiration cycle timing information may then be used to control the outlet valve 22 in dependence on the phase of the respiration cycle. The fan speed monitoring thus provides a simple way to determine inhalation phases, which may then be used to control the timing of the outlet valve 22 of the mask.

[0063] In addition to controlling the outlet valve, the controller may turn off the fan during an inhalation time or an exhalation time. This gives the mask different operating modes, which may be used to save power.

[0064] For a given drive level (i.e. voltage) the fan speed increases at lower pressure across the fan because of the reduced load on the fan blades. This gives rise to an increased flow. Thus, there is an inverse relationship between the fan speed and the pressure difference.

[0065] This inverse relationship may be obtained during a calibration process or it may be provided by the fan manufacturer. The calibration process for example involves analyzing the fan speed information over a period during which the subject is instructed to inhale and exhale regularly with normal breathing. The captured fan speed information can then be matched to the breathing cycle, from which threshold values can then be set for discriminating between inhalation and exhalation.

[0066] Figure 3A shows schematically the rotor position (as a measured sensor voltage) against time.

[0067] The rotational speed may be measured from the frequency of the AC component (caused by the switching events in the motor) of the DC voltage to the fan. This AC component originates from the current variation that the fan draws, imposed on the impedance of the power supply.

[0068] Figure 3A shows the signal during inhalation as plot 40 and during exhalation as plot 42. There is a frequency reduction during exhalation caused by an increased load on the fan by the increased pressure gradient. The observed frequency changes thus results from the different fan performance during the breathing cycle.

[0069] Figure 3B shows the frequency variation over time, by plotting the fan rotation speed versus time. There is a maximum difference in fan rotation speed Δ_{fan} between successive maxima and minima, and this correlates with the depth of breathing. This is the first value derived from the fan rotation signal. The time between these points is used to derive the second value, for example the frequency corresponding to this time period (which is then twice the breathing rate).

[0070] Note that the first value maybe obtained from the raw fan rotation signal or there may be smoothing carried out first. Thus, there are at least two different two ways to calculate the maximum swing, based on untreated real-time speeds or treated speeds. In practice, there is noise or other fluctuations added on the real-time signals. A smoothing algorithm may be used to treat the real-time signal and calculate the first value from the smoothed signal.

[0071] During the exhalation, fan operation forces air out of the area between face and mask. This enhances comfort because exhalation is made easier. It can also draw additional air onto the face which lowers the temperature and relative

humidity. Between inhalation and exhalation, the fan operation increases comfort because fresh air is sucked into the space between the face and the mask thereby cooling that space.

[0072] In one example, during inhalation, the outlet valve is closed (either actively or passively) and the fan can be switched off to save power. This provides a mode of operation which is based on detecting the respiration cycle.

[0073] The precise timing of the inhalation and exhalation phases can be inferred from previous respiration cycles, if the fan is turned off for parts of the respiration cycle, and hence not giving pressure information.

[0074] For the fan assisted exhalation, power needs to be restored just before the exit valve opens again. This also makes sure that the next inhale-exhale cycle remains properly timed and sufficient pressure and flow are made available.

[0075] Around 30% power savings are easily achievable using this approach, resulting in prolonged battery life. Alternatively, the power to the fan can be increased by 30% for enhanced effectiveness.

[0076] With different fan and valve configurations the measurement of the fan rotation speed enables control to achieve increased comfort.

[0077] In fan configurations where the filter is in series with the fan the pressure monitoring may be used to measure the flow resistance of the filter, in particular based on the pressure drop across the fan and filter. This can be done at switch on, when the mask is not on the face for a period of time. That resistance can be used as a proxy for the age of the filter.

[0078] As mentioned above, a fan using an electronically commutated brushless DC motor has internal sensors that measure the position of the rotor and switch the current through the coils in such a way that the rotor rotates.

[0079] Figure 4 shows an H-bridge circuit which functions as an inverter to generate an alternating voltage to the stator coils 50 of the motor from a DC supply VDD, GND. The inverter has a set of switches S1 to S4 to generate an alternating voltage across the coil 50. The switches are controlled by signals which depend on the rotor position, and these rotor position signals may be used to monitor the fan rotation.

[0080] The way the pressure information (or proxy pressure information) and fan rotation speed enable breathing flow information to be derived will now be explained.

[0081] The mask basically needs to calculate the user's breathing ventilation. Based on the breathing ventilation, the oxygen uptake rate VO₂ is then calculated. Optionally, based on the VO₂ level for different activities, a measure of fitness or sports progress can also be derived. Thus, the mask may provides fitness training information in addition to physiologic data such as oxygen uptake rates.

[0082] The breathing ventilation rate is defined by the following equation:

$$BVR = V * f \quad (1)$$

[0083] Here BVR is the breathing ventilation rate in L/min, V is the individual breath volume, and f is the breathing frequency (i.e. breathing rate).

[0084] The use of a differential pressure sensor or the fan rotation signal to measure the breathing ventilation rate can be applied to any architecture of intelligent mask, such as with an exhalation fan direction, inhalation fan direction or both.

[0085] Simply by way of example, an exhaling fan direction is assumed.

[0086] Normally the inhaling volume and exhaling volume are balanced. In order to derive the BVR, the breath volume and breathing frequency are needed.

[0087] Once the intelligent mask is working, the controller can record a period of data, such as 5 seconds, which is longer than an individual breathing cycle. Within that volume of data, the maximum and minimum data point for the mask rotation speed, and the corresponding timing instants, enable the frequency to be easily calculated (see Figure 3B).

$$f = 1/2(t_{\max} - t_{\min}) \quad (2)$$

[0088] For the breathing volume calculation, the inhaled or exhaled volume is to be calculated. This example is based on the exhaled breath volume. The volume depends on the breathing flow rate FR_{nose} (e.g. from the nose) and the fan flow rate FR_{fan}, and the air flow through the filter. There are two scenarios:

- (i) FR_{nose} < FR_{fan}, at this time P_{cavity} < 0, and the air flow direction through the filter is external to internal;
- (ii) FR_{nose} > FR_{fan}, at this time P_{cavity} > 0, the air flow direction through the filter is internal to external.

[0089] Figure 5A shows the situation with FR_{nose} < FR_{fan}, P_{cavity} < 0 with filter air flow entering the chamber 18.

[0090] Figure 5B shows a situation with FR_{nose} > FR_{fan}, P_{cavity} > 0 with the filter air flow leaving the chamber 18.

[0091] These two images both relate to exhalation, with the fan turned on.

[0092] The filter permeability performance (represented by value K) provides a linear relationship between pressure (P) and air flow through the filter FR_{filter} :

$$FR_{filter} = K * P \quad (3)$$

[0093] With increasing pressure P, the flow rate (L/s) through the filter will increase. The value K is a permeability coefficient, and different filters have different value of K.

[0094] Based on a known filter permeability performance, once the pressure has been measured from the pressure sensor or indirectly measured the pressure from fan signal, the value FR_{filter} is obtained.

[0095] Depending on the pressure value (or the fan signal), the flow direction through the filter is also known. As a result. The breathing flow rate FR_{nose} at each moment can be calculated:

$$FR_{nose} = FR_{fan} - FR_{filter}, \quad \text{if } P_{cavity} < 0 \quad (4a)$$

[0096] This corresponds to the flows shown in Figure 5A.

$$FR_{nose} = FR_{fan} + FR_{filter}, \quad \text{if } P_{cavity} > 0 \quad (4b)$$

[0097] This corresponds to the flows shown in Figure 5B.

[0098] The fan speed (for a constant fan drive signal) satisfies the following relation:

$$n(t)/n(0) = P_{cavity}(t)/P_{cavity}(0) \quad (5)$$

Where $n(0)$ is the default fan speed when the cavity pressure is $P_{cavity}(0)$ where $P_{cavity}(0)$ is the baseline of the cavity pressure, which means the user is not breathing. $n(t)$ is the fan speed at time t and when the cavity pressure is $P_{cavity}(t)$. As a result, according to the fan rotation feedback signal, it is also easy to calculate the breathing flow rate FR_{nose} .

[0099] According to the breathing flow rate, breath volume V can be determined as an integral over one cycle, namely one exhalation cycle in this example:

$$V = \int_{t_0}^{t_n} (FR_{nose} * t) dt \quad (6)$$

[0100] Here t_0 is the time at which an exhalation cycle began, t_n is the time at which exhaling finished. Based on equations (1) - (6) the ventilation rate BVR can thus be calculated.

[0101] The instantaneous rate of oxygen consumption, VO_2 , can be calculated according to the following equation:

$$VO_2 = e^{b \left(\frac{1}{BM} \ln BVR - a \right) + \ln BM} \quad (7)$$

Where VO_2 represents oxygen uptake rate at time t and has units of liters of oxygen per minute. Values a and b are constants and are dependent on age and gender. BM is body mass with units of kg.

[0102] To enable this conversion from body mass and ventilation rate to oxygen uptake, a user profile is used from which the weight, age and gender of the user is extracted. The information of age, gender and weight is for example input using an app on the smartphone (or other user input device) when the user uses the mask for the first time, in order to set up their user profile. They may of course update this profile to reflect changes in their weight over time (and the age may be updated automatically).

[0103] Values a and b can be determined in known manner, for example as outlined in T. Johnson: A guide to selected algorithms, distribution, and databases used in exposure models developed by the office of air quality planning and standards, in U.S. Environmental Protection Agency, North Carolina, 2002.

[0104] Any other known mapping between the ventilation rate and the rate of oxygen consumption may be used. Such mappings are approximations, and a number of different approximations are possible.

[0105] With equation (7), the VO₂ consumption when the user is using the mask can be calculated.

[0106] By tracking a maximum value of this continuous and near instantaneous VO₂ determination, a VO₂max value can be recorded. For example, the user may perform a 3km or 5km run, by recording the maximum value of VO₂ during the run, the VO₂max value can be estimated.

[0107] The classic breathing ventilation response to incremental exercise has been the source of much study in exercise physiology over many years. When increasing exercise intensity, more oxygen volume is needed to support the exercise. As a result, the breathing ventilation increases (frequency and breath volume increase). However, for trained people, the ventilation can be 20-30% lower at the same work rate.

[0108] This is because exercise increases the number of capillaries per mm² in heart muscle thus increasing the delivery of glucose and oxygen to hard working heart muscle cells. Therefore, the efficiency of heart is increased. With exercise, lung volume increases, which speeds up the rate of gas exchange at the lung thus ensuring plenty of oxygenated blood is produced. Finally, muscle in trained athletes releases less lactate than in untrained subjects, and training can improve the ability of the liver to remove circulating lactate.

[0109] If people train properly, it can significantly reduce the ventilation intake and improve the fitness level.

[0110] The mask of the invention provides information which can be used as feedback which reflects the fitness level, and can be monitored for improving after a prolonged regime of exercise following an exercise protocol. With different exercise intensity, the ventilation and VO₂ will be different.

[0111] The exercise protocol can be based on any kind of sports activity such as jogging, running or biking. Take running for example, a user can wear the mask during a run for the same distance within the same controlled time every day. Using digital connectivity from the mask to a remote device such as a smart watch or smart phone, the user can obtain the ventilation and VO₂ data every time the run is complete. This data can be stored in the smart phone, and the data can be plotted each the user wants to see the progress. The user can see the fitness improvement level. The data may be processed to be presented in a more user friendly way, for example giving fitness and progress information.

[0112] The mask may be for covering only the nose and mouth (as shown in Figure 1) or it may be a full face mask. The mask is for filtering ambient air.

[0113] The mask design described above has the main air chamber formed by the filter material, through which the user breathes in air. An alternative mask design has the filter in series with the fan as also mentioned above. In this case, the fan assists the user in drawing in air through the filter, thus reducing the breathing effort for the user. An outlet valve enables breathed out air to be expelled and an inlet valve may be provided at the inlet.

[0114] The invention may use the detected the pressure variations caused by breathing for controlling an inlet valve and/or the outlet valve.

[0115] One option as discussed above is the use of the fan only for drawing air from inside the air chamber to the outside, for example when an exhaust valve is open. In such a case, the pressure inside the mask volume may be maintained by the fan below the external atmospheric pressure so that there is a net flow of clean filtered air into the mask volume during exhalation. Thus, low pressure may be caused by the fan by during exhalation and by the user during inhalation (when the fan may be turned off).

[0116] An alternative option is the use of the fan only for drawing air from the ambient surroundings to inside the air chamber. In such a case, the fan operates to increase the pressure in the air chamber, but the maximum pressure in the air chamber in use remains below 4 cmH₂O higher than the pressure outside the air chamber, in particular because no high pressure assisted breathing is intended. Thus, a low power fan may be used.

[0117] It will thus be seen that the invention may be applied to many different mask designs, with fan-assisted inhalation or exhalation, and with an air chamber formed by a filter membrane or with a sealed hermetic air chamber.

[0118] In all cases, the pressure inside the air chamber preferably remains below 2 cmH₂O, or even below 1 cmH₂O or even below 0.5 cmH₂O, above the external atmospheric pressure. The pollution mask is thus not for use in providing a continuous positive airway pressure, and is not a mask for delivering therapy to a patient.

[0119] The mask is preferably battery operated so the low power operation is of particular interest.

[0120] Figure 6 shows a mask controlling method. The method comprises:

in step 70, drawing air into and/or out of an air chamber of the mask using a fan which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;

in step 72, determining a rotation speed of the fan;

in step 74, determining a pressure between the air chamber and the ambient surroundings;

in step 76, analyzing the rotation speed of the fan over time and the pressure over time thereby to determine breathing flow information; and

in step 78, providing the breathing flow information to a user as an output.

[0121] Step 74 may comprise determining a pressure between the air chamber and the ambient surroundings from the rotation speed of the fan, such that the fan speed is used as a proxy of pressure measurement.

[0122] The analyzing step 76 for example comprises the sub-steps of:

- in sub-step 76a, deriving a filter flow rate through the filter (16) based on the pressure and on filter permeability characteristics of the filter;
- in sub-step 76b, deriving a fan flow rate from the fan rotation speed;
- in sub-step 76c, deriving a breathing flow rate based on a sum of, or difference between, the filter flow rate and the fan flow rate;
- in sub-step 76d, deriving a breathing flow volume from the breathing flow rate over the time of a breathing inhalation or exhalation; and
- in sub-step 76e, deriving a VO₂ measure from the breathing flow volume and breathing flow rate.

[0123] This VO₂ measure may be the breathing flow information provided to the user. A maximum recorded value of the VO₂ measure may instead or additionally be provided as the breathing flow information.

[0124] The mask may be supplemented with additional functionality and user interface options but these are outside the scope of this disclosure.

[0125] As discussed above, embodiments make use of a controller, which can be implemented in numerous ways, with software and/or hardware, to perform the various functions required. A processor is one example of a controller which employs one or more microprocessors that maybe programmed using software (e.g., microcode) to perform the required functions. A controller may however be implemented with or without employing a processor, and also maybe implemented as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions.

[0126] Examples of controller components that may be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

[0127] In various implementations, a processor or controller may be associated with one or more storage media such as volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM. The storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform the required functions. Various storage media maybe fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller.

[0128] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A pollution mask comprising:

- an outer wall (12) for, when the mask is worn, defining air chamber (18) between the outer wall and the face of the user;
- a filter (16) which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;
- a fan (20) for drawing air from outside the air chamber (18) into the air chamber and/or drawing air from inside the air chamber to the outside;
- a means (34, 36) for determining a rotation speed of the fan;
- means for determining a pressure between the air chamber and the ambient surroundings;
- a controller (30) which is adapted to analyze the rotation speed of the fan over time and the pressure over time thereby to determine breathing flow information; and
- an output (38) for providing the breathing flow information to the user.

2. A mask as claimed in claim 1, wherein the means for determining a pressure between the air chamber and the ambient surroundings is implemented by the controller, which is adapted to derive a pressure between the air chamber and the ambient surroundings from the rotation speed of the fan, such that the fan speed is used as a proxy of pressure measurement.

3. A mask as claimed in claim 1, wherein the means for determining a pressure between the air chamber and the ambient surroundings comprises a differential pressure sensor.

4. A mask as claimed in any one of claims 1 to 3, wherein:

the fan (20) is driven by an electronically commutated brushless motor, and the means for determining rotation speed comprises an internal sensor of the motor; or
the means (36) for determining a rotation speed comprises a circuit for detecting a ripple on the electrical supply to a motor which drives the fan.

5. A mask as claimed in any one of claims 1 to 4, wherein the controller is adapted to:

derive a filter flow rate through the filter (16) based on the pressure and on filter permeability characteristics of the filter;
derive a fan flow rate from the fan rotation speed; and
derive a breathing flow rate based on a sum of, or difference between, the filter flow rate and the fan flow rate.

6. A mask as claimed in claim 5, wherein the controller is adapted to determine the timing of inhaling and exhaling from the pressure, and to derive the breathing flow rate during inhalation or exhalation.

7. A mask as claimed in claim 5 or 6, wherein the controller is adapted to derive a breathing flow volume from the breathing flow rate over the time of a breathing inhalation or exhalation.

8. A mask as claimed in claim 7, wherein the controller is adapted to derive a VO₂ measure from the breathing flow volume and breathing rate.

9. A mask as claimed in claim 8, wherein the controller is adapted to record a maximum VO₂ level over a time period and provide it to the output as the breathing flow information.

10. A mask as claimed in any one of claims 1 to 9, wherein the filter comprises an outer wall (16) of the air chamber.

11. A mask as claimed in any one of claims 1 to 10, wherein the fan is only for drawing air from inside the air chamber to the outside.

12. A mask as claimed in any one of claims 1 to 11, wherein the volume of the air chamber is less than 250cm³.

13. A non-therapeutic method of controlling a pollution mask, the method comprising:

(70) drawing air into and/or out of an air chamber of the mask using a fan which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;
(72) determining a rotation speed of the fan;
(74) determining a pressure between the air chamber and the ambient surroundings;
(76) analyzing the rotation speed of the fan over time and the pressure over time thereby to determine breathing flow information; and
(78) providing the breathing flow information to a user as an output.

14. A method as claimed in claim 13, comprising determining a pressure between the air chamber and the ambient surroundings from the rotation speed of the fan, such that the fan speed is used as a proxy of pressure measurement.

15. A method as claimed in claim 13 or 14, comprising:

(76a) deriving a filter flow rate through the filter (16) based on the pressure and on filter permeability characteristics of the filter;
(76b) deriving a fan flow rate from the fan rotation speed;
(76c) deriving a breathing flow rate based on a sum of, or difference between, the filter flow rate and the fan flow rate;
(76d) deriving a breathing flow volume from the breathing flow rate over the time of a breathing inhalation or exhalation; and

EP 3 791 936 A1

(76e) deriving a VO₂ measure from the breathing flow volume and breathing rate.

5

10

15

20

25

30

35

40

45

50

55

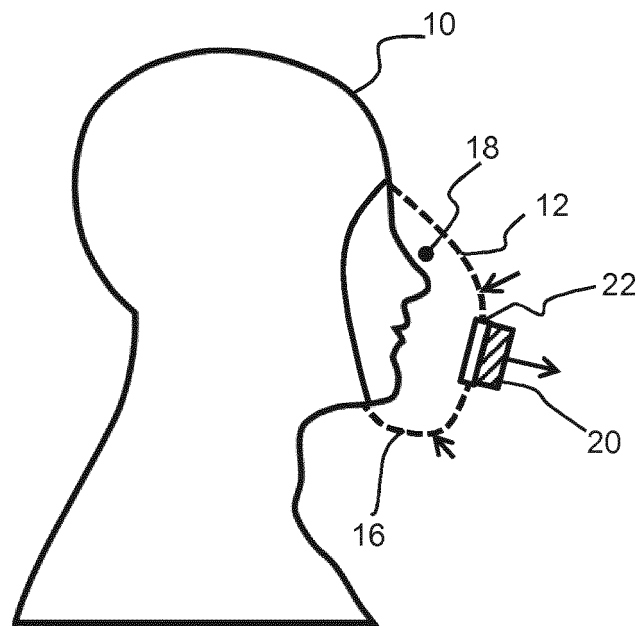


FIG. 1

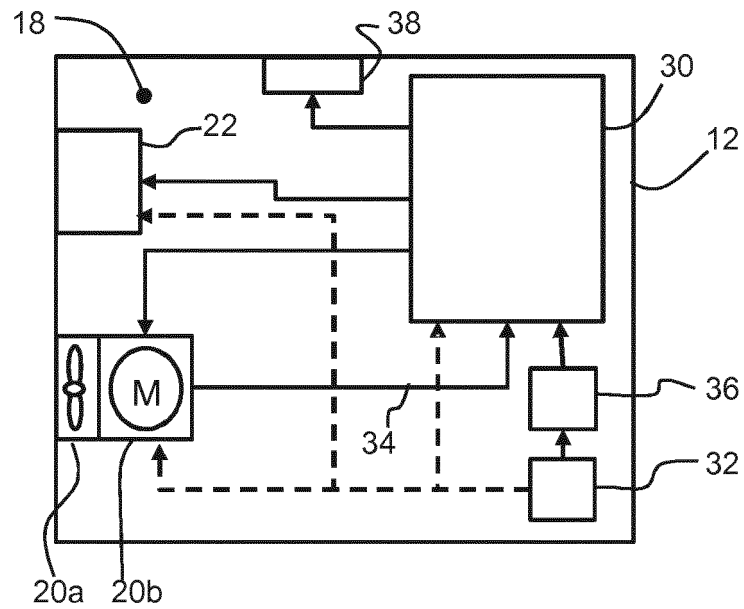


FIG. 2

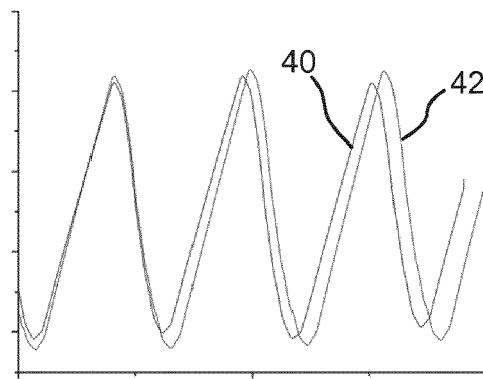


FIG. 3A

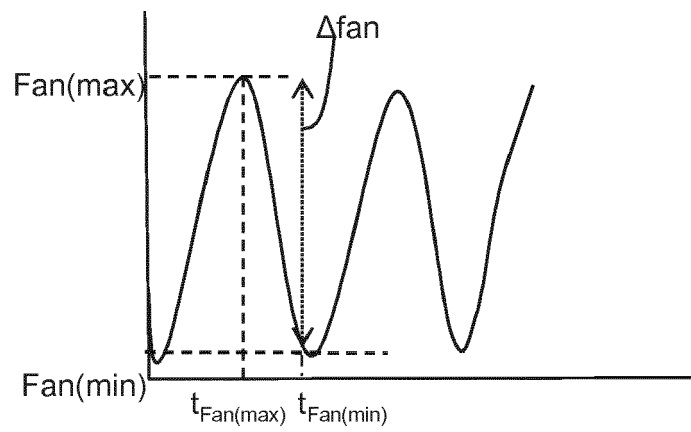


FIG. 3B

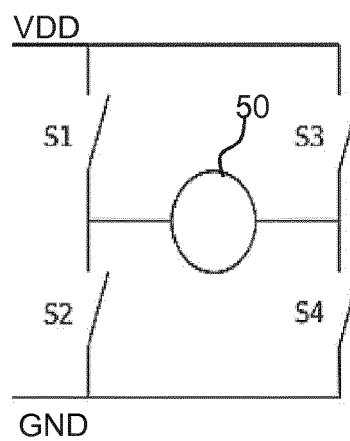


FIG. 4

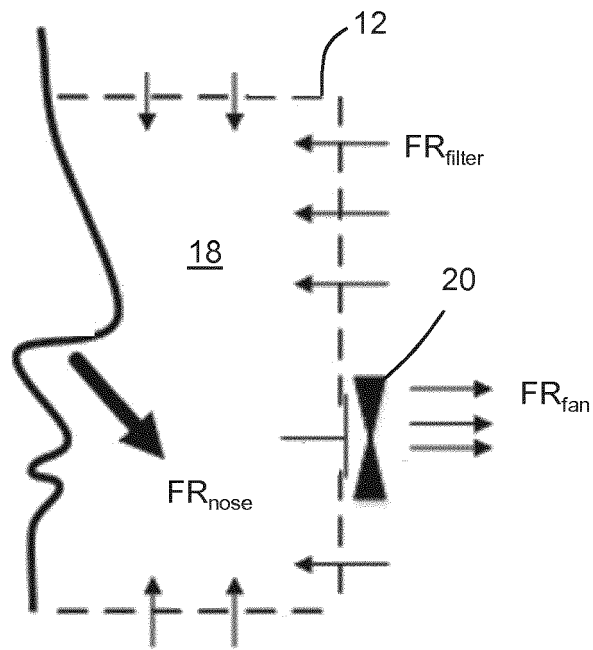


FIG. 5A

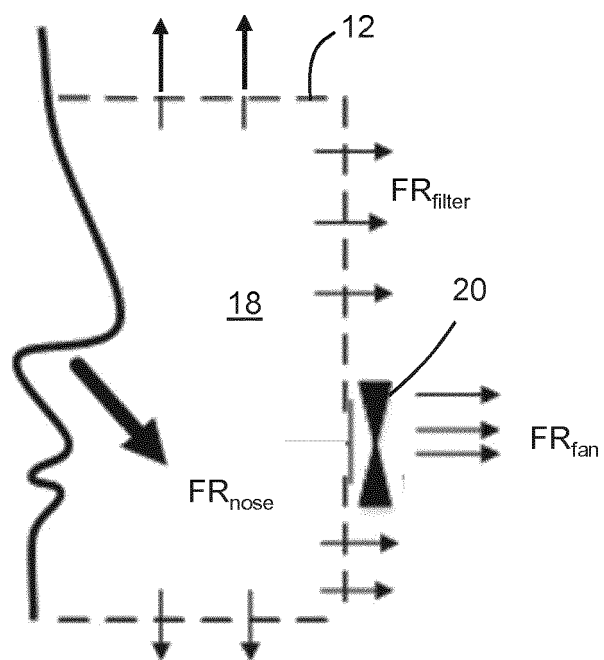


FIG. 5B

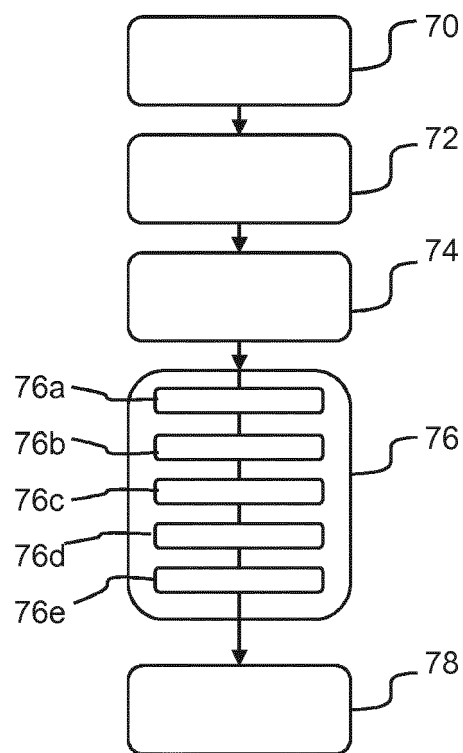


FIG. 6



EUROPEAN SEARCH REPORT

 Application Number
 EP 19 19 7180

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 9 399 109 B2 (BREATHE TECHNOLOGIES INC [US]) 26 July 2016 (2016-07-26)	1,3-13, 15	INV. A62B18/00
Y	* figures * * figures 3-6 * * column 4, lines 44-51 * * column 5, lines 27-42 * * column 6, line 55 - column 7, line 17 *	2,4,14	
X	US 6 644 310 B1 (DELACHE ALAIN J [FR] ET AL) 11 November 2003 (2003-11-11) * figures * * figures 8-12, 15 * * column 4, lines 7-9 * * column 14, lines 13-20 *	1-15	
X	US 5 134 995 A (GRUENKE ROGER A [US] ET AL) 4 August 1992 (1992-08-04) * figures * * figures 15, 18, 19,22 * * column 5, lines 27-42 *	1-15	
Y,D	WO 2018/215225 A1 (KONINKLIJKE PHILIPS NV [NL]) 29 November 2018 (2018-11-29) * figures * * page 3, lines 13-19 * * claims 7,8 *	2,4,14	TECHNICAL FIELDS SEARCHED (IPC) A62B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 12 March 2020	Examiner Andlauer, Dominique
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 19 19 7180

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

12-03-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 9399109 B2	26-07-2016	EP 2819730 A1	07-01-2015
		US 2013228181 A1	05-09-2013
		WO 2013130645 A1	06-09-2013
US 6644310 B1	11-11-2003	CA 2423244 A1	04-04-2002
		DE 60131553 T2	06-11-2008
		EP 1322369 A2	02-07-2003
		ES 2296818 T3	01-05-2008
		JP 4854910 B2	18-01-2012
		JP 2004509711 A	02-04-2004
		US 6644310 B1	11-11-2003
		WO 0226305 A2	04-04-2002
US 5134995 A	04-08-1992	AT 190230 T	15-03-2000
		AT 315415 T	15-02-2006
		AU 663054 B2	28-09-1995
		AU 686034 B2	29-01-1998
		AU 6371798 A	30-07-1998
		CA 2097502 A1	22-06-1992
		CA 2206784 A1	22-06-1992
		DE 69132030 D1	13-04-2000
		DE 69132030 T2	19-10-2000
		DE 69133504 T2	10-08-2006
		DK 0563044 T3	14-08-2000
		DK 0968734 T3	22-05-2006
		EP 0563044 A1	06-10-1993
		EP 0968734 A2	05-01-2000
		ES 2145739 T3	16-07-2000
		ES 2256989 T3	16-07-2006
		JP 2927958 B2	28-07-1999
		JP H06503484 A	21-04-1994
		US 5134995 A	04-08-1992
		WO 9211054 A1	09-07-1992
WO 2018215225 A1	29-11-2018	CN 108939337 A	07-12-2018
		EP 3630247 A1	08-04-2020
		WO 2018215225 A1	29-11-2018

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2018215225 A [0009]

Non-patent literature cited in the description

- **T. JOHNSON.** A guide to selected algorithms, distribution, and databases used in exposure models developed by the office of air quality planning and standards. *U.S. Environmental Protection Agency*, 2002 [0103]