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(54) **AIR QUALITY MONITORING DEVICE**

(71) Applicant: **GONGGAM SENSORS CO., LTD.**, Daejeon (KR)

(72) Inventors: **Myunghee SON**, Daejeon (KR); **Sung Hoon BAEK**, Daejeon (KR)

(73) Assignee: **GONGGAM SENSORS CO., LTD.**, Daejeon (KR)

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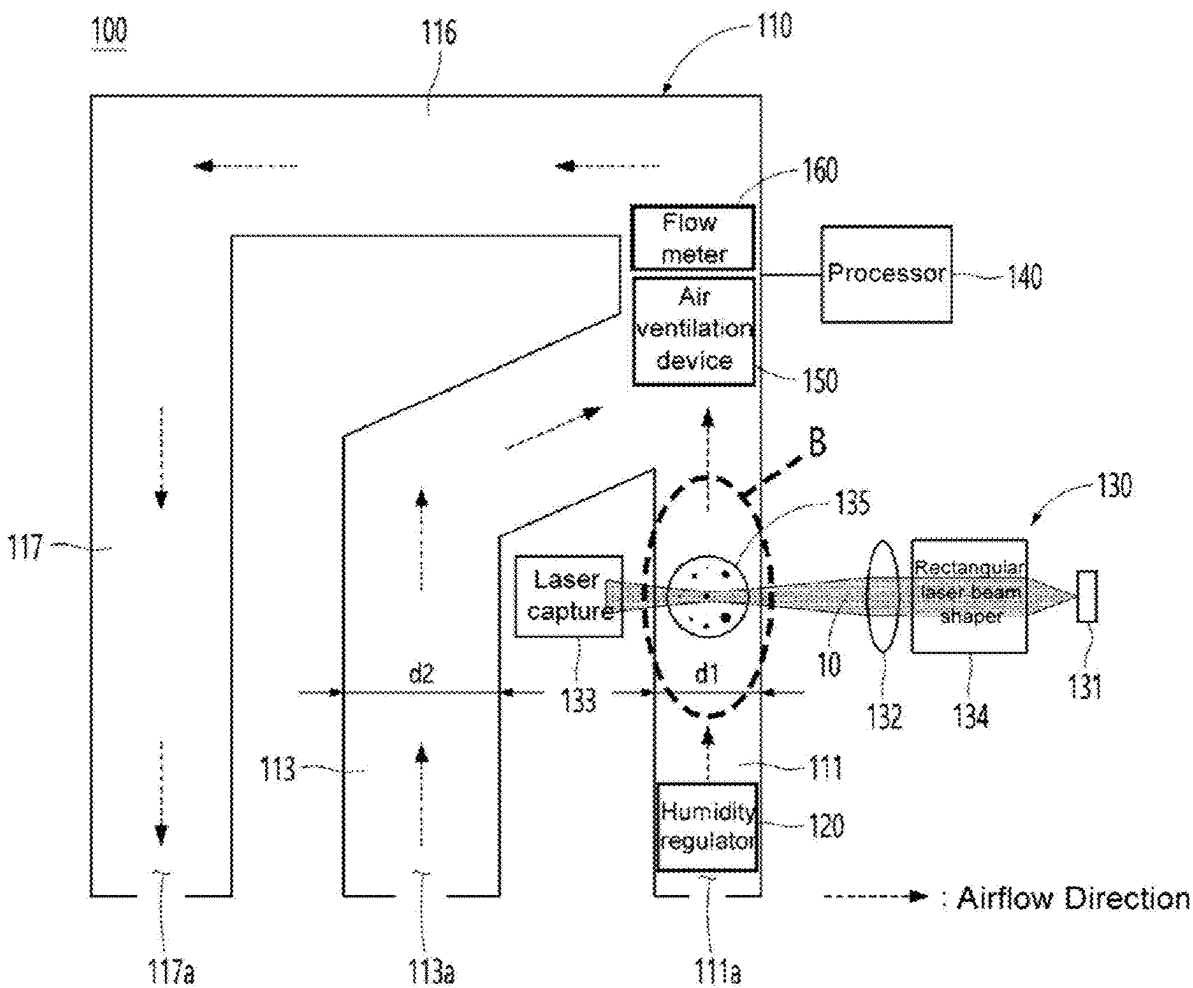
(57) **ABSTRACT**

This invention relates to an air quality measurement device, featuring a casing with a main inlet duct formed in a straight line and of a predetermined length or longer to allow air to flow from an inlet at the bottom to the top; a flow meter located at the top of the main inlet duct to measure the airflow rate; a laser module that irradiates a laser beam onto the air flowing along the main inlet duct; a light sensor that measures the amount of light scattered by dust particles contained in the air; and a processor that receives the measured values from the light sensor, performs continuous high-speed sampling, estimates the speed of dust particles based on the changes in light intensity, and uses the speed of particles to derive their mass.



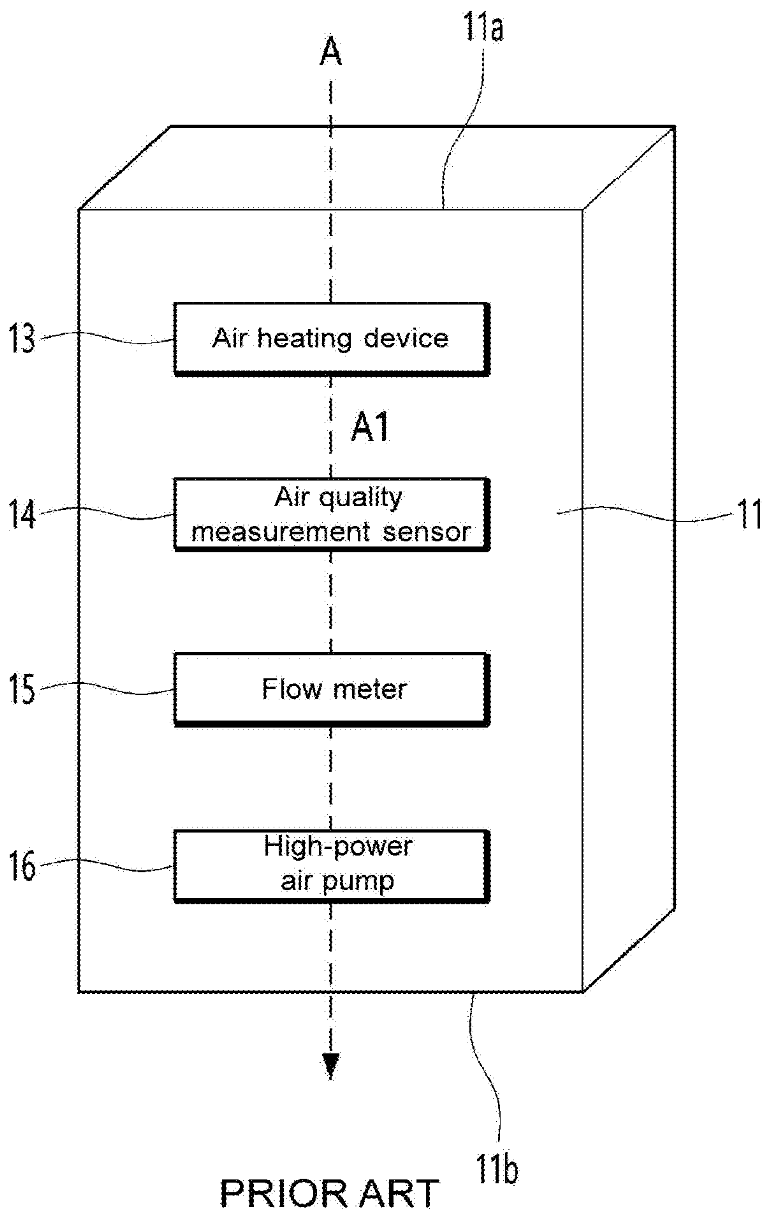

A
11a
13
Air heating device
A1
14
Air quality
measurement sensor
11
15
Flow meter
16
High-power
air pump
11b
PRIOR ART

FIG. 1

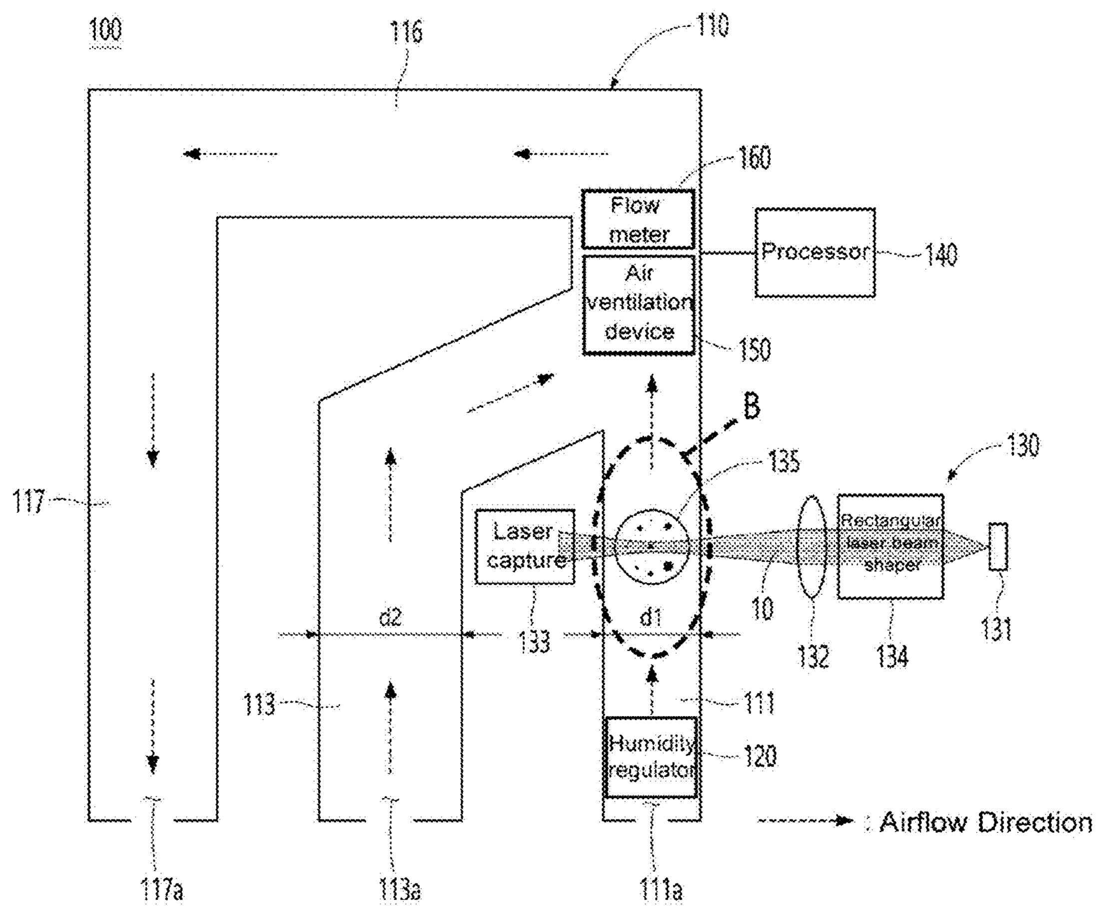

100
116
110
160
Flow meter
Processor
140
Air ventilation device
150
B
135
130
117
Laser capture
Rectangular laser beam shaper
131
d2
d1
10
133
132
134
113
111
Humidity regulator
120
: Airflow Direction
117a
113a
111a

FIG. 2

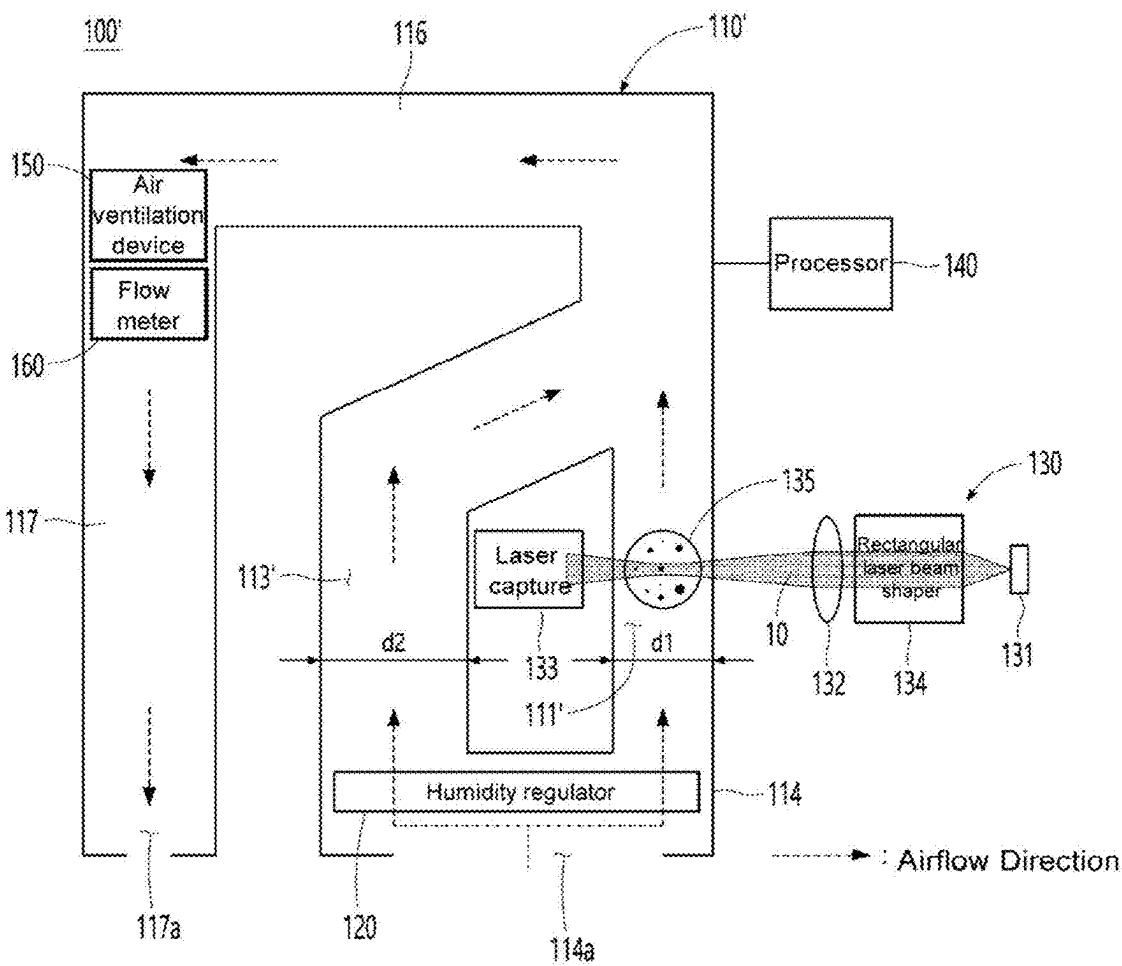

100'
116
110'
150
Air ventilation device
Flow meter
160
Processor
140
117
113'
Laser capture
135
130
Rectangular laser beam shaper
10
131
132
134
d2
133
d1
111'
Humidity regulator
114
117a
120
114a
: Airflow Direction

FIG. 3

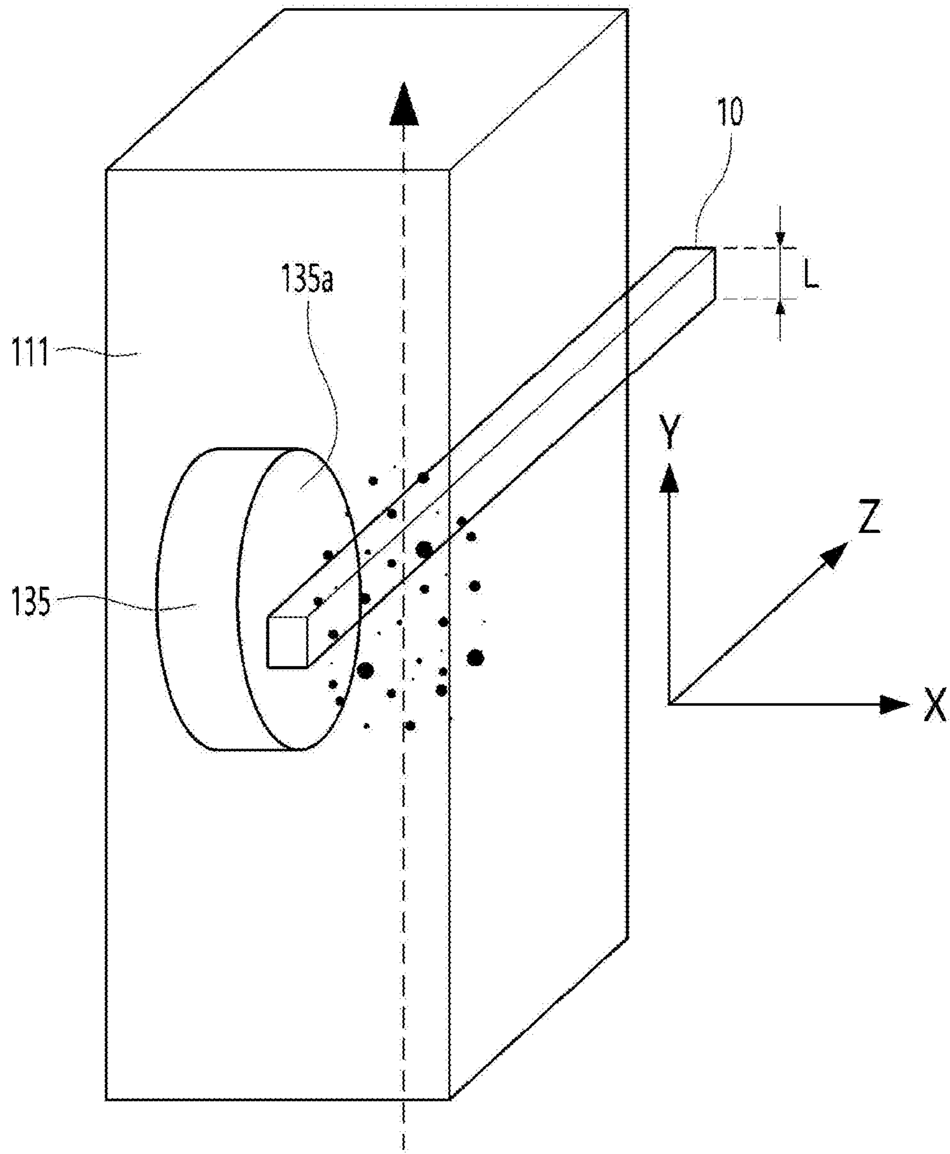


FIG. 4

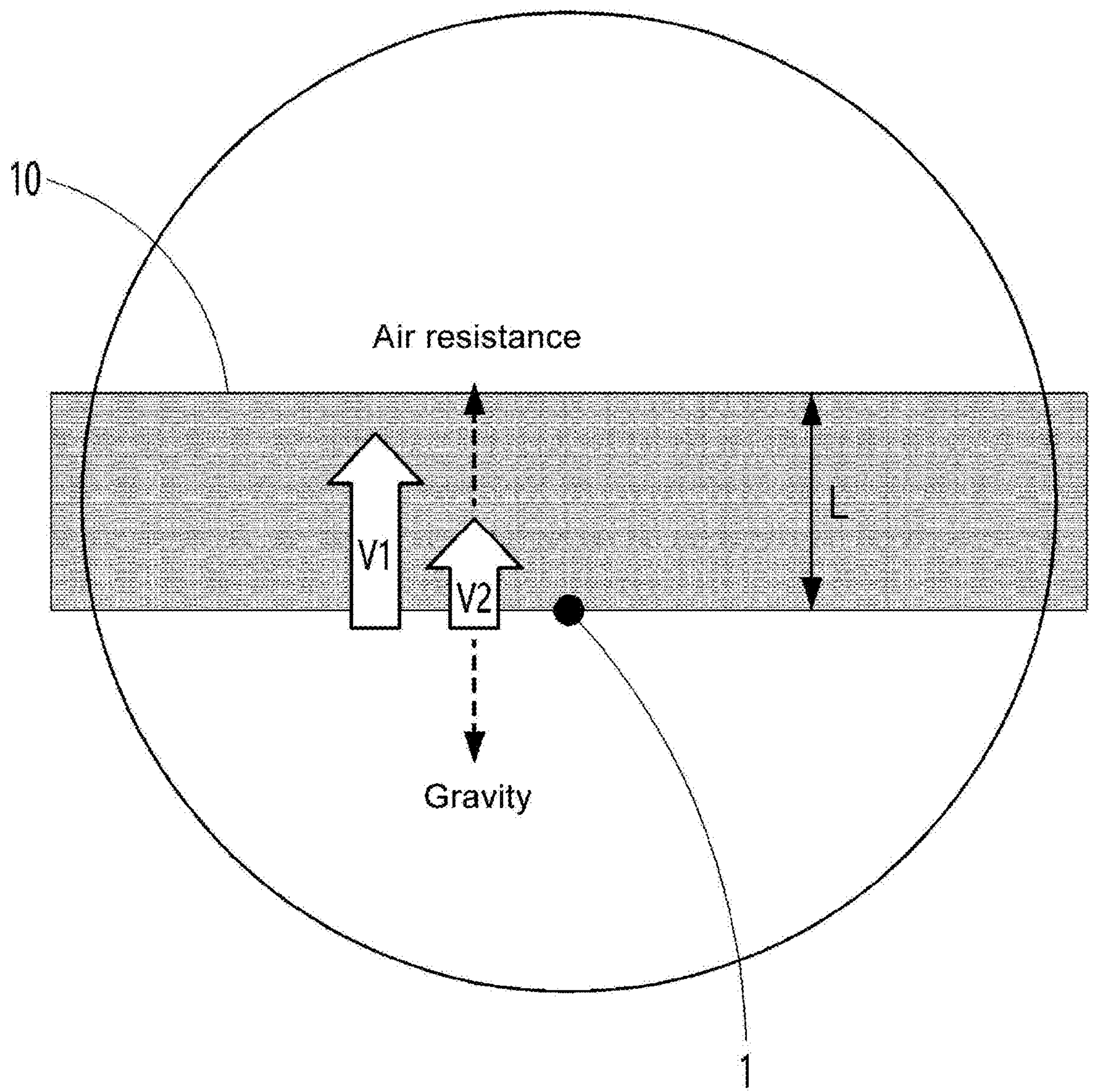


FIG. 5a

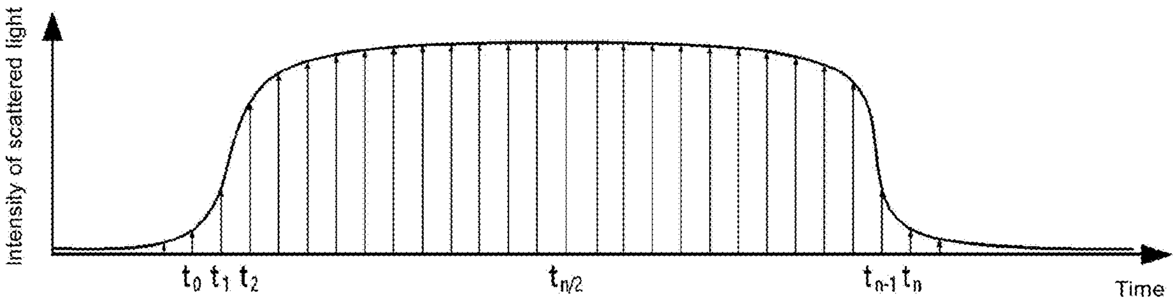


FIG. 5b

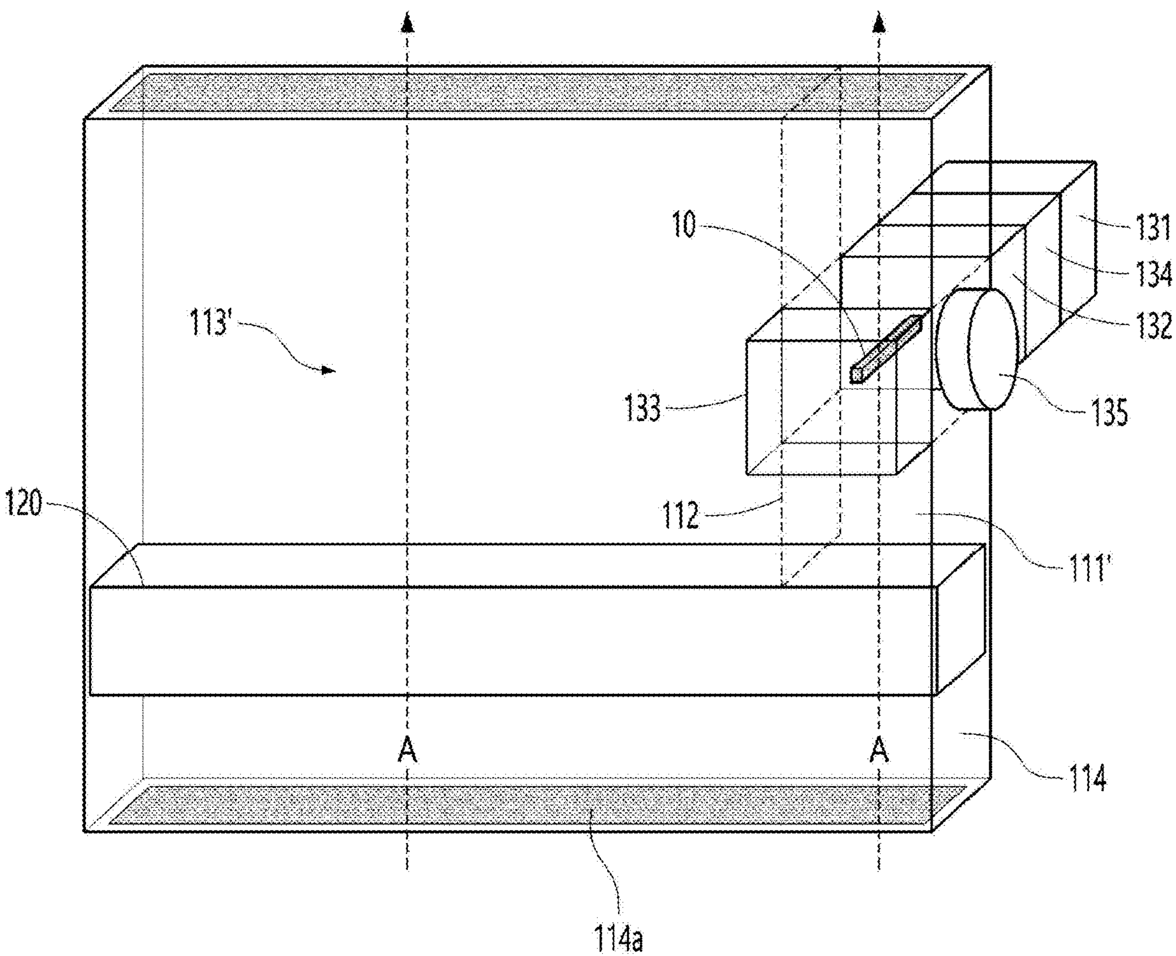


FIG. 6

AIR QUALITY MONITORING DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to Korean Patent Application No. 10-2024-0020893, filed Feb. 14, 2024 and the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to an air quality monitoring device. It concerns a device capable of measuring dust contained in the air to assess air quality.

BACKGROUND ART

[0003] Typically, light-scattering particulate matter monitoring devices are employed to measure the concentration of particulate matter, such as fine dust, in the air. These devices operate by illuminating light and detecting the scattered light to determine the concentration of particulate matter.

[0004] FIG. **1** schematically shows the configuration of a conventional particulate matter monitoring device. As depicted, in the conventional particulate matter monitoring device, the air A enters an inlet **11***a* at the top and the measured air A**1** is discharged through an outlet **11***b* at the bottom.

[0005] An air heating device **13**, an air quality measurement sensor **14**, a flow meter **15**, and a high-power air pump **16** are sequentially positioned along the path where the air A moves vertically from top to bottom.

[0006] The conventional particulate matter monitoring device introduces the air A at a constant flow rate into the inlet **11***a* using a high-power air pump **16**, whereupon the air quality measurement sensor **14** measures the concentration of particulate matter. Before measurement by the air quality measurement sensor **14**, the air heating device **13** increases the temperature of air A to decrease the relative humidity of air, thereby dehumidifying the hygroscopic particulate matter.

[0007] However, heating air A with the air heating device **13** raises the air's temperature, thereby generating buoyancy in the opposite direction of the airflow. A high-power air pump **16** is necessitated to enable air to flow against this buoyancy that is opposite to the direction of the airflow. Both the high-power air pump **16** and this buoyancy having the reverse direction against airflow significantly decrease the internal air pressure within the air passage, thereby leading to a significant expansion of air volume. This expansion of air volume can cause measurement errors for particulate matter.

[0008] The air heating device **13** generates heat, which in turn creates buoyancy and alters the airflow. However, devices that measure atmospheric pollutants such as fine dust require a steady airflow.

[0009] Furthermore, according to Bernoulli's principle, the air pressure inside the air passage decreases in proportion to the height of the passage, generating air energy upward in the opposite direction of the airflow. To compensate for this, the high-power air pump **16** requires additional power.

[0010] Moreover, the traditional methods that allow the air to flow vertically from top to bottom cause heavier dust particles to deposit on the inside of the casing **11**, thus regular cleaning is required.

[0011] Additionally, traditional light-scattering measurement devices cannot measure the mass of dust particles. They deterministically infer the density of particles and convert it to mass for concentration measurement. This method is prone to error for particulate matter such as yellow dust that has a notably high density.

DISCLOSURE

Technical Problem

[0012] The present invention introduces an air quality monitoring device that can more accurately measure the concentration of dust in the atmosphere. By illuminating air vertically flowing up from the bottom and detecting the scattered light by dust particles, this invention calculates the speed of each dust particle using the duration of light-scattering. The mass of each dust particle can be determined from the speed so this invention enables a more precise measurement of atmospheric dust concentration. This invention can measure the mass of yellow dust particles and general dust particles that have different density, thereby enabling a more accurate measurement of particulate matter concentration based on mass.

Technical Solution

[0013] According to an embodiment of the present invention, the air quality monitoring device comprises a casing with a main inlet duct formed in a straight line of a predetermined length or longer to allow atmospheric air to enter an inlet at the bottom and flow upwards; a flow meter provided at the top of the main inlet duct to measure the flow rate of the air; a laser module that emits a laser beam into the air flowing in the main inlet duct; a light sensor that measures the amount of light scattered by dust particles contained in the air; and a processor that receives measured values from the light sensor, performs continuous high-speed sampling, measures the speed of dust particles from the changes of light intensity, and derives their mass using their speed.

[0014] Additionally, the casing includes a secondary inlet duct that allows more air to be introduced from a secondary inlet placed at its bottom. The top of the secondary inlet duct is connected to the top of the main inlet duct to allow its air to be merged with the air that entered the main inlet duct.

[0015] Moreover, it includes a common inlet duct that is formed to allow air to be introduced from a common inlet at its bottom and a secondary inlet duct that is connected to both the top of the common inlet duct at its bottom and the top of the main inlet duct at its top. A portion of the air that flows out from the common inlet duct branches and flows into the main inlet duct, while the remaining portion of the air flows into the secondary inlet duct and is merged with the air flowing out from the top of the main inlet duct.

[0016] Furthermore, the cross-sectional area of the secondary inlet duct is formed to be larger than that of the main inlet duct.

[0017] The laser module includes a laser source that generates a laser beam, a lens that changes the shape and direction of the laser beam generated by the laser source, and a laser capture that confines the laser beam after the laser beam passes through the main inlet duct.

[0018] The focus depth of the laser beam emitted by the laser module is formed to be equal to or greater than the width of the main inlet duct.

[0019] Additionally, the laser module includes a rectangular laser beam shaper that changes the cross-sectional shape of the laser beam generated by the laser source into a rectangle.

[0020] The casing further includes an outlet duct formed at the bottom to allow air that passes through the main inlet duct to be discharged and a direction-changing duct that connects the top of the main inlet duct and the top of the outlet duct to change the direction of airflow.

[0021] The inlet and outlet are placed at the same height.

[0022] The device further includes an air ventilation device provided inside the casing, which creates negative air pressure to allow air to flow from the inlet to the outlet.

[0023] Moreover, the cross-sectional area of the common inlet duct is formed to be equal to or larger than the sum of the cross-sectional areas of the main inlet duct and that of the secondary inlet duct to ensure that the speed of dust particles in the main inlet duct is above a predetermined minimum speed.

[0024] Details of other embodiments are included in the detailed description and drawings.

Advantageous Effect

[0025] The air quality monitoring device according to this invention offers the following benefits:

[0026] By irradiating a laser beam into the air and measuring each speed of dust particles contained in the air using the intensity and duration of the scattered light when a dust particle scatters the laser beam, it is possible to calculate the mass of each dust particle. Consequently, this provides the advantage of being able to determine the concentration of fine or coarse dust particles more accurately than existing real-time fine dust monitoring devices that lack information on the mass of dust particles.

DESCRIPTION OF DRAWINGS

[0027] FIG. **1** is a schematic diagram showing a conventional particulate matter monitoring device.

[0028] FIG. **2** is a schematic diagram showing an air quality monitoring device according to an embodiment of the present invention.

[0029] FIG. **3** is a schematic diagram showing an air quality monitoring device according to another embodiment of the present invention.

[0030] FIG. **4** is an enlarged perspective view of the light sensor and laser beam section corresponding to part 'B' of FIG. **2**.

[0031] FIG. **5***a* is a conceptual diagram of a dust particle passing through a laser beam in the air. FIG. **5***b* is a graph showing the intensity of scattered light emitted while a dust particle passes through the laser beam over time.

[0032] FIG. **6** is an enlarged perspective view showing some of the parts around the inlet duct of an air quality monitoring device without a physical wall between the main inlet duct and the secondary inlet duct according to another embodiment of the present invention.

DESCRIPTION OF REFERENCE NUMERALS

[0033] **1**: Dust particle
[0034] **10**: Laser beam
[0035] **100**, **100'**: Air quality monitoring device
[0036] **110**, **110'**: Casing
[0037] **111**, **111'**: Main inlet duct
[0038] **111***a*: Inlet
[0039] **113**, **113'**: Secondary inlet duct
[0040] **113***a*: Secondary inlet
[0041] **114**: Common inlet duct
[0042] **114***a*: Common inlet
[0043] **116**: Direction-changing duct
[0044] **117**: Outlet duct
[0045] **117***a*: Outlet
[0046] **120**: Humidity regulator
[0047] **130**: Laser module
[0048] **131**: Laser source
[0049] **132**: Lens
[0050] **133**: Laser capture
[0051] **134**: Rectangular laser beam shaper
[0052] **135**: Light sensor
[0053] **135***a*: Measurement surface of the light sensor
[0054] **140**: Processor
[0055] **150**: Air ventilation device
[0056] **160**: Flow meter

MODE FOR INVENTION

[0057] Hereinafter, with reference to the accompanying drawings, embodiments of the present invention are described in detail so that those skilled in the art to which this invention pertains can easily implement the invention. It is understood that the invention can be implemented in various different forms and is not limited to the embodiments described herein.

[0058] It is noted that the drawings are schematic and not necessarily drawn to scale. The relative dimensions and proportions of parts in the drawings have been exaggerated or minimized for clarity and convenience and should not be considered limiting. Arbitrary dimensions are illustrative and not restrictive. Identical reference numerals are used in two or more drawings to denote similar structural elements or parts for the purpose of indicating similar features.

[0059] The embodiments of the present invention specifically illustrate ideal embodiments of the invention, and as a result, various modifications in the drawings are anticipated. Therefore, the embodiments are not limited to the specific forms shown and include, for example, variations due to manufacturing.

[0060] The objective of the present invention is to measure the mass of each dust particle, such as fine dust or coarse dust in the atmosphere, to measure the concentration of fine dust or coarse dust more accurately. The air quality monitoring device according to the present invention measures the mass of each dust particle. Since dust particles in the air experience gravitational force downward and air resistance force upward, each dust particle has a different speed depending on its weight and size, from which its mass is calculated by measuring its speed.

[0061] The air quality monitoring device according to the present invention includes a structure capable of creating a sophisticated constant slow airflow to improve the precision of measurement regardless of external interference.

[0062] Referring to FIGS. **2** to **5**, the air quality monitoring device according to the present invention is described in detail.

[0063] Firstly, the air quality monitoring device **100** according to an embodiment of the present invention includes a casing **110**, a flow meter **160**, a laser module **130**, a light sensor **135**, and a processor **140**.

[0064] The casing **110** includes an inlet **111***a* formed at the bottom and has a main inlet duct **111** formed in a straight line of a length that is equal to or longer than a predetermined length. Atmospheric air flows into the inside of the main inlet duct **111** through the inlet **111***a*. The air introduced into the main inlet duct **111** flows vertically upwards along the main inlet duct **111**. Thus, dust particles in the air experience gravitational force downward and air resistance force upward, and each particle can have a different speed based on its weight and size.

[0065] As mentioned, by having the main inlet duct **111** formed in a straight line and with a length that is a predetermined length or longer, the main inlet duct **111** allows the air to flow in a straight direction at a constant speed.

[0066] The casing **110** further includes a secondary inlet duct **113**. In this invention, the secondary inlet duct is provided in two exemplary forms, as shown in FIGS. **2** and **3**.

[0067] First, FIG. **2** shows the secondary inlet duct that is provided according to one embodiment. In this embodiment, the secondary inlet duct **113** is a predetermined distance away from the main inlet duct **111** and has a separate air passage. The secondary inlet duct **113** has a secondary inlet **113***a* at the bottom. The top of the secondary inlet duct **113** is connected to the top of the main inlet duct **111** so that the air of the main inlet duct **111** can be merged with the air of the secondary inlet duct **113**.

[0068] The secondary inlet duct **113** is formed with a secondary inlet **113***a* at the bottom. Air introduced from the secondary inlet **113***a* flows in the secondary inlet duct **113**.

[0069] The air introduced into the casing **110** always flows at a constant flow rate. However, as in this embodiment, when the air at a constant flow rate is divided between the main inlet duct **111** and the secondary inlet duct **113**, the airflow speed slows down compared to the case when air enters only the main inlet duct **111**. Thus, the secondary inlet duct **113** serves to reduce the airflow speed flowing in the main inlet duct **111**.

[0070] Especially, the cross-sectional area d**2** of the secondary inlet duct **113** can be formed to be larger than the cross-sectional area d**1** of the main inlet duct **111**. Therefore, the flow rate in the secondary inlet duct **113** is greater than that in the main inlet duct **111**, and the airflow speed flowing in the main inlet duct **111** can be further reduced.

[0071] Slowing down the airflow speed flowing in the main inlet duct **111** enhances the resolution of dust particle speed that is processed by the processor **140** with the light sensor **135**, thus dust particle speeds can be more accurately measured.

[0072] In this way, each dust particle in the main inlet duct **111** experiences gravitational force downwards and air resistance force upwards due to the air flowing upwards. Within the main inlet duct **111**, which has a length that is predetermined or longer and is formed in a straight line, an equilibrium is established for each dust particle when the air resistance force becomes equal to the gravitational force. At this point, each dust particle flows at its stable speed. Since each particle has different gravitational force and air resistance, the speed of each particle is different.

[0073] The air resistance force is determined by the particle size and the difference between the airflow speed and the dust particle speed, while the gravitational force is determined by the mass of the particle. In the equilibrium, the air resistance force is equal to the gravitational force in magnitude and opposite to the gravitational force in direction. By measuring the size and speed of particles using light-scattering technology and maintaining a constant airflow speed, the mass of each dust particle can be determined.

[0074] FIG. **3** shows the configuration of the secondary inlet duct according to another embodiment. In this variant, the main inlet duct **111'** and the secondary inlet duct **113'** do not have separate inlets. That is, air that is introduced into a common inlet **114***a* flows into both the main inlet duct **111'** and the secondary inlet duct **113'** after passing through the common inlet duct **114**.

[0075] When a constant flow rate of air is introduced into the casing **110'**, it branches and flows into both the main inlet duct **111'** and the secondary inlet duct **113'**, thus the airflow speed decreases in the main inlet duct **111'**. Thus, the secondary inlet duct **113'** functions to decrease the speed of airflow in the main inlet duct **111'**.

[0076] Specifically, the cross-sectional area d**2** of the secondary inlet duct **113'** can be made larger than the cross-sectional area d**1** of the main inlet duct **111'**. Therefore, if the flow rate of air entering the secondary inlet duct **113'** is greater than that entering the main inlet duct **111'**, the airflow speed in the main inlet duct **111'** can be further reduced.

[0077] The casing **110** further includes an outlet duct **117** and a direction-changing duct **116**. The outlet duct **117** has an outlet **117***a* at the bottom. The air within the outlet duct **117** flows downward and is discharged externally from the outlet **117***a*. The outlet **117***a*, the inlet **111***a*, the common inlet **114***a*, and the secondary inlet **113***a* can all be placed at the same height.

[0078] The direction-changing duct **116** is arranged to begin at the intersection of the tops of the main inlet duct **111**, **111'** and the secondary inlet duct **113**, **113'** and end at the intersection with the top of the outlet duct **117**. Namely, one side of the direction-changing duct **116** is connected to both the main inlet duct **111**, **111'** and the secondary inlet duct **113**, **113'** to make air passage. The other side of the direction-changing duct **116** is connected to the outlet duct **117** to make air passage.

[0079] The direction-changing duct **116** is designed to change the direction of air flowing out from the top of the main inlet duct **111**, **111'** to point towards the outlet duct **117**.

[0080] The outlet **117***a* of the outlet duct **117** is positioned at the same level as the inlet **111***a*, the common inlet **114***a*, and the secondary inlet **113***a*. In essence, the inlet **111***a*, the common inlet **114***a*, and the outlet **117***a* are located on a virtually horizontal plane.

[0081] The rationale for aligning the inlet **111***a*, the common inlet **114***a*, and the outlet **117***a* at the same height is the following considerations:

[0082] First, the heat generated by the humidity regulator **120** creates buoyancy. If the inlet **111***a*, common inlet **114***a*, and outlet **117***a* have different heights, the buoyancy at the inlet **111***a* and common inlet **114***a* differs from that at the outlet **117***a*, leading to unintended changes in flow rate. Therefore, the heights of the inlet **111***a*, the common inlet

114*a*, and the outlet **117***a* are aligned to prevent such unintended changes of flow rate.

[0083] Additionally, according to Bernoulli's principle, the height of a pipe affects the pressure inside it. If the inlet **111***a*, the common inlet **114***a*, and the outlet **117***a* have different heights, the air pressure at these points changes and results in unintended airflows. Hence, the aligned heights of the inlet **111***a*, the common inlet **114***a*, and the outlet **117***a* eliminate unintended airflows.

[0084] The main inlet ducts **111**, **111'**, secondary inlet ducts **113**, **113'**, and the outlet duct **117** are vertically formed, though slight deviations within a certain error range are acceptable. That is, they extend and generally up down nearly perpendicular to a horizontal plane.

[0085] A flow meter **160** is located inside the casing **110**. In one embodiment of the invention, as shown in FIG. **2**, the flow meter **160** is positioned at the top of the main inlet ducts **111**, **111'**, while in another embodiment, as shown in FIG. **3**, it is located in the outlet duct **117**.

[0086] Since the ratio of flow rates in the main inlet duct **111**, **111'** and the secondary inlet duct **113**, **113'** are constant, the flow rate in the main inlet duct **111**, **111'** is measurable regardless of where the flow meter **160** is located along the airflow path.

[0087] Therefore, the flow meter **160** can also be located at the direction-changing duct **116**, the main inlet ducts **111**, **111'**, the secondary inlet ducts **113**, **113'**, or the common inlet duct **114**.

[0088] The air ventilation device **150** generates negative pressure to ensure that air flows through the main inlet ducts **111**, **111'** towards the outlet duct **117**. The air ventilation device **150** can be located at the top of the main inlet ducts **111**, **111'** as shown in FIG. **2** or at the top of the outlet duct **117** as shown in FIG. **3**. Additionally, it can be placed anywhere along the airflow path, such as in the main inlet ducts **111**, **111'**, the secondary inlet ducts **113**, **113'**, the common inlet duct **114**, the direction-changing duct **116**, or the outlet duct **117**.

[0089] The flow meter **160** and air ventilation device **150** aim to maintain the airflow speed in the main inlet duct **111**, **111'** at a predetermined rate. Therefore, the processor **140** obtains instant flow rates from the flow meter **160** and adjusts the strength of the air ventilation device **150** depending on the instant flow rate to keep the flow rate at a predetermined value.

[0090] The laser module **130** emits a laser beam into the air flowing in the main inlet ducts **111**, **111'**. The laser module **130** includes a laser source **131**, a lens **132**, and a laser capture **133**. The laser source **131**, the lens **132**, and the laser capture **133** are positioned to cross the main inlet ducts **111**, **111'** perpendicularly as shown in FIGS. **2** and **3**, thus dust particles cannot deposit inside the laser module **130**.

[0091] The laser beam generated by the laser source **131** passes through the lens **132** and irradiates the main inlet ducts **111**, **111'**. The lens **132** narrows the thickness of the laser beam. The main inlet ducts **111**, **111'** are located between the lens **132** and the laser capture **133**. After the laser beam passes through the lens **132**, it irradiates the main inlet ducts **111**, **111'**. Then the laser capture **133** confines and removes the laser beam.

[0092] The air quality monitoring device **100** according to this invention emits a laser beam into the main inlet ducts **111**, **111'**, and uses the duration of light scattered by a dust particle contained in the air to calculate the speed of these particles. The accuracy of speed measurement can be improved by a sufficiently long duration of scattered light. In addition, it is required to obtain a constant precise slow airflow speed in the main inlet ducts **111**, **111'**.

[0093] For accurate measurement, the thickness of the laser beam within the main inlet ducts **111**, **111'** must remain constant. Therefore, the focus depth of the laser beam emitted by the laser module **130** should be equal to or greater than the width of the main inlet ducts **111**, **111'**. Specifically, the focus depth of the laser beam can be longer than the width of the main inlet ducts **111**, **111'**, or the width of the main inlet ducts **111**, **111'** can be shorter than the focus depth of the laser beam.

[0094] For a laser module **130** with a short focus depth, the width of the main inlet ducts **111**, **111'** needs to be narrow, then it increases the airflow speed. Thus, secondary inlet ducts **113**, **113'** are required to achieve a finely slow airflow speed.

[0095] The typical laser beam generated by the laser source **131** has a circular shape. However, the time it takes for dust particles to pass through the circular cross-section of the laser beam (the duration of scattered light) may differ between the center and the edge of the circle. To prevent this, the laser module **130** can include a rectangular laser beam shaper **134** that transforms the cross-sectional shape of the laser beam into a rectangle. Typically, the rectangular laser beam shaper **134** is placed between the laser source **131** and the lens **132**.

[0096] With the rectangular laser beam shaper **134**, the traveling distance of dust particles passing through the laser beam **10** is always constant, regardless of the distance between the dust particle and the center of the beam.

[0097] The light sensor **135** measures the amount of light that the laser beam is scattered by a dust particle contained in the air. The values measured by the light sensor **135** are transmitted to the processor **140**.

[0098] The light sensor **135** is located inside the casing **110**, specifically within the main inlet ducts **111**, **111'**, near the focal point of the laser beam **10**, thus the amount of scattered light can be measured when the laser beam is scattered by a dust particle.

[0099] FIG. **4** is an enlarged perspective view of the light sensor **135** and the laser beam **10** at the intersection corresponding to part 'B' of FIG. **2**. Generally, the sensing surface of the light sensor **135** is three-dimensionally orthogonal to two directions of the laser beam **10** and the airflow. That is, if the airflow direction is the Y-axis (opposite to gravity) and the laser beam direction is the Z-axis, then the measuring surface **135***a* of the light sensor **135** faces the X-axis.

[0100] The processor **140** performs continuous high-speed sampling of the values transmitted by the light sensor **135** and measures the size and speed of each dust particle from the temporal changes in light intensity.

[0101] The processor **140** includes an analog-to-digital converter (not shown) to perform continuous high-speed sampling. FIG. **5***a* illustrates a moment when a dust particle **1** passes through the laser beam **10** irradiated by the laser module **130**. As shown in FIG. **5***a*, the intensity of scattered light changes while the dust particle **1** moves from the lowest to the highest position within the laser beam **10**.

[0102] The analog-to-digital converter continuously and rapidly samples the output data of the light sensor **135** and stores them in the processor **140**'s memory in temporal order. These data can be represented as a graph shown in FIG. **5***b*.

[0103] As described above, the processor **140** measures the speed of a dust particle **1** from the changes of light intensity detected by the light sensor **135**. Specifically, the speed of a dust particle **1** is measured from the time t**0** and the time tn. The time t**0** is the time when the intensity of light starts to increase at the lowest position of the laser beam **10**. The time tn is the time when the increased intensity of light ends at the highest position of the laser beam **10**.

[0104] After determining the speed of the dust particle **1**, the processor **140** derives the mass or density of the dust particle **1** based on the size of the dust particle **1** and the difference in speed between the air and the dust particle **1**. The principle for deriving the mass of each dust particle **1** is as follows:

[0105] As the air in the main inlet ducts **111**, **111**' flows upwards, a dust particle **1** rises due to air resistance. However, the speed of the dust particle **1** is reduced due to downward gravity. The air resistance depends on the difference in speed between the air and the dust particle **1**. In a steady state when each dust particle **1** reaches a constant speed, the air resistance force equals gravitational force.

[0106] Using this principle, the mass of each dust particle **1** is given by Equation 1.

$$\mathrm{mg} = c(v_1 - v_2)^2 \pi r^2 \quad \text{[Equation 1]}$$

[0107] In Equation 1, m represents the mass of a dust particle, g is the Earth's gravitational acceleration, c is a constant derived from the air density and the drag coefficient of a dust particle, v**1** is the airflow speed, v**2** is the speed of a dust particle, n is the mathematical constant pi, and r is the radius of a dust particle.

[0108] The speed of a dust particle, v**2**, can be calculated using the following Equation 2.

$$v_2 = \frac{L}{t_n - t_0} \quad \text{[Equation 2]}$$

[0109] In Equation 2, tn represents the time when a dust particle is at the highest position in the laser beam area **10**. t**0** is the time when a dust particle is at the lowest position in the laser beam area **10**. L is the thickness of the laser beam **10**.

[0110] Here, the time when a dust particle is at the lowest position of the laser beam **10** refers to the time at which the intensity of scattered light begins to increase, and the time when a dust particle is at the highest position of the laser beam **10** refers to the time at which the intensity of scattered light begins to decrease. Thus, the values of tn and t**0** can be obtained from the graph shown in FIG. **5***b*.

[0111] An analog-to-digital converter (not shown in the drawings) or one integrated within the processor **140** continuously samples the analog output of the light sensor **135** at regular intervals, converting them into digital data which are then sequentially stored in the processor **140**'s memory or in a separate memory (not shown in the drawings).

[0112] At the time t**0** when a dust particle encounters the laser beam **10**, the dust particle scatters the beam and the output of the light sensor **135** increases. While the dust particle passes through the laser beam **10**, the output of the light sensor **135** remains high. At the time tn when the particle completes passing through, the output of the light sensor **135** decreases. This sampling data can be represented as a graph shown in FIG. **5***b*.

[0113] Furthermore, the processor **140** can also derive the density of a dust particle **1**, which can be obtained by Equation 3 driven from Equation 1.

$$\rho = c_2(v_1 - v_2)^2 / r \quad \text{[Equation 3]}$$

[0114] In Equation 3, ρ represents the density of a dust particle, and c**2** is a constant determined by the air density, the drag coefficient of the dust particle, and the Earth's gravitational acceleration. v**1** is the speed of the air in the main inlet duct **111**, v**2** is the speed of a dust particle, and r is the radius of the dust particle.

[0115] The air quality monitoring device **100**, **100**' according to this invention also includes a humidity regulator **120** and an air ventilation device **150**. The humidity regulator **120** removes moisture contained in the air flowing through the inlet ducts **111**, **111**' from the inlets **111***a*, **114***a*. Therefore, the humidity regulator **120** is located inside the main inlet duct **111**, **111**' or the common inlet duct **114**, positioned above the inlets **111***a*, **114***a* but below the light sensor **135**.

[0116] As air passes through the humidity regulator **120**, it is heated, and its relative humidity decreases. Although not shown in the drawings, an external temperature and humidity sensor (not shown) can alternatively be installed at the inlets **111***a*, **114***a* to measure the air's temperature and relative humidity. This external temperature and humidity sensor sends the measured temperature and relative humidity to the processor **150**.

[0117] Additionally, the humidity regulator **120** may include an internal temperature and humidity sensor (not shown) to measure the temperature and relative humidity of the heated air, which can be transmitted to the processor **140**.

[0118] Meanwhile, there can be an absence of physical wall dividing the main inlet duct and the secondary inlet duct. FIG. **6** shows a conceptual example of the air quality monitoring device without a physical wall between the main inlet duct **111**' and the secondary inlet duct **113**'.

[0119] FIG. **6** is an enlarged perspective view of the inlet duct part of another embodiment depicted in FIG. **3**, where the boundary **112** dividing the main inlet duct **111**' and the secondary inlet duct **113**' does not exist as a physical wall. The main inlet duct **111**', secondary inlet duct **113**', and common inlet duct **114** can be created without any wall between them, functionally defined as separate spaces. The common inlet duct **114** draws air from the atmosphere, and the secondary inlet duct **113**' functions to reduce the airflow speed in the main inlet duct **111**' by dividing the air from the common inlet duct **114**.

[0120] If the speed v**2** of a dust particle **1** in the main inlet duct **111**' falls below a predetermined speed, the dust particle **1** can attach to internal components such as the light sensor **135**, thereby impairing measurement performance. To solve this problem, the cross-sectional area of the common inlet duct **114** is made larger than the combined cross-sectional areas of the main inlet duct **111**' and the secondary inlet duct **113**'. This configuration ensures that the dust particle **1** in the main inlet duct **111'** maintains a speed above the predetermined (minimum) speed. This is because the airflow speed in the common inlet duct **114** is slower than in the main inlet duct **111'**. There is no dust particle **1** whose speed is below the predetermined speed in the main inlet duct **111'** because dust particle **1** whose speed will be below the predetermined speed in the main inlet duct **111'** cannot pass through the common inlet duct **114** that has a slow flow rate. The dust particle **1** above the predetermined speed rises and cannot adhere to the inside of the main inlet duct **111'** due to its speed.

[0121] FIG. **6** shows a rectangular-shaped laser beam **10**. The rectangular laser beam shaper **134** makes the shape of the cross-sectional area of the laser beam **10** in the form of a rectangle or quadrilateral. One side of this rectangle should be parallel to the direction of the air. The cross-section of the laser beam emitted from the laser source **131** forms a circle, while the rectangular laser beam shaper **134** transforms the circular laser beam into a rectangular one. The rectangular laser beam shaper **134** can be implemented using existing beam shaping technologies such as a top hat shaper. The rectangular laser beam emitted from the rectangular laser beam shaper **134** passes through the lens **132**, which narrows the thickness of the beam.

[0122] The method of creating a rectangular laser beam is not limited to the use of the rectangular laser beam shaper mentioned in this embodiment. Therefore, the rectangular laser beam shaper **134** can be placed elsewhere, and the positions of the rectangular laser beam shaper **134** and the lens **132** are interchangeable.

[0123] As described above, the air quality monitoring devices **100**, **100'** according to this invention have a structure that controls the air to flow vertically from bottom to up at a precise constant slow speed uninterrupted by external influences. Each dust particle in the air, pulled by gravity in the opposite direction of the airflow, has a different speed depending on its weight and size. The mass of each particle can be obtained by measuring the size and speed of the particle with optical and electronic technologies according to this invention.

[0124] The air quality monitoring devices **100**, **100'** as described above can calculate the concentration of fine or coarse particulate matter by measuring the number of dust particles, along with the mass and size of each particle. The concentration of fine or coarse particulate matter is defined in terms of mass per unit volume. Therefore, knowing the count, size, and mass (density) allows a for highly accurate measurement of particulate matter concentration.

[0125] In contrast to traditional light-scattering measurement devices, which estimated the concentration of particulate matter without measuring the density of particles, leading to inaccuracies. The air quality monitoring device according to this invention can measure the concentration of particulate matter precisely by knowing the count, size, and mass (density).

[0126] Furthermore, the measuring device according to this invention can also be applied to measure impurities in water. By substituting air with water and dust particles with waterborne impurities in the detailed description of this invention, it is possible to measure the size, mass, and count of each impurity in the water.

[0127] While the embodiments of the invention have been described with reference to the accompanying drawings, it is understood that those skilled in the art may realize the invention can be implemented in other specific forms without departing from the technical spirit or essential features thereof.

[0128] Therefore, the described embodiments should be considered in all respects as illustrative and not restrictive. The scope of the invention is indicated by the following claims rather than the foregoing and description, all changes or modifications derived from the meaning and scope of the claims and their equivalents should be interpreted as being included within the scope of the present invention.

What is claimed is:

1. An air quality monitoring device comprising:

A casing with a main inlet duct formed in a straight line of a predetermined length or longer to allow atmospheric air to enter an inlet at the bottom and flow upwards;

A flow meter located at the top of the main inlet duct to measure the flow rate;

A laser module that emits a laser beam into the air flowing in the main inlet duct;

A light sensor that measures the amount of light scattered by a dust particle contained in the air; and

A processor that receives the measured values from the light sensor, performs continuous high-speed sampling, estimates the speed of a dust particle from the changes in light intensity, and derives its mass or density with the speed of the dust particle.

2. The air quality monitoring device of claim **1**, wherein the casing further includes a secondary inlet duct, which is connected to the main inlet duct at its top, allows more air to be introduced to a secondary inlet formed at its bottom and merges the air of its top with the air that flows out from the main inlet duct.

3. The air quality monitoring device of claim **1**, further includes a common inlet duct formed to allow air to flow into a common inlet at its bottom; and a secondary inlet duct connected to the top of the common inlet duct at its bottom and the top of the main inlet duct at its top, wherein a portion of the air flowing out from the common inlet duct branches and flows into the main inlet duct, while the remaining portion of the air flowing out from the common inlet duct flows into the secondary inlet duct and the air flowing out from the top of the main inlet duct is merged with the air flowing out from the secondary inlet.

4. The air quality monitoring device of claim **2**, wherein the cross-sectional area of the secondary inlet duct is formed to be larger than that of the main inlet duct.

5. The air quality monitoring device of claim **1**, wherein the laser module includes:

A laser source that generates a laser beam;

A lens that changes the shape and direction of the laser beam generated by the laser source; and

A laser capture that confines the laser beam after the laser beam passes through the main inlet duct.

6. The air quality monitoring device of claim **5**, wherein the focus depth of the laser beam emitted by the laser module is formed to be equal to or greater than the width of the main inlet duct.

7. The air quality monitoring device of claim **5**, wherein the laser module further includes a rectangular laser beam shaper that changes the cross-sectional shape of the circular laser beam generated by the laser source into a rectangle.

8. The air quality monitoring device of claim **1**, wherein the casing further includes an outlet duct formed at the bottom to allow air that has passed through the main inlet duct to be discharged and a direction-changing duct that connects the top of the main inlet duct and the top of the outlet duct to change the direction of airflow.

9. The air quality monitoring device of claim **8**, wherein the inlet and the outlet are placed at the same height.

10. The air quality monitoring device of claim **8**, further includes an air ventilation device provided inside the casing, which creates negative pressure to allow air to flow from the inlet to the outlet.

11. The air quality monitoring device of claim **3**, wherein the cross-sectional area of the common inlet duct is formed to be larger than the sum of the cross-sectional areas of the main inlet duct and the secondary inlet duct to ensure that the speed of dust particles in the main inlet duct is above a predetermined minimum speed.

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