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(54) **SENSOR DEVICE FOR FLAME PRESENCE DETECTION**

(57) Sensor device (10) for detecting a flame (12), comprising: a carbon dioxide sensor (20) for detecting a CO_2 concentration; a fuel sensor (30) for detecting the combustion of a fuel; an electrostatic charge variation sensor (40) for detecting electrostatic charge variations generated by the flame (12); and a control unit (50). The control unit (50) is configured to: acquire a carbon dioxide signal (S_A) indicative of the concentration of carbon dioxide, a fuel signal (Sc) indicative of the fuel combustion, and an electrostatic charge variation signal (S_Q) indicative of a difference between the electrostatic charge variations detected by a first (40a) and a second (40b) electrode of the electrostatic charge variation sensor (40); determine a quantized signal (S_Q') based on the electrostatic charge variation signal (S_Q); determine an aggregate datum (I_A) based on the carbon dioxide signal (S_A), the fuel signal (Sc) and the electrostatic charge variation signal (S_Q); and generate, based on the aggregate datum (I_A), a flame signal (S_F) indicative of the presence or absence of the flame.

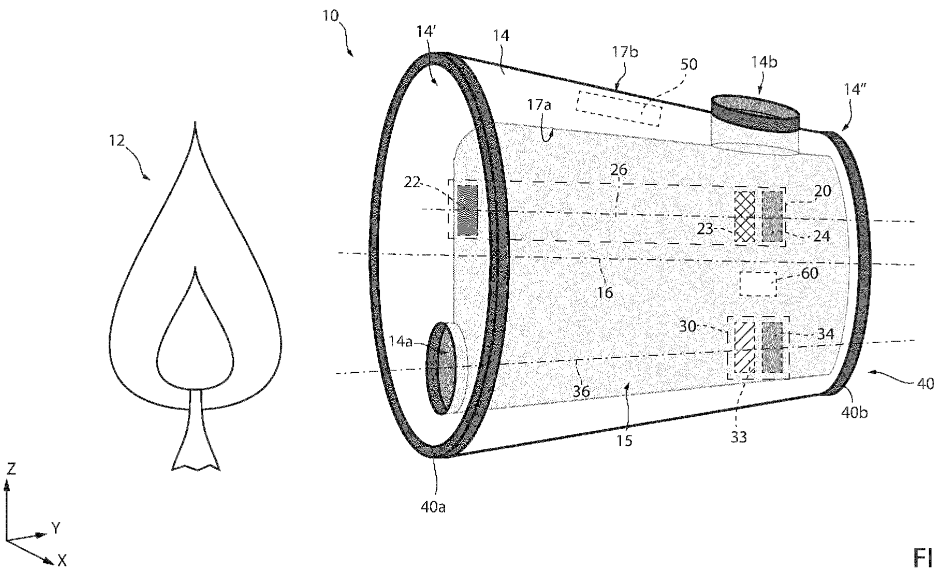

FIG. 1

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Description

THECNICAL FIELD

[0001] The present invention relates to a sensor device for flame presence detection, in particular for an ignition system. Furthermore, it relates to an ignition system comprising the sensor device, to a flame presence detection method and to a computer program product thereof.

STATE OF THE PRIOR ART

[0002] As is known, ignition systems use sparks to ignite flammable fuel-air mixtures. These sparks are usually generated electrically, for example using piezoelectric material. This ignition mode is exploited, for example, in the combustion chambers of combustion engines, as well as in kitchen hobs and gas cookers.

[0003] An important functionality for ignition systems is the possibility of shutting off the fuel supply when the flame is not lit or goes out. This avoids that, in the absence of a flame, the fuel continues to be supplied to the ignition system and is dispersed in the environment, thus risking the occurrence of accidents such as fires or bursts in the environments where the fuel is dispersed.

[0004] Furthermore, a cause of lack of flame ignition may be the degradation over time or a malfunction of a spark generator of the ignition system. The impossibility of generating a spark by the spark generator causes for example a non-start condition of the combustion engine burner and, if fuel is introduced during this non-start condition, an explosion of the same burner may potentially occur. Therefore, the spark generator may be one of the causes responsible for the lack of flame ignition.

[0005] The issue of controlling the spark generation and flame detection for the correct and safe use of the ignition system is therefore known.

[0006] In other words, performing the following activities is needed:

- shutting off the fuel supply if the flame is not detected;
- shutting off the fuel supply if the spark generator does not work correctly; and
- promptly calling for maintenance in case of malfunction of the spark generator.

[0007] Nowadays, there exist several solutions for flame detection.

[0008] For example, known solutions are based on optical detection and exploit analyses of ultraviolet radiation (UV) and infrared radiation (IR), individually or in combination with each other. Infrared sensors are the most common technique to verify the presence of a flame and use optical filters to filter the radiation to be detected as a function of the fuel used. In fact, exemplarily considering the case of domestic boilers or industrial burners which use methane as fuel, the methane-air mixture is converted through combustion into carbon dioxide and water; as a result, the optical detection at wavelengths corresponding to the presence of carbon dioxide allows to correlate an increase in the concentration of carbon dioxide molecules to the condition of igniting a flame. However, these optical approaches have detection accuracy issues mainly due to the presence of water vapor and other elements (e.g., dirt on optical filters and IR detectors) which negatively affect the measurement. Furthermore, radiation generated by heat sources other than sparks and flames (e.g., the sun, surrounding hot bodies, incandescent lamps, etc.) causes a high risk of false positives.

[0009] Another approach for flame detection is based on visible radiation sensors, i.e. on digital cameras and video processing. In this case, however, sophisticated and expensive electronics is required for real-time processing of the acquired images (in detail, for high-frequency frame grabbing) and this makes this solution acceptable only for specific applications.

[0010] Furthermore, monitoring of the spark generator activity may also be based on acoustic analysis through microphone. However, in this case a fast, high-frequency data processing is required to analyze the audio signal and classify it based on the presence or absence of the spark. However, this solution is affected by the ambient acoustic noise and therefore has poor accuracy and reliability.

[0011] Document US 2006/204911 A1 relates to an improved method and apparatus for improving the efficiency of gas appliances.

[0012] Document US 4 245 977 A relates to a method and apparatus for igniting and detecting a flame in a burner system using a combustable hydrocarbon fuel.

[0013] The aim of the present invention is to provide a sensor device for flame presence detection, an ignition system comprising the sensor device, a flame presence detection method and a computer program product thereof, which overcome the drawbacks of the prior art.

SUMMARY OF THE INVENTION

[0014] According to the present invention there are provided a sensor device for flame presence detection, an ignition system comprising the sensor device, a flame presence detection method and a computer program product thereof, as defined in the annexed claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] For a better understanding of the present invention, a preferred embodiment is now described, purely by way of non-limiting example, with reference to the attached drawings, wherein:

- Figure 1 is a schematic perspective view in ghost of a sensor device for flame presence detection, according to an embodiment;
- Figures 2 and 3 are schematic views of apparatuses

comprising an ignition system which includes the sensor device of Figure 1, according to respective embodiments;

- Figure 4 is a graph showing a known absorption spectrum of some chemical compounds, as the wavelength varies;
- Figure 5 is a graph showing a known emission spectrum of an example of fuel (in detail, methane), as the wavelength varies;
- Figures 6A-6C are graphs showing examples of respective electrical signals acquired in the absence of the flame through respective sensors of the sensor device of Figure 1, while Figures 7A-7C are graphs showing examples of the same electrical signals acquired in the presence of the flame;
- Figure 8 is a block diagram schematically showing a flame detection method, performed through the sensor device of Figure 1, according to an embodiment;
- Figures 9 and 10 are block diagrams schematically showing respective details of the detection method of Figure 8, according to an embodiment;
- Figures 11A and 11B are 3D graphs showing examples of data obtained thorough the detection method of Figure 8, respectively in case of absence and presence of the flame;
- Figures 12A-12F are graphs showing respective signals obtained through the detection method of Figure 8, according to a first exemplary sequence of ignition and shutting-off of the flame;
- Figures 13A-13F are graphs showing respective signals obtained through the detection method of Figure 8, according to a second exemplary sequence of ignition and shutting-off of the flame;
- Figure 14 is a graph showing an example of a detail of one of the signals obtained through the detection method of Figure 8; and
- Figure 15 is a block diagram which schematically shows a different embodiment of a detail of the detection method of Figure 8.

[0016] In particular, the Figures are shown with reference to a triaxial Cartesian system defined by an axis X, an axis Y and an axis Z, orthogonal to each other.

[0017] In the following description, elements common to the different embodiments have been indicated with the same reference numerals.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Figure 1 shows a sensor device 10 which, in use, allows the detection of the presence of a flame 12.

[0019] For example, and as better shown in Figures 2 and 3, the sensor device 10 is comprised in an ignition system 100 which, in use, allows the ignition of the flame 12.

[0020] By way of non-limiting example, the ignition system 100 may be used in an apparatus such as a kitchen hob, as shown in Figure 2. However, in a similar manner, the ignition system 100 may be used in an apparatus such as a combustion boiler (Figure 3, in detail in a boiler combustion chamber), a camping gas stove (not shown), etc.

[0021] As shown in Figure 2, the ignition system 100 comprises a dispensing device 102, a spark generator 104 and the sensor device 10. Furthermore, the ignition system 100 may comprise a main control unit 106 (e.g., a controller, a dedicated control unit or a vehicle control unit, VCU) which is operatively coupled (e.g., electrically, through electrical connections) to the dispensing device 102, the spark generator 104 and the sensor device 10.

[0022] The dispensing device 102 is coupeable to a fuel source (e.g., gas cylinder, petrol tank, etc.) which contains fuel to be burned to produce the flame 12. As a result, in use the dispensing device 102 receives the fuel from the fuel source.

[0023] The dispensing device 102 is further controllable, for example by the main control unit 106, to dispense the fuel received from the fuel source. For example, the fuel may be dispensed at the stove of the kitchen hob or in the boiler combustion chamber, or in any case, in the place where the flame 12 is to be generated.

[0024] The spark generator 104 is controllable, for example by the main control unit 106, to generate a spark for igniting the fuel, giving rise to the flame 12. For example, the spark generator 104 comprises an electronic spark generator or a piezoelectric element which, when mechanically compressed, generates an electric discharge in the air and therefore a spark.

[0025] For this purpose, the spark generator 104 is coupled to the dispensing device 102 in such a way as to produce the flame 12 when the spark is generated at the fuel dispensed by the dispensing device 102. In other words, and in a per se known manner, the ignition system 100 is designed in such a way that the spark generator 104 and the dispensing device 102 are sufficiently close to each other so that the spark generated by the spark generator 104 triggers the ignition of the fuel coming from the dispensing device 102.

[0026] Furthermore, the sensor device 10 is operatively coupled to the dispensing device 102 and to the spark generator 104 so as to detect the presence of the flame 12 generated thereby. In other words, the sensor device 10 is arranged in proximity to the dispensing device 102 and to the spark generator 104, at a distance such as to allow the sensor device 10 to receive the ionized air from the combustion and therefore to detect the flame 12 (e.g., a few mm or cm from where the flame 12 develops).

[0027] In detail, in use the main control unit 106 receives from the sensor device 10 a flame signal S_F, indicative of the presence or absence of the flame 12 and better described hereinbelow and controls the dispensing device 102 as a function the flame signal S_F, in such a way as to prevent fuel dispensing if the flame signal S_F is indicative of the absence of the flame 12.

[0028] In other words, the main control unit 106 blocks the flow of fuel dispensed by the dispensing device 102 when the sensor device 10 detects no flame 12, thereby preventing an accumulation of unburned fuel which may lead to uncontrolled bursts and fires. Considering the exemplary case of the combustion boiler, the main control unit 106 prevents that, in the absence of a flame 12 which consumes the fuel, the combustion chamber is filled with fuel beyond the allowed limit to the point that, when a spark is actually generated, the combustion in the combustion chamber is violent and uncontrolled and leads to damaging the boiler. Similarly, in the case of the hob, the main control unit 106 prevents the air in the kitchen from saturating with fuel, thus avoiding the risk of explosions and fires in the house.

[0029] With reference again to Figure 1, the structure of the sensor device 10 is now described.

[0030] The sensor device 10 comprises: a carbon dioxide sensor 20 configured to detect a concentration of carbon dioxide in the air, generated by the flame 12; a fuel sensor 30 configured to detect the presence of fuel combustion; an electrostatic charge variation sensor 40 including a first and a second electrode 40a and 40b spaced from each other and configured to detect respective electrostatic charge variations generated by the flame 12; and a control unit 50 which is operatively coupled (e.g., electrically coupled, for example through respective electrical connections) to the carbon dioxide sensor 20, the fuel sensor 30 and the electrostatic charge variation sensor 40, and is configured to implement, in use, a detection method 200 for detecting the flame 12, better described hereinbelow.

[0031] In particular, the sensor device 10 comprises a tubular body 14 which has an inlet opening 14a and an outlet opening 14b. The openings 14a, 14b are fluidically coupled to each other through a fluidic channel 15 of the tubular body 14, which extends through the tubular body 14 and which defines a fluidic path between the inlet opening 14a and the outlet opening 14b. For example, the inlet opening 14a has a distance from the flame 12 which is smaller than the respective distance of the outlet opening 14b from the flame 12.

[0032] In greater detail, the tubular body 14 (e.g., of cylindrical shape) has a first end 14' and a second end 14" opposite to each other along a longitudinal axis 16 of the tubular body 14. For example, the tubular body 14 has a main extension along the longitudinal axis 16, so that the fluidic channel 15 extends mainly along the longitudinal axis 16 (exemplarily shown in Figure 1 as parallel to the axis Y). In use, the first end 14' faces the flame 12 and the second end 14" extends on the opposite side of the tubular body 14 with respect to the flame 12. For example, the inlet opening 14a may extend at the first end 14' while the outlet opening 14b may extend at the second end 14".

[0033] Orthogonally to the longitudinal axis 16 (therefore parallel to a plane XZ defined by the axes X and Z), the tubular body 14 may have an annular section which, by way of non-limiting example, has a circular shape. Nevertheless, other shapes may similarly be chosen, for example a triangular, square, etc. shape.

[0034] In detail, the tubular body 14 has an internal surface 17a, facing the fluidic channel 15 and delimiting the latter, and an external surface 17b facing towards an environment external to the tubular body 14.

[0035] The fluidic channel 15 is in fluidic communication with the external environment and therefore with the flame 12, if any. In other words, the air present in the fluidic channel 15 is indicative of the presence or absence of the flame 12. In fact, when the flame 12 is present which heats the surrounding air causing convective motions therein, the fluidic channel 15 is flown through by an air flow which is due to the flame 12 and which transfers from the inlet opening 14a to the outlet opening 14b. This air flow is heated by the flame 12 and comprises both gases which are indicative of the presence of combustion (in detail, carbon dioxide generated by combustion and unburned fuel) and ionized particles which cause electrostatic charge variations.

[0036] The control unit 50, the carbon dioxide sensor 20, the fuel sensor 30 and the electrostatic charge variation sensor 40 are accommodated in the tubular body 14, for example they are carried thereby and are fixed thereto.

[0037] In detail, the carbon dioxide sensor 20 and the fuel sensor 30 extend at least partially into the fluidic channel 15, so as to acquire information on the air present in the fluidic channel 15.

[0038] In use, the carbon dioxide sensor 20 detects the concentration of carbon dioxide in the air by measuring the absorption of light radiation at a carbon dioxide optical absorption wavelength (equal to about 4.3 um) . Carbon dioxide is a common product of any combustion, therefore the concentration of carbon dioxide in the air may be indicative of the presence of the flame 12.

[0039] In greater detail, the carbon dioxide sensor 20 comprises a light radiation emitter 22, a carbon dioxide optical filter 23 and a carbon dioxide detector 24, which are aligned in succession to each other along a carbon dioxide alignment axis 26 extending through the fluidic channel 15 and exemplarily shown as parallel to the axis Y.

[0040] The light radiation emitter 22 comprises, for example, a light-emitting diode (LED) and in use emits light radiation. In detail, the light radiation emitted by the light radiation emitter 22 has a wavelength comprised between about 2 um and about 15 um, so as to cover the carbon dioxide optical absorption wavelength.

[0041] In greater detail, the light radiation emitter 22 faces the fluidic channel 15 and is controlled in use by the control unit 50 to emit the light radiation through the fluidic channel 15.

[0042] The carbon dioxide optical filter 23 is an optical filter, in particular a band-pass filter (in detail, a narrowband filter) and designed in such a way as to transmit the light radiation with a wavelength comprised in a carbon dioxide wavelength range (which comprises the carbon dioxide absorption wavelength at about 4.3 μm) and to block the light radiation with a wavelength not comprised in the carbon dioxide wavelength range. For example, the bandwidth at half of the transmission peak is equal to about 5% of the carbon dioxide wavelength, therefore it is equal to about 0.2 um (e.g., the carbon dioxide optical filter 23 has a lower cut-off frequency equal to about 4.175 um and a upper cut-off frequency equal to about 5.512 um). As a result, in use the carbon dioxide optical filter 23 is transparent to the light radiation emitted by the light radiation emitter 22 and with a wavelength equal to about the carbon dioxide absorption wavelength, while blocking the remaining part of the light radiation spectrum.

[0043] The carbon dioxide detector 24 is an optical detector, in particular sensitive to infrared radiation (IR) and for example of MEMS type.

[0044] For example, the carbon dioxide detector 24 is a thermal MOS (TMOS) transistor. The TMOS transistor is a known field effect transistor device and typically used in sensor applications to determine the amount of infrared radiation (IR) emitted by an object or a body under examination. The IR radiation emitted, received by the TMOS transistor, causes the generation of charge carriers in the conductive channel of the TMOS transistor and, therefore, a variation of the output current of the latter. Greater details regarding the TMOS transistor may be found for example in the document EP3689816 of the present Applicant.

[0045] The carbon dioxide detector 24 is arranged at a distance from the light radiation emitter 22. In particular, the carbon dioxide detector 24 may extend on the opposite side of the fluidic channel 15 with respect to the light radiation emitter 22, along the carbon dioxide alignment axis 26, so as to maximize the optical path of the light radiation between the light radiation emitter 22 and the carbon dioxide detector 24 and therefore to maximize the optical absorption by the carbon dioxide of the light radiation at the carbon dioxide absorption wavelength.

[0046] The carbon dioxide optical filter 23 faces the fluidic channel 15 and is interposed, along the carbon dioxide alignment axis 26, between the light radiation emitter 22 and the carbon dioxide detector 24. In detail, the carbon dioxide optical filter 23 is arranged at the carbon dioxide detector 24, for example it is closer to the latter than to the light radiation emitter 22.

[0047] As a result, the carbon dioxide detector 24 detects in use the light radiation emitted by the light radiation emitter 22 and filtered by the carbon dioxide optical filter 23 and generates a carbon dioxide signal S_A (an electrical signal, for example a digital signal) indicative of the concentration of carbon dioxide in the fluidic channel 15.

[0048] In particular, generating the carbon dioxide signal S_A starting from the light radiation impinging on the carbon dioxide detector 24 occurs in a per se known manner. For example, the concentration of carbon dioxide may be calculated as a function of the light radiation absorption intensity at the carbon dioxide absorption wavelength (given by the ratio between the light radiation intensity measured by the carbon dioxide detector 24 and the total intensity of light radiation provided by the light radiation emitter 22, at the carbon dioxide absorption wavelength) and as a function of a relative distance (known as decided during the design step) between the light radiation emitter 22 and the carbon dioxide detector 24 (e.g., using the well-known Beer-Lambert law). By way of example, Figure 4 shows the light radiation absorption spectrum as the gas to be detected varies and, in particular, shows that carbon dioxide has an absorption peak at about 4.3 um.

[0049] In use, the fuel sensor 30 detects the fuel combustion. This occurs by measuring the emission spectrum of the flame 12, and in particular by analyzing the emission of the flame 12 at an optical emission wavelength identifying the fuel used. In fact, the fuel combustion generates an optical emission spectrum which identifies the fuel used (i.e. it has one or more emission peaks at respective wavelengths which are specific for each fuel). As a result, detecting an absorption peak at the optical emission wavelength of interest for the fuel used entails detecting that the combustion of the fuel is in progress, and therefore allows the presence of the flame to be deduced.

[0050] In the following, reference is exemplarily made to the case in which the fuel is methane (CH_4), with a fuel emission wavelength equal to about 3.3 um; however, other fuels may be similarly considered (e.g., LPG with a fuel emission wavelength comprised between about 400 μm and about 440 um, or hydrogen) and the fuel sensor 30 may be modified accordingly (e.g., so as to emit and detect ultraviolet radiation in the case of LPG). Nonetheless, these values are exemplary and may vary, as known to the person skilled in the art, as a function of different environmental factors and conditions; greater details in this regard may for example be found in the document "Infrared Emission Spectra of Flames", by Earle K. Plyler et al, 1948.

[0051] In detail, the fuel sensor 30 comprises a fuel optical filter 33 and a fuel detector 34.

[0052] The inlet opening 14a, the fuel optical filter 33, and the fuel detector 34 are aligned in succession to each other along a fuel alignment axis 36 extending through the fluidic channel 15 and exemplarily shown as parallel to the axis Y and to the carbon dioxide alignment axis 26. In this manner, the radiation emitted by the flame 12 arrives at the fuel detector 34 first traversing the inlet opening 14a and then the fuel optical filter 33.

[0053] The fuel optical filter 33 is an optical filter, in particular a band-pass filter and designed in such a way as to transmit the light radiation with a wavelength comprised in a fuel wavelength range (which comprises the emission wavelength characteristic of the fuel, hereinafter also referred to as fuel emission wavelength) and to block the light radiation with a wavelength not comprised in the fuel wavelength range. For example, the fuel wavelength range is comprised between about 2.84 um and about 3.55 um and therefore the fuel optical filter 33 is a narrow-band filter and is centered at about 3.3 um. As a result, in use the fuel optical filter 33 is transparent to the light radiation emitted by the flame 12 and with a wavelength equal to about the fuel emission wavelength, while blocking the remaining part of the spectrum of the radiation emitted by the flame 12.

[0054] The fuel detector 34 is an optical detector, in particular sensitive to infrared radiation (IR) and for example of MEMS type. For example, the fuel detector 34 is a TMOS transistor.

[0055] The fuel detector 34 is arranged at a distance from the inlet opening 14a. In particular, the fuel detector 34 may extend on the opposite side of the fluidic channel 15 with respect to the inlet opening 14a, along the fuel alignment axis 36.

[0056] The fuel optical filter 33 faces the fluidic channel 15 and is interposed, along the fuel alignment axis 36, between the inlet opening 14a and the fuel detector 34. In detail, the fuel optical filter 33 is arranged at the fuel detector 34, for example it is closer to the latter than to the inlet opening 14a.

[0057] As a result, the fuel detector 34 detects in use the emission spectrum of the radiation emitted by the flame 12 and filtered by the fuel optical filter 33 and generates a fuel signal S_C (an electrical signal, for example a digital signal) indicative of the presence of the combustion. For example, the fuel signal Sc assumes at each instant a respective value corresponding to the amplitude at that instant of the emission peak characteristic of fuel combustion, which is substantially proportional to the amount of fuel burned and, as a result, is proportional to the intensity of the flame 12 at that instant.

[0058] In particular, generating the fuel signal Sc starting from the radiation impinging on the fuel detector 34 occurs in a per se known manner. For example, the fuel concentration may be calculated as a function of the measured emission intensity of the radiation emitted by the flame 12 at the fuel emission wavelength. By way of example, Figure 5 shows the emission spectrum of the radiation generated by the flame 12 when the fuel used is methane (with a main absorption peak at about 3.3 um).

[0059] In use, the electrostatic charge variation sensor 40 detects environmental electrostatic charge variations indicative of the flame 12 as they are caused by the presence in the air of particles which have been ionized by the combustion which generates the flame 12.

[0060] In detail, the first electrode 40a of the electrostatic charge variation sensor 40 extends at the first end 14' of the tubular body 14 and the second electrode 40b of the electrostatic charge variation sensor 40 extends at the second end 14" of the tubular body 14, so as to maximize the relative distance between the electrodes 40a and 40b and therefore so as to maximize the difference of electrostatic charge variations detected by the electrodes 40a and 40b.

[0061] In detail, each electrode 40a, 40b may have a metal surface or be of a totally metal material coated with a dielectric material, or still have a metal surface arranged under an external case of the tubular body 14. In any case, during use, each electrode 40a, 40b is electrostatically coupled to the environment wherein the sensor device 10 and the flame 12 are present, in order to detect the electrostatic charge variation induced by the fuel combustion.

[0062] According to one embodiment, each electrode 40a, 40b is a metal element carried by the tubular body 14. Optionally, when a possible use of the sensor device 10 in a humid environment is envisaged, each electrode 40a, 40b is inserted inside a waterproof case or in any case it is shielded by means of one or more protective layers, thereby preventing a direct contact of the electrode 40a, 40b with water or humidity: in this case, the waterproof case or the one or more protective layers are of a material (e.g., dielectric material, such as plastic material) such as not to shield the electrostatic charge generated by the flame 12, which is to be acquired by the electrode 40a, 40b. Other embodiments are possible, as evident to the person skilled in the art, so that the electrodes 40a, 40b are electrostatically coupled to the flame 12 during use.

[0063] In use, each electrode 40a, 40b detects a respective electrostatic charge variation caused by the combustion which originates the flame 12, and generates a respective detection signal S_R indicative of said electrostatic charge variation.

[0064] Furthermore, the electrostatic charge variation sensor 40 generates at output an electrostatic charge variation signal S_Q (an electrical signal, for example a digital signal) indicative of a difference between the electrostatic charge variations detected by the first and the second electrodes 40a, 40b. In detail, the electrostatic charge variation signal S_Q is a function of the mutual difference of the detection signals S_R measured by the electrodes 40a, 40b. For example, and in a manner not shown, the electrostatic charge variation sensor 40 may comprise an analog subtractor (e.g., a differential amplifier) or a sensor control unit to calculate the difference of the detection signals S_R measured by the electrodes 40a, 40b.

[0065] For illustrative purposes, Figures 6A-6C show respectively examples of the fuel signal Sc, the electrostatic charge variation signal S_Q and the carbon dioxide signal S_A, which have been acquired in the absence of the flame 12. As may be noted, in the absence of the flame 12 the fuel signal S_C is substantially null, the electrostatic charge variation signal S_Q is substantially equal to a baseline value (e.g., due to background noise or electrostatic disturbances present in the environment and also indicated hereinafter with the reference B) and the carbon dioxide signal S_A is substantially equal to a respective baseline value (e.g., due to the concentration of carbon dioxide naturally present in the air).

[0066] On the other hand, Figures 7A-7C show respectively examples of the fuel signal Sc, the electrostatic charge variation signal S_Q and the carbon dioxide signal

S_A, which have been acquired in the presence of the flame 12 (in particular, the flame 12 is present in the time interval $t_1 \leq t \leq t_2$ and is absent in the remaining part of the time period shown) . As may be noted, in the presence of the flame 12: the fuel signal S_C goes from a first value, substantially zero, to a second value, greater than the first value (e.g., greater than about four orders of magnitude and dependent on the flow of fuel dispensed by the dispensing device 102) and oscillates around this second value; the electrostatic charge variation signal S_Q has significant oscillations around the baseline value (e.g., with oscillation peaks which have an amplitude, relative to the baseline, equal for example to three or four times the baseline value); and the carbon dioxide signal S_A has an evident growth over time with respect to the baseline value (e.g., substantially linear growth due to the increase in the concentration, in the air, of carbon dioxide generated by the combustion of the flame 12) .

[0067] In a manner not shown, the control unit 50 (such as a microprocessor, a microcontroller or a dedicated calculation unit) may comprise, coupled to each other, a data storage unit (such as a memory, e.g. a non-volatile memory) for storing the acquired data, and a processing unit for processing the acquired data. For example, the control unit 50 is integrated into the tubular body 14.

[0068] In use, the control unit 50 implements the detection method 200 of the presence of the flame 12.

[0069] An embodiment of the detection method 200 is shown in Figure 8 and is now discussed.

[0070] In detail, the detection method 200 is performed iteratively, so as to update the information on the presence or absence of the flame 12 in real time. For the sake of simplicity, an iteration of the detection method 200, hereinafter referred to as current iteration and also indicated with the reference k, is described hereinbelow.

[0071] At a step S05 of the detection method 200, the carbon dioxide signal S_A is acquired through the carbon dioxide sensor 20, as previously described.

[0072] At a step S10 of the detection method 200, the fuel signal S_C is acquired through the fuel sensor 30, as previously described.

[0073] At a step S15 of the detection method 200, the electrostatic charge variation signal S_Q is acquired through the electrostatic charge variation sensor 40, as previously described. In particular, the electrostatic charge variation signal S_Q is generated by the electrostatic charge variation sensor 40, for example by acquiring the detection signals S_R through the electrodes 40a, 40b, calculating a difference between the detection signals S_R and optionally digitizing, filtering and/or amplifying the signal thus obtained.

[0074] Steps S05-S15 may be performed in succession to each other or in parallel to each other.

[0075] In particular, the signals S_A, S_C and S_Q are acquired through respective scrolling buffers. In detail, at each iteration the signals S_A, S_C and S_Q are acquired in a time window for example having a predefined duration equal to a time window period (for example equal to a few seconds). In other words, at each iteration the signals S_A, S_C and S_Q are considered with a time duration equal to the time window period and therefore each comprising the last sample acquired (i.e. the sample acquired at the current iteration, hereinafter also referred to as current sample) and a plurality N of samples preceding the current sample. At each iteration, the oldest sample of each signal S_A, S_C and S_Q is discarded and a new sample of each signal S_A, S_C and S_Q is stored in the respective buffer.

[0076] At a step S20 consecutive to step S15, a quantized signal S_Q' is determined by processing the electrostatic charge variation signal S_Q.

[0077] In particular, the quantized signal S_Q' is substantially a filtered version of the electrostatic charge variation signal S_Q, wherein the strong oscillations that identify the electrostatic charge variation signal S_Q are not present.

[0078] One embodiment of determining the quantized signal S_Q' is better described with reference to Figure 9.

[0079] In detail and as shown in Figure 9, at a sub-step S20A of step S20, the baseline B of the electrostatic charge variation signal S_Q is calculated.

[0080] At a sub-step S20B consecutive to sub-step S20A, the baseline B is subtracted from the electrostatic charge variation signal S_Q to calculate a variability signal Sv, which contains an information content on the flame 12 present in the oscillations of the electrostatic charge variation signal S_Q around the baseline B without however depending on the same baseline B anymore.

[0081] At a sub-step S20C consecutive to sub-step S20B, a normalized signal S_N is determined through a comparison (in detail, a punctual comparison) of the variability signal Sv with a charge variation threshold value. The normalized signal S_N is a binary signal and allows the variability of the oscillations of the variability signal Sv to be reduced to a variation between only two values. In detail, at each time instant the normalized signal S_N assumes a first value (e.g., 0) if the corresponding value of the variability signal Sv is lower than the charge variation threshold value, or it assumes a second value (e.g., 1) if the corresponding value of the variability signal Sv is greater than, or equal to, the charge variation threshold value. In particular, the charge variation threshold value is chosen heuristically as a function of the trade-off between maximum sensitivity to electrostatic charge variations (which requires a minimum charge variation threshold value) and minimum influence on the background noise measurement (which requires a maximum charge variation threshold value). By way of non-limiting example, the charge variation threshold value is equal to the multiplication of the background noise (or noise level, NL) by a multiplication factor, for example equal to about 5 times. As a result, at sub-step S20C the background noise of the variability signal Sv is calculated, the charge variation threshold value is calculated, the variability signal Sv is compared with the charge variation threshold value and the value of the variability signal S_V

as a function of this comparison is determined at each instant.

[0082] At a sub-step S20D consecutive to sub-step S20C, a clustering interval $S_{N,k}$ of the normalized signal S_N is determined, corresponding to the current iteration k and therefore to the current time instant t_k. The clustering interval $S_{N,k}$ is a portion of the normalized signal S_N, obtained through buffering on M samples (values) of the normalized signal S_N. In detail, the clustering interval $S_{N,k}$ comprises the value of the normalized signal S_N corresponding to the time instant considered (i.e. to the current time instant t_k of the current iteration k) and a predefined plurality M' of values of the normalized signal S_N corresponding to a respective plurality M' of time instants preceding (in detail, immediately preceding) the time instant considered. In other words, the clustering interval $S_{N,k}$ comprises the M values of the normalized signal S_N in the time period $t_{k-M'}\leq t\leq t_k$, with M=M'+1.

[0083] At a sub-step S20E consecutive to sub-step S20D, it is determined which value of the normalized signal S_N, between the first value (e.g., 0) and the second value (e.g., 1), has the greatest number of occurrences in the clustering interval $S_{N,k}$ considered and corresponding to the current iteration k. In other words, the numbers of occurrences of 0 and 1 in the clustering interval $S_{N,k}$ are calculated and it is determined which of the two values has a greater occurrence.

[0084] At a sub-step S20F consecutive to sub-step S20E, the quantized signal S_Q' is generated in such a way that, at each time instant, the quantized signal S_Q' assumes a respective first value (e.g., 0) if the value of the normalized signal S_N with the greatest occurrence in the clustering interval $S_{N,k}$ considered is the first value (e.g., 0), or assumes a respective second value (e.g., 1) if the value of the normalized signal S_N with the greatest occurrence in the clustering interval $S_{N,k}$ considered is the second value (e.g., 1). In other words, considering the current iteration k, if the clustering interval $S_{N,k}$ has more 0s than 1s, the value of the quantized signal S_Q' at the current time instant t_k is set equal to 0.

[0085] In this manner a rejection of the values of the normalized signal S_N may be obtained which are insulated over time and are generated for example by noise in the measurement, allowing greater accuracy in the detection of the flame 12 at the expense of a greater latency in the detection (for example, in the transition from lit to extinguished flame the quantized signal S_Q' shows a delay in the change of value with respect to the real situation which is due to the buffering performed at step S20D) .

[0086] As a result, the number M of samples present in the clustering interval $S_{N,k}$ is heuristically chosen as a function of the trade-off between maximum rejection of the insulated values (i.e. false positives or false negatives) of the normalized signal S_N (which requires a maximum number M of samples) and minimum latency in the transition from one value to another of the quantized signal S_Q' (which requires a minimum number M of samples) . By way of non-limiting example, the number M is equal to a few tens or hundreds of samples.

[0087] With reference again to Figure 8, at a step S25 consecutive to step S20, an aggregate datum I_A indicative of the aggregation of the carbon dioxide signal S_A, the fuel signal Sc and the electrostatic charge variation signal S_Q is determined. In particular, the aggregate datum I_A is a function of the carbon dioxide signal S_A, the fuel signal Sc and the electrostatic charge variation signal S_Q.

[0088] In greater detail, the aggregate datum I_A is defined, at each time instant, through a respective set of aggregate datum points (indicated by $I_{A,k}$ with reference to the current iteration k). In other words, each set of aggregate datum points $I_{A,k}$ is associated with a respective time instant.

[0089] The set of aggregate datum points $I_{A,k}$ of the current iteration k comprises a plurality P of aggregate datum points $I_{A,k}$. Each aggregate datum point $I_{A,k}$ is defined by a respective value of the carbon dioxide signal S_A, a respective value of the fuel signal Sc and a respective value of the electrostatic charge variation signal S_Q, taken at a respective time instant (different for each aggregate datum point $I_{A,k}$ of the set). These values of the signals S_A, Sc and S_Q which form the aggregate datum point $I_{A,k}$ of the current iteration k are the values of the signals S_A, Sc and S_Q corresponding to a time instant which may be the time instant t_k of the current iteration k considered or a time instant among a plurality P' of time instants preceding (in detail, immediately preceding) the time instant t_k of the current iteration k considered. More in detail, since each aggregate datum point $I_{A,k}$ corresponds to a respective time instant, the set of aggregate datum points $I_{A,k}$ of the current iteration k is indicative of portions of the carbon dioxide signal S_A, the fuel signal S_C and the electrostatic charge variation signal S_Q comprised in the time period $t_{k-P'}\leq t\leq t_k$, with P=P'+1. In other words, these portions of the signals S_A, S_C and S_Q corresponding to the set of aggregate datum points $I_{A,k}$ are temporally defined by the time instant t_k of the current iteration k (corresponding to the set of aggregate datum points $I_{A,k}$ considered) and by said plurality P' of time instants preceding the time instant t_k.

[0090] Each aggregate datum point $I_{A,k}$ therefore comprises three values and as a result is associable with a point in a three-dimensional space defined by three axes corresponding respectively to the carbon dioxide signal S_A, the fuel signal S_C and the electrostatic charge variation signal S_Q. In view of this, the set of aggregate datum points $I_{A,k}$ may be graphically represented as a cluster of points in this 3D space. Examples of these 3D graphs are shown in Figures 11A and 11B, better described hereinbelow and corresponding respectively to the case of absence and presence of the flame 12.

[0091] Furthermore, since each set of aggregate datum points $I_{A,k}$ corresponds to a respective iteration and therefore to a respective time instant considered, the variations over time of the signals S_A, S_C and S_Q are graphically displayable as a video wherein each frame coincides with the 3D graph of a respective set of aggregate datum points $I_{A,k}$. In detail, two consecutive frames differ from each other by only one aggregate datum point $I_{A,k}$ (as in the transition between the two frames the oldest sample of the first frame is discarded and the sample acquired at the time instant of the second frame is added).

[0092] At a step S30 consecutive to step S25, the flame signal S_F, indicative of the presence or absence of the flame 12, is generated, as a function of the aggregate datum I_A.

[0093] In particular, generating the flame signal S_F is better described with reference to Figure 10 and is exemplarily discussed for the sole current iteration k (i.e. for generating a sole value of the flame signal S_F, corresponding to the time instant t_k).

[0094] Furthermore, generating the flame signal S_F is described herein also with reference to Figures 11A and 11B, which show in the 3D space respective sets of aggregate datum points $I_{A,k}$. In detail, the 3D space of Figures 11A and 11B is defined with reference to a triaxial Cartesian system wherein the axes are orthogonal to each other and correspond to the signals S_A, S_C and S_Q. For purposes of greater illustrative clarity, the signals S_A, S_C and S_Q on the axes of the 3D space are normalized so as to vary each between 0 and 1 (for example, this is obtained by considering, for each axis, the maximum value and the minimum value measurable for the respective signal and adapting the scale on the axis accordingly); however, other forms of representation are possible (e.g., each axis varies between the minimum and maximum measurable values for the respective signal).

[0095] In detail and as shown in Figure 10, at a sub-step S30A of step S30, a centroid C of the set of aggregate datum points $I_{A,k}$ of the current iteration k is calculated. In other words, a barycenter of the aggregate datum points $I_{A,k}$ of the set considered is calculated in 3D space. Centroid C is shown in Figures 11A and 11B. In particular, the set of aggregate datum points $I_{A,k}$ of Figure 11A is a reference set which corresponds with certainty to the case in which the flame 12 is absent (i.e. it is determined in a preliminary calibration step for example, making sure that there is no active combustion); in view of this, the centroid C of Figure 11A is a useful reference point in the following analysis (e.g., it may correspond to the origin of the axes of the 3D space), and therefore hereinafter it is referred to as reference centroid and is indicated with the reference C_{ref}.

[0096] At a sub-step S30B consecutive to sub-step S30A, a distance (or centroidal distance) D_C of the centroid C from the reference centroid C_{ref} is calculated. For example, the distance D_C is shown in Figure 11B, while it is null in the case of Figure 11A.

[0097] At a sub-step S30C consecutive to sub-step S30B, the distance D_C is compared with a threshold distance D_T.

[0098] At a sub-step S30D consecutive to sub-step S30C, the value of the flame signal S_F corresponding to the current time instant t_k is assigned. In particular, the flame signal S_F assumes, at the current iteration k, a respective first value (e.g., 0) if the distance D_C is smaller than the threshold distance D_T, or assumes a respective second value (e.g., 1) if the distance D_C is greater than, or equal to, the threshold distance D_T. In particular, the first value of the flame signal S_F is indicative of the absence of the flame 12 and the second value of the flame signal S_F is indicative of the presence of the flame 12. In other words, if the set of aggregate datum points $I_{A,k}$ has a large distance from the reference set of aggregate datum points $I_{A,k}$ the presence of the flame 12 is determined, whereas if the set of aggregate datum points $I_{A,k}$ has a reduced distance from the reference set of aggregate datum points $I_{A,k}$ the absence of the flame 12 is determined.

[0099] As a result, the threshold distance D_T is chosen heuristically as a function of the trade-off between maximum sensitivity in recognizing the presence of the flame 12 (which requires a minimum threshold distance D_T) and minimum number of false positives (which requires a maximum threshold distance D_T). By way of non-limiting example, the threshold distance D_T is comprised, in normalized value, between about 0.6 and about 0.7.

[0100] Figures 12A-12F show the signals previously described, in an exemplary case wherein the flame 12 is absent in the period $t_0 \leq t < t_1$, the flame 12 is present in the period $t_1 \leq t < t_2$ and the flame 12 is absent in the period $t_2 \leq t < t_3$. In detail, Figure 12A shows the carbon dioxide signal S_A, Figure 12B shows the fuel signal Sc, Figure 12C shows the electrostatic charge variation signal S_Q, Figure 12D shows the quantized signal S_Q', Figure 12E shows a temperature signal S_T better described hereinbelow, and Figure 12F shows the flame signal S_F.

[0101] As may be seen in Figures 12A-12F, in the presence of the flame 12 the carbon dioxide signal S_A grows in a constant manner, the fuel signal Sc oscillates around its second value, the electrostatic charge variation signal S_Q oscillates in a significant manner around its baseline, the quantized signal S_Q' assumes the second value (with the value change latency that has been previously described and is due to the buffering used), the temperature signal S_T increases (e.g., in a substantially linear manner) and the flame signal S_F assumes its second value. On the other hand, when the flame 12 shuts off, the carbon dioxide signal S_A decreases after reaching a maximum value (in detail, with a dynamic which is also a function of the degree of aeration of the environment wherein combustion develops), the fuel signal Sc decreases from the second value towards the first value (in detail, in a gradual manner due to factors such as the heat retained by objects close to the flame 12, which is released over time and is detected by the fuel detector 34 as if it were indicative of the presence of fuel in the air), the electrostatic charge variation signal S_Q returns to being substantially equal to its baseline, the quantized signal S_Q' assumes the first value (with the value change latency which has been previously described), the temperature signal S_T decreases after reaching a maximum value and the flame signal S_F assumes its first value. Furthermore, it may be noted how shortly before the generation of the flame 12 (e.g., about 1 second before), the electrostatic charge variation signal S_Q shows a spark generation pattern which, in some cases and as better described below, is indicative of the generation of a spark.

[0102] For purposes of further illustration, Figures 13A-13F show the signals previously described, in a different exemplary case wherein the flame 12 is absent in the period $t_0 \leq t < t_1$ (however three spark generation patterns are present in the electrostatic charge variation signal S_Q, in succession to each other), the flame 12 is present in the period $t_1 \leq t < t_2$ but the fuel flow is immediately reduced to a minimum, the flame 12 is absent in the period $t_2 \leq t < t_3$, the flame 12 is present in the period $t_3 \leq t < t_4$ and the fuel flow is at the maximum level allowed by the dispensing device 102, the flame 12 is absent in the period $t_4 \leq t < t_5$, the flame 12 is present in the period $t_5 \leq t < t_6$ and the fuel flow is at the maximum level allowed and the flame 12 is absent in the period $t_6 \leq t < t_7$. The behavior of the signals shown in Figures 13A-13F is in line with what has been described for Figures 12A-12F and therefore is not described again herein.

[0103] In addition to what has been previously described, the detection method 200 may also verify whether sparks generated by the spark generator 104 are detected, so as to signal, if necessary, an anomalous operating condition of the spark generator 104. This is achieved through steps S35 and S40 shown in Figure 8, optional.

[0104] In particular, at step S35 consecutive to step S30, a condition of generating a spark for igniting the flame 12 is verified, as a function of the electrostatic charge variation signal S_Q.

[0105] In particular, this comprises verifying whether the electrostatic charge variation signal S_Q has a spark generation pattern. The spark generation pattern is indicative of the generation of a spark.

[0106] An example of the spark generation pattern is shown in Figure 14 with the reference 70. In the example of Figure 14, the spark generation pattern 70 has a plurality of characteristic peaks, in succession to each other. In particular, the spark generation pattern 70 comprises, in succession to each other: a first negative peak 70a at a first time position t_{P1} and with a first amplitude A_{P1} relative to the baseline B of the electrostatic charge variation signal S_Q; a second positive peak 70b at a second time position t_{P2} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, a second amplitude A_{P2} approximately equal, in absolute value, to the first amplitude A_{P1}; a third negative peak 70c at a third time position t_{P3} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, a third amplitude A_{P3} much smaller, in absolute value, than the first amplitude A_{P1} (e.g., four or five times smaller); a fourth positive peak 70d at a fourth time position t_{P3} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, a fourth amplitude A_{P4} approximately equal, in absolute value, to the third amplitude A_{P3}; a fifth negative peak 70e at a fifth time position t_{P5} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, a fifth amplitude A_{P5} approximately equal to the third amplitude A_{P3}; a sixth positive peak 70f at a sixth time position t_{P6} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, a sixth amplitude Apg intermediate, in absolute value, between the second amplitude A_{P2} and the fourth amplitude A_{P4}; a seventh negative peak 70g at a seventh time position t_{P7} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, a seventh amplitude A_{P7} smaller, in absolute value, than the third amplitude A_{P3}; an eighth positive peak 70h at an eighth time position t_{P8} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, an eighth amplitude A_{P8} approximately equal, in absolute value, to the seventh amplitude A_{P7}; and a ninth negative peak 70i at a ninth time position t_{P9} and having, relative to the baseline B of the electrostatic charge variation signal S_Q, a ninth amplitude A_{P9} approximately equal, in absolute value, to the seventh amplitude A_{P7}. In detail, the electrostatic charge variation signal S_Q is indicative of the generation of a spark when one or more criteria relating to the electrostatic charge variation signal S_Q and identifying the generation of a spark are met. These criteria may be defined by conditions on mutual distances between at least one part of the peaks of the electrostatic charge variation signal S_Q, amplitudes and/or widths of such peaks, etc. In general, these criteria are established heuristically and, in a manner known per se to the person skilled in the art, specifically for each case considered (e.g., by acquiring electrostatic charge variation signals S_Q which do not identify the generation of a spark and electrostatic charge variation signals S_Q which identify the generation of a spark and comparing them with each other).

[0107] In fact, the shape of the spark generation pattern 70 depends on different factors, such as the environment wherein the spark is generated (e.g., the shape, the dimensions and the materials of the combustion chamber in the case of the combustion engine) and the spark generator 104 used (e.g., its shape, the technology used to generate the spark, etc.). As a result, the case shown in Figure 14 is exemplary but does not correspond to all possible spark generation patterns.

[0108] Furthermore, the spark generation pattern 70 may not always be indicative of the spark since in certain cases it may have a non-repeatable and standard shape and therefore not easily identifiable through the previously described approach; for example, this may occur in case the spark generator 104 is based on piezoelectric technology. In view of this, the shape of the spark generation pattern 70 and the criteria which define the condition of generating a spark are obtained heuristically during the design step.

[0109] In view of what has been discussed, at step S35 the electrostatic charge variation signal S_Q is processed in a per se known manner to identify any peaks thereof (i.e. positive peaks or negative peaks) and, subsequently, to verify whether the criteria on the peaks which define the condition of generating a spark are confirmed. In detail, at step S35 there are identified, if any, a number of peaks of the electrostatic charge variation signal S_Q and, for each peak, a respective maximum amplitude with respect to the baseline B and a respective time position (or instant) of the maximum value of the peak. Greater details regarding the identification modes of such peaks may be found for example in the patent document US 2022/0366768 A1, of the present Applicant.

[0110] At step S40 consecutive to step S35, a spark warning signal is generated if the generation of a spark is confirmed and, for a predefined time interval starting from the generation of a spark, the flame signal S_F is indicative of the absence of the flame 12. For example, the spark warning signal is a digital electrical signal which has a first value by default (e.g., 0) but which may assume a second value (e.g., 1) which allows for example a visual or sound alarm to be generated to signal a malfunction of the spark generator 104. In detail, the spark warning signal is generated when the spark generation pattern 70 is detected and if, within the predefined time interval starting from the generation of a spark (e.g., starting from the time instant corresponding to a predefined peak of the spark generation pattern 70), no flame is detected.

[0111] From an examination of the characteristics of the invention made according to the present invention, the advantages that it affords are evident.

[0112] In particular, the sensor device 10 and the detection method 200 allow data to be acquired through a plurality of sensors of different types and allow data fusion to be performed on these data in order to detect the presence or absence of the flame 12 with high accuracy, preventing the risk of fires or bursts due to uncontrolled combustions.

[0113] The high accuracy results from the redundancy of information (different from each other) acquired through the sensors 20, 30 and 40, which allows specific limits of each of these sensors 20, 30 and 40 to be compensated for. For example, the sole carbon dioxide sensor 20 carries out a measurement of carbon dioxide, whose concentration however depends on the environment in which the sensor device 10 is present (e.g., it may be higher in a closed and crowded room while it may be lower in the open air); as a result, this measurement is strongly influenced by factors external to the flame 12. Furthermore, the fuel sensor 30 performs, to detect the fuel concentration, an optical measurement of the emission spectrum of the flame 12 at wavelengths comprised in the IR; as a result, each hot body external and close to the sensor device 10 (e.g., people, animals or metal elements which have previously been heated by a heat source) emits radiation in the IR which may influence the measurement. Furthermore, the electrostatic charge variation sensor 40 is sensitive to any electrostatic charge variation induced in the environment external to the sensor device 10, therefore also this measurement is not sufficiently accurate if considered alone. Instead, the strategy of aggregating the signals coming from these sensors 20, 30, 40 allows to overcome the intrinsic limits of each of them and to increase the detection accuracy.

[0114] Furthermore, the present solution is immune to ambient acoustic noise, which may instead influence the known detection performed acoustically (e.g., through microphones).

[0115] The detection method 200 also requires lower computational cost, energy consumption and time compared to the solutions currently on the market with similar accuracies.

[0116] Furthermore, the sensor device 10 allows to detect a flame 12 which is even several tens of centimeters away.

[0117] Furthermore, generating the spark warning signal is useful for signaling a malfunction of the spark generator 104 which could lead to bursts and fires of the fuel. In fact, exemplarily considering the case of a hob, when a user manually controls the spark generator 104 to ignite the fire, the dispensing device 102 starts to dispense the fuel and at the same time the spark generator 104 generates the spark. If a malfunction of the spark generator 104 is present and the user repeats the gesture of igniting the flame 12 several times, an accumulation of unburned fuel may be created in the air which, as soon as a spark is generated, generates a violent combustion which may damage surrounding objects and people.

[0118] Finally, it is clear that modifications and variations may be made to the invention described and illustrated herein without thereby departing from the scope of the present invention, as defined in the attached claims.

[0119] For example, the different embodiments described may be combined with each other so as to provide further solutions.

[0120] Furthermore, the sensor device 10 may comprise a temperature sensor 60 which, in use, detects the temperature of the air in the fluidic channel 15 or in the environment external to the sensor device 10. As evident, the temperature of the air depends on the presence or absence of the flame 12 which, when present, heats the surrounding air. In this case, the control unit 50 is also operatively coupled to the temperature sensor 60. In particular, the temperature sensor 60 is carried by the tubular body 14 (e.g., it is accommodated therein). For example, the temperature sensor 60 faces the fluidic channel 15 so as to detect the temperature of the air flow which flows therethrough.

[0121] In case the temperature sensor 60 is also present, the detection method 200 further comprises (in a manner not shown) acquiring, through the temperature sensor 60, the temperature signal S_T indicative of the temperature of the air and, if the temperature signal S_T is indicative of the absence of the flame 12 while the flame signal S_F is indicative of the presence of the flame 12, the modification of the flame signal S_F such that it is indicative of the absence of the flame 12. Alternatively o in addition to the modification of the flame signal S_F, a sensor warning signal may be generated which is indicative of an inconsistency between the measurements of the sensors 20, 30, 40 and 60 and therefore of the malfunction of one of the sensors 20, 30, 40 and 60. In other words, the temperature control is a further verification which is carried out through a further sensor in order to signal a malfunction condition of one of the sensors 20, 30, 40 and 60 and/or to add a further condition to the determination of the flame signal S_F (which is indicative of the presence of the flame 12 only if both the temperature sensor 60 and the sensors 20, 30 and 40 detect the presence of the flame 12).

[0122] Furthermore, the electrostatic charge variation sensor 40 may have two single-ended data acquisition channels (in detail, one for each electrode) or it may comprise two electrostatic charge variation sub-sensors each including a respective electrode (i.e. the sub-sensors have non-differential and single-ended inputs). In these cases, the electrostatic charge variation signal S_Q acquired by the electrostatic charge variation sensor 40 is obtained by calculating the difference of the signals acquired through the electrodes.

[0123] Furthermore, a different embodiment of the determination of the quantized signal S_Q' of step S20 of the detection method 200 is described with reference to Figure 15.

[0124] In detail and as shown in Figure 15, sub-steps S20AS20C are initially performed, in a manner similar to what has been previously described with reference to Figure 9. In this manner the normalized signal S_N is obtained. In the following the normalized signal S_N is considered to have N samples (i.e. $S_N=[S_{N,0},...,S_{N,N-1}]$, where the $S_{N,n}$s with $0 \leq n \leq N-1$ are the samples of the normalized signal S_N).

[0125] After sub-step S20C, an augmented normalized signal S_{NA} including the normalized signal S_N and additional samples having the first value of the normalized signal S_N (e.g., 0) is generated (sub-step S20G). These additional samples precede and follow the normalized signal S_N in such a way that the augmented normalized signal S_{NA} comprises, in succession to each other, K additional samples, the N samples of the normalized signal S_N and other K additional samples. As a result, the augmented normalized signal S_{NA} has N+2K samples, where the first K samples and the last K samples are set to 0. In other words, $S_{NA,i}=0$ for $0 \leq i \leq K-1$, $S_{NA,i}=S_{N,i}$ for $K \leq i \leq K+N-1$ and $S_{NA,i}=0$ for $K+N \leq i \leq N+2K-1$.

[0126] At sub-step S20H a copy signal S_E equal to the augmented normalized signal S_{NA} is generated, i.e. a copy of the augmented normalized signal S_{NA} is stored.

[0127] At sub-step S20I a counter (or index) i is initialized to the value K (i.e. i=K).

[0128] At sub-step S20J, for the sample of the augmented normalized signal S_{NA} identified by the index i, a first cumulative value SL_i and a second cumulative value SR_i are calculated. The first and the second cumulative values SL_i and SR_i are respectively calculated according to the following mathematical expressions $SL_i = \sum_{j=i-K}^{i-1} S_{NA,j}$ and $SR_i = \sum_{j=i+1}^{i+K} S_{NA,j}$. As a result, the first and the second cumulative values SL_i and SR_i are indicative of the sum of the samples of the augmented normalized signal S_{NA} which precede and, respectively, follow the sample $S_{NA,i}$.

[0129] At sub-step S20K it is verified whether the sample $S_{NA,i}$ of the augmented normalized signal S_{NA} is equal to the second value (e.g., 1). If the sample $S_{NA,i}$ is not equal to 1, the method proceeds to a sub-step S20L; otherwise, if the sample $S_{NA,i}$ is equal to 1, the method proceeds to a sub-step S20M.

[0130] At sub-step S20L it is verified whether the first cumulative value SL_i is greater than a threshold cumulative value and whether the second cumulative value SR_i is greater than the threshold cumulative value.

[0131] If both of these conditions are confirmed, a sub-step S20N is performed wherein the sample $S_{NA,i}$ assumes the second value (i.e., it is set to be equal to 1, it is overwritten with this value).

[0132] Otherwise, if at least one of these conditions is not confirmed, a sub-step S20O is performed wherein the sample $S_{NA,i}$ assumes the first value (i.e., it is set to be equal to 0, it is overwritten with this value).

[0133] At sub-step S20M, it is verified whether the first cumulative value SL_i is greater than the threshold cumulative value or whether the second cumulative value SR_i is greater than the threshold cumulative value.

[0134] If none of these conditions is confirmed, a sub-step S20P is performed wherein the sample $S_{NA,i}$ assumes the first value (i.e., it is set to be equal to 0, it is overwritten with this value).

[0135] Otherwise, if at least one of these conditions is confirmed, a sub-step S20Q is performed wherein the sample $S_{NA,i}$ assumes the second value (i.e., it is set to be equal to 1, it is overwritten with this value).

[0136] In particular, the threshold cumulative value is indicated in Figure 15 with the reference TH and is chosen heuristically in such a way as to allow the convergence of the method described at steps S20G-S20V. By way of non-limiting example, the threshold cumulative value is equal to about 4.

[0137] Following sub-steps S20N-S20Q, it is verified (sub-step S20R) whether the counter i is lower than the number N.

[0138] If this is confirmed, a sub-step S20S is performed wherein the counter i is updated by adding a unit (i.e. i=i+1) and the method returns to sub-step S20J.

[0139] On the other hand, if this is not confirmed (i.e. i=N), a sub-step S20T is performed wherein the augmented normalized signal S_{NA} updated through sub-steps S20J-S20Q is compared with the copy signal S_E to verify whether they match each other. In other words, it is verified whether the copy signal S_E and the augmented normalized signal S_{NA} have, at each instant, the same value.

[0140] If the copy signal S_E and the augmented normalized signal S_{NA} do not match, a sub-step S20U is performed wherein the copy signal S_E is updated so as to be equal to the augmented normalized signal S_{NA}. Thereafter the method returns to sub-step S20I to perform a new sub-iteration.

[0141] On the other hand, if the copy signal S_E and the augmented normalized signal S_{NA} match, the quantized signal S_Q' is generated as a function of the augmented normalized signal S_{NA} updated through sub-steps S20I-S20U. In particular, the quantized signal S_Q' is equal to the portion of the augmented normalized signal S_{NA} that is devoid of the additional 2K samples. In other words, $S_{Q,i}$'$=S_{NA,i}$ for $K \leq i \leq K+N-1$.

[0142] The steps of Figure 15 are alternative to the steps of Figure 9 and allow the quantized signal S_Q' to be determined without the previously described latency, as they are not based on the buffering of the normalized signal S_N.

Claims

1. A sensor device (10) for detecting the presence of a flame (12), comprising:

    - a carbon dioxide sensor (20) configured to detect a concentration of carbon dioxide in the air, generated by the flame (12);
    - a fuel sensor (30) configured to detect the combustion of a fuel used to produce the flame (12);
    - an electrostatic charge variation sensor (40) including a first (40a) and a second (40b) electrode spaced from each other and configured to detect respective electrostatic charge variations generated by the flame (12); and
    - a control unit (50) operatively coupled to the carbon dioxide sensor (20), the fuel sensor (30) and the electrostatic charge variation sensor (40),

    the control unit (50) being configured to:

    - acquire, through the carbon dioxide sensor (20), a carbon dioxide signal (S_A) indicative of the concentration of carbon dioxide generated by the flame (12);
    - acquire, through the fuel sensor (30), a fuel signal (S_C) indicative of the presence of combustion of the fuel used to produce the flame (12);
    - acquire, through the electrostatic charge variation sensor (40), an electrostatic charge variation signal (S_Q) indicative of a difference between the electrostatic charge variations detected by the first (40a) and the second (40b) electrodes;
    - determine a quantized signal (S_Q') by processing the electrostatic charge variation signal (S_Q);
    - determine an aggregate datum (I_A) indicative of the aggregation of the carbon dioxide signal (S_A), the fuel signal (S_C) and the electrostatic charge variation signal (S_Q); and
    - generate, as a function of the aggregate datum (I_A), a flame signal (S_F) indicative of the presence or absence of the flame (12).

2. The sensor device according to claim 1, further comprising a tubular body (14) having an inlet opening (14a) and an outlet opening (14b) fluidically coupled to each other through a fluidic channel (15) of the tubular body (14), which extends through the tubular body (14) and which defines a fluidic path between the inlet opening (14a) and the outlet opening (14b), in fluidic communication with the flame (12) such that, when the flame (12) is present, the fluidic channel (15) is flown through by an air flow which is caused by the flame (12) and which transfers from the inlet opening (14a) to the outlet opening (14b), and
wherein the control unit (50), the carbon dioxide sensor (20), the fuel sensor (30) and the electrostatic charge variation sensor (40) are accommodated in the tubular body (14) and the carbon dioxide sensor (20) and the fuel sensor (30) extend into the fluidic channel (15).

3. The sensor device according to claim 2, wherein the carbon dioxide sensor (20) comprises:

    - a light radiation emitter (22) facing the fluidic channel (15) and controllable by the control unit (50) to emit light radiation through the fluidic channel (15);
    - a carbon dioxide optical filter (23) facing the fluidic channel (15) and configured to filter the light radiation emitted by the light radiation emitter (22) so as to transmit the light radiation having a wavelength comprised in a carbon dioxide wavelength range comprising a carbon dioxide absorption wavelength; and
    - a carbon dioxide detector (24) arranged at a distance from the light radiation emitter (22) and configured to detect the light radiation filtered by the carbon dioxide optical filter (23) and to generate the corresponding carbon dioxide signal (S_A),

    wherein the light radiation emitter (22), the carbon dioxide optical filter (23) and the carbon dioxide detector (24) are aligned in succession to each other along a carbon dioxide alignment axis (26) extending through the fluidic channel (15).

4. The sensor device according to claim 2 or 3, wherein the fuel sensor (30) comprises:

- a fuel optical filter (33) facing the fluidic channel (15) and configured to filter the radiation generated by the flame (12) so as to transmit the radiation having a wavelength comprised in a fuel wavelength range comprising a fuel emission wavelength; and
- a fuel detector (34) configured to detect the radiation filtered by the fuel optical filter (33) and to generate the corresponding fuel signal (Sc),

wherein the inlet opening (14a), the fuel optical filter (33), and the fuel detector (34) are aligned in succession to each other along a fuel alignment axis (36) extending through the fluidic channel (15).

5. The sensor device according to any of claims 2-4, wherein the tubular body (14) has a first end (14') and a second end (14") opposite to each other along a longitudinal axis (16) of the tubular body (14), the first end (14') being configured to face the flame (12) and the second end (14") being configured to extend on the opposite side of the tubular body (14) with respect to the flame (12), and
wherein the first electrode (40a) extends at the first end (14') of the tubular body (14) and the second electrode (40b) extends at the second end (14") of the tubular body (14) .

6. The sensor device according to any of the preceding claims, further comprising a temperature sensor (60) configured to detect a temperature of the air dependent on the presence or absence of the flame (12), the control unit (50) being further operatively coupled to the temperature sensor (60) and being further configured to:

- acquire, by the temperature sensor (60), a temperature signal (S_T) indicative of the temperature of the air; and
- if the temperature signal (S_T) is indicative of the absence of the flame (12) while the flame signal (S_F) is indicative of the presence of the flame (12), impose that the flame signal (S_F) is indicative of the absence of the flame (12) and/or generate a sensor warning signal.

7. An ignition system (100) for igniting a flame (12), the ignition system (100) comprising:

- a dispensing device (102) coupeable to a fuel source and controllable to dispense a fuel received from the fuel source;
- a spark generator (104) controllable to generate a spark and coupled to the dispensing device (102) in such a way as to produce the flame (12) when the spark is generated at the fuel dispensed by the dispensing device (102); and
- a sensor device (10) according to any of claims 1-6, operatively coupled to the dispensing device (102) and to the spark generator (104) so as to detect the presence of the flame (12).

8. The ignition system according to claim 7, further comprising a main control unit (106) operatively coupled to the dispensing device (102), the spark generator (104) and the sensor device (10) and configured to:

- receive from the sensor device (10) the flame signal (S_F) indicative of the presence or absence of the flame (12); and
- control the dispensing device (102) as a function of the flame signal (S_F), in such a way as to prevent fuel dispensing if the flame signal (S_F) is indicative of the absence of the flame (12).

9. A detection method (200) of the presence of a flame (12) through a sensor device (10),

the sensor device (10) comprising:

- a carbon dioxide sensor (20) configured to detect a concentration of carbon dioxide in the air, generated by the flame (12);
- a fuel sensor (30) configured to detect the combustion of a fuel used to produce the flame (12);
- an electrostatic charge variation sensor (40) including a first (40a) and a second (40b) electrode spaced from each other and configured to detect respective electrostatic charge variations generated by the flame (12); and
- a control unit (50) operatively coupled to the carbon dioxide sensor (20), the fuel sensor (30) and the electrostatic charge variation sensor (40),

the detection method (200) comprising the steps of:

- acquiring (S05), by the control unit (50) and through the carbon dioxide sensor (20), a carbon dioxide signal (S_A) indicative of the concentration of carbon dioxide generated by the flame (12);
- acquiring (S10), by the control unit (50) and through the fuel sensor (30), a fuel signal (Sc) indicative of the presence of combustion of the fuel used to produce the flame (12);
- acquiring (S15), by the control unit (50) and through the electrostatic charge varia-

tion sensor (40), an electrostatic charge variation signal (S_Q) indicative of a difference between the electrostatic charge variations detected by the first (40a) and the second (40b) electrodes;
- determining (S20), by the control unit (50), a quantized signal (S_Q') by processing the electrostatic charge variation signal (S_Q);
- determining (S25), by the control unit (50), an aggregate datum (I_A) indicative of the aggregation of the carbon dioxide signal (S_A), the fuel signal (Sc) and the electrostatic charge variation signal (S_Q); and
- generating (S30), by the control unit (50) and as a function of the aggregate datum (I_A), a flame signal (S_F) indicative of the presence or absence of the flame (12).

10. The detection method according to claim 9, wherein the step of determining (S20) the quantized signal (S_Q') comprises:

- calculating (S20A) a baseline (B) of the electrostatic charge variation signal (S_Q);
- calculating (S20B) a variability signal (Sv) by subtracting the baseline (B) from the electrostatic charge variation signal (S_Q);
- determining (S20C) a normalized signal (S_N) by comparing the variability signal (Sv) with a charge variation threshold value, the normalized signal (S_N) assuming, at each time instant, a first value (0) if the corresponding value of the variability signal (Sv) is lower than the charge variation threshold value or a second value (1) if the corresponding value of the variability signal (Sv) is greater than, or equal to, the charge variation threshold value;
- for each time instant of the normalized signal (S_N), determining (S20D) a respective clustering interval ($S_{N,k}$) of the normalized signal (S_N), the clustering interval ($S_{N,k}$) comprising the value of the normalized signal (S_N) corresponding to the time instant considered and a predefined plurality of values of the normalized signal (S_N) corresponding to a respective plurality of time instants preceding the time instant considered;
- for each clustering interval ($S_{N,k}$) of the normalized signal (S_N), determining (S20E) which value of the normalized signal (S_N), between the first value (0) and the second value (1), has a greater occurrence in the considered clustering interval ($S_{N,k}$); and
- generating (S20F) the quantized signal (S_Q') in such a way that, at each time instant, the quantized signal (S_Q') assumes a respective first value (0) if the value of the normalized signal (S_N) with greater occurrence in the clustering interval ($S_{N,k}$) of the normalized signal (S_N) corresponding to the time instant considered is the first value (0), or assumes a respective second value (1) if the value of the normalized signal (S_N) with greater occurrence in the clustering interval ($S_{N,k}$) of the normalized signal (S_N) corresponding to the time instant considered is the second value (1).

11. The detection method according to claim 9, wherein the step of determining (S20) the quantized signal (S_Q') comprises, in succession to each other:

a. calculating (S20A) a baseline (B) of the electrostatic charge variation signal (S_Q);
b. calculating (S20B) a variability signal (Sv) by subtracting the baseline (B) from the electrostatic charge variation signal (S_Q);
c. determining (S20C) a normalized signal (S_N) by comparing the variability signal (Sv) with a charge variation threshold value, the normalized signal (S_N) assuming, at each time instant, a first value (0) if the corresponding value of the variability signal (Sv) is lower than the charge variation threshold value or a second value (1) if the corresponding value of the variability signal (Sv) is greater than, or equal to, the charge variation threshold value, the normalized signal (S_N) having a number N of samples;
d. generating (S20G) an augmented normalized signal (S_{NA}) which comprises the normalized signal (S_N), K additional first samples preceding the normalized signal (S_N), and K additional second samples successive to the normalized signal (S_N), each additional first and second sample assuming the first value of the normalized signal (S_N);
e. generating (S20H) a copy signal (S_E) equal to the augmented normalized signal (S_{NA});
f. initializing (S20I) an index i to the value K;
g. calculating (S20J), for an i-th sample ($S_{NA,i}$) of the augmented normalized signal (S_{NA}), a respective first cumulative value (SL_i) and a respective second cumulative value (SR_i), the first cumulative value (SL_i) being indicative of a sum of the samples of the augmented normalized signal (S_{NA}) preceding the i-th sample ($S_{NA,i}$) and the second cumulative value (SR_i) being indicative of a sum of the samples of the augmented normalized signal (S_{NA}) which follow the i-th sample ($S_{NA,i}$) ;
h. verifying (S20K) whether the i-th sample ($S_{NA,i}$) is equal to the second value of the normalized signal (S_N);
i. if the i-th sample ($S_{NA,i}$) is not equal to the second value of the normalized signal (S_N), verifying (S20L) whether the first cumulative value (SL_i) is greater than a threshold cumulative value and whether the second cumulative value

(SR_i) is greater than the threshold cumulative value;

j. if the i-th sample ($S_{NA,i}$) is not equal to the second value of the normalized signal (S_N) and both the first cumulative value (SL_i) and the second cumulative value (SR_i) are greater than the threshold cumulative value, updating (S20N) the i-th sample ($S_{NA,i}$) to the second value of the normalized signal (S_N);

k. if the i-th sample ($S_{NA,i}$) is not equal to the second value of the normalized signal (S_N) and at least one of the first cumulative value (SL_i) and the second cumulative value (SR_i) is not greater than the threshold cumulative value, updating (S20O) the i-th sample ($S_{NA,i}$) to the first value of the normalized signal (S_N);

l. if the i-th sample ($S_{NA,i}$) is equal to the second value of the normalized signal (S_N), verifying (S20M) whether the first cumulative value (SL_i) or the second cumulative value (SR_i) are greater than the threshold cumulative value;

m. if the i-th sample ($S_{NA,i}$) is equal to the second value of the normalized signal (S_N) and none of the first cumulative value (SL_i) and the second cumulative value (SR_i) is greater than the threshold cumulative value, updating (S20P) the i-th sample ($S_{NA,i}$) to the first value of the normalized signal (S_N);

n. if the i-th sample ($S_{NA,i}$) is equal to the second value of the normalized signal (S_N) and at least one of the first cumulative value (SL_i) and the second cumulative value (SR_i) is greater than the threshold cumulative value, updating (S20Q) the i-th sample ($S_{NA,i}$) to the second value of the normalized signal (S_N);

o. verifying (S20R) whether the index i is lower than the number N;

p. if the index i is lower than the number N, updating (S20S) the index i by adding a unit and repeating steps g-o with the updated index i;

q. if the index i is not lower than the number N, verifying (S20T) whether the copy signal (S_E) matches the augmented normalized signal (S_{NA});

r. if the copy signal (S_E) does not match the augmented normalized signal (S_{NA}), updating (S20U) the copy signal (S_E) so that it is equal to the augmented normalized signal (S_{NA}) and repeating steps f-q with the updated copy signal (S_E); and

s. if the copy signal (S_E) matches the augmented normalized signal (S_{NA}), generating (S20V) the quantized signal (S_Q') as a function of the augmented normalized signal (S_{NA}) .

12. The detection method according to any of claims 9-11, wherein the step of determining (S25) the aggregate datum (I_A) comprises determining, at each time instant, a respective set of aggregate datum points ($I_{A,k}$) defining the aggregate datum (I_A) in the time instant considered,
wherein, in each set of aggregate datum points ($I_{A,k}$), each aggregate datum point ($I_{A,k}$) is defined by a respective value of the carbon dioxide signal (S_A), a respective value of the fuel signal (S_C) and a respective value of the electrostatic charge variation signal (S_Q) corresponding to a respective time instant which is equal to the time instant corresponding to the set of aggregate datum points ($I_{A,k}$) considered or is equal to a time instant between a plurality of time instants preceding the time instant corresponding to the set of aggregate datum points ($I_{A,k}$) considered, in such a way that the set of aggregate datum points ($I_{A,k}$) considered is indicative of respective portions of the carbon dioxide signal (S_A), the fuel signal (Sc) and the electrostatic charge variation signal (S_Q) temporally defined by the time instant corresponding to the set of aggregate datum points ($I_{A,k}$) considered and by said plurality of time instants preceding the time instant corresponding to the set of aggregate datum points ($I_{A,k}$) considered.

13. The detection method according to claim 12, wherein the step of generating (S30) the flame signal (S_F) comprises, at each time instant:

- calculating (S30A) a centroid (C) of the respective set of aggregate datum points ($I_{A,k}$);
- calculating (S30B) a respective distance (D_C) of the centroid (C) of the respective set of aggregate datum points ($I_{A,k}$) from a reference centroid (C_{ref}) of a reference set of aggregate datum points indicative of the absence of the flame (12) ;
- comparing (S30C) the respective distance (D_C) with a threshold distance (D_T); and
- assigning (S30D) to the flame signal (S_F) a respective first value (0) if the respective distance (D_C) is lower than the threshold distance (D_T), or a respective second value (1) if the respective distance (D_C) is greater than, or equal to, the threshold distance (D_T),

wherein the first value (0) of the flame signal (S_F) is indicative of the absence of the flame (12) and the second value (1) of the flame signal (S_F) is indicative of the presence of the flame (12).

14. The detection method according to any of claims 9-13, further comprising the steps of:

- verifying (S35), by the control unit (50) and as a function of the electrostatic charge variation signal (S_Q), a condition of generating a spark for igniting the flame (12); and
- if the generation of a spark is confirmed and,

for a predefined time interval starting from the generation of a spark, the flame signal (S_F) is indicative of the absence of the flame (12), generating (S40), by the control unit (50), a spark warning signal.

15. The detection method according to claim 14, wherein the step of verifying (S35) the condition of generating the spark comprises verifying whether the electrostatic charge variation signal (S_Q) has a spark generation pattern (70) indicative of the generation of a spark.

16. A computer program product storable in a control unit (50), the computer program being designed such that, when executed, the control unit (50) becomes configured to perform a detection method (200) according to any of claims 9-15.

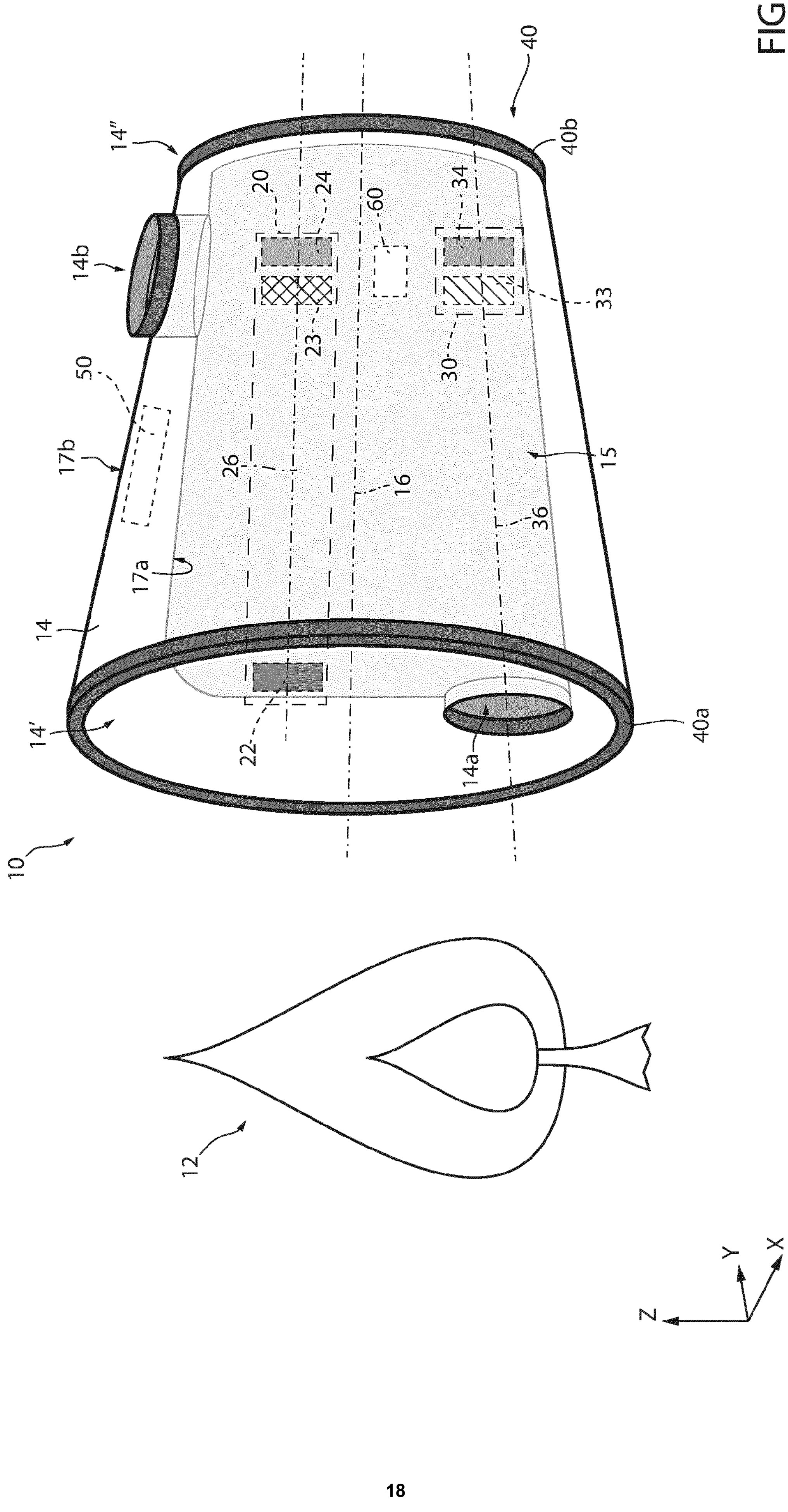

10
12
14
14'
14"
14a
14b
15
16
17a
17b
20
22
23
24
26
30
33
34
36
40
40a
40b
50
60
X
Y
Z

FIG. 1

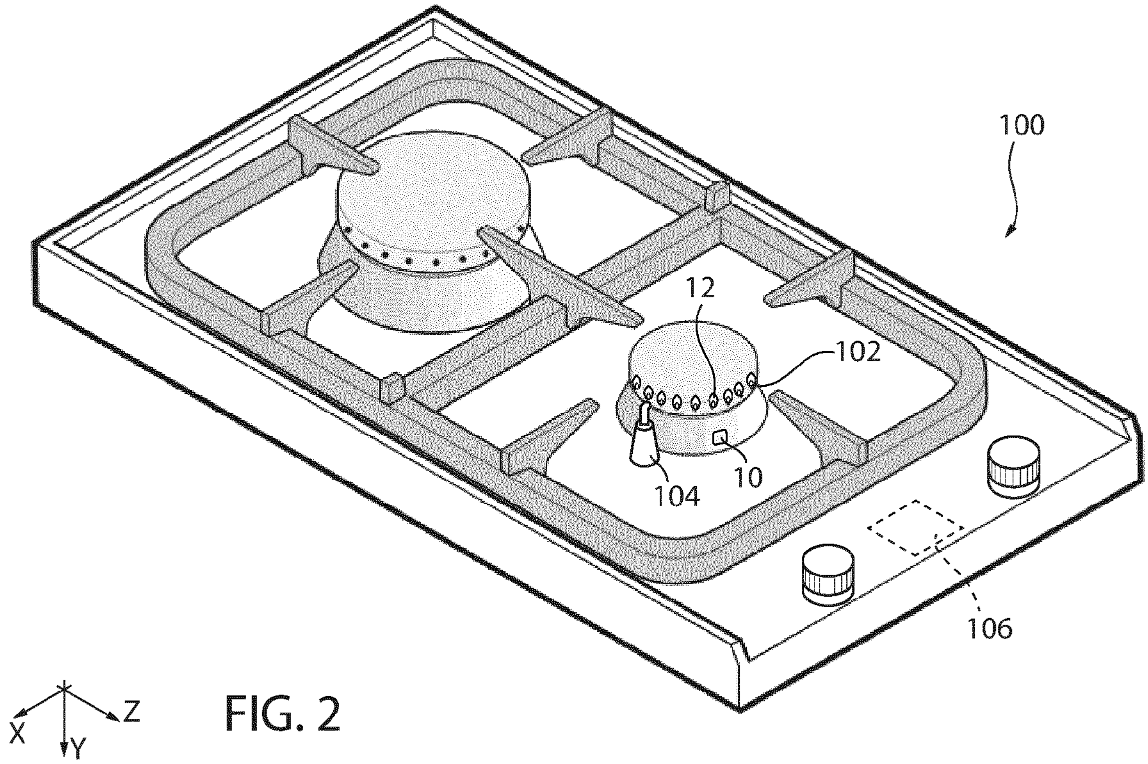


FIG. 2

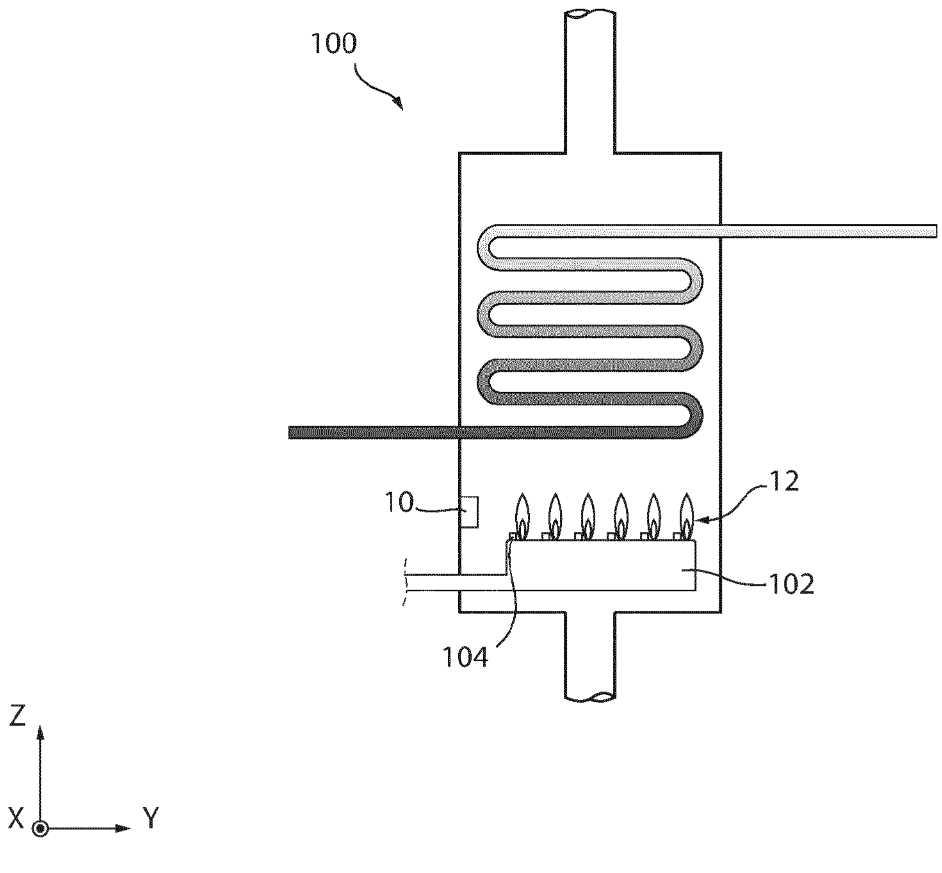
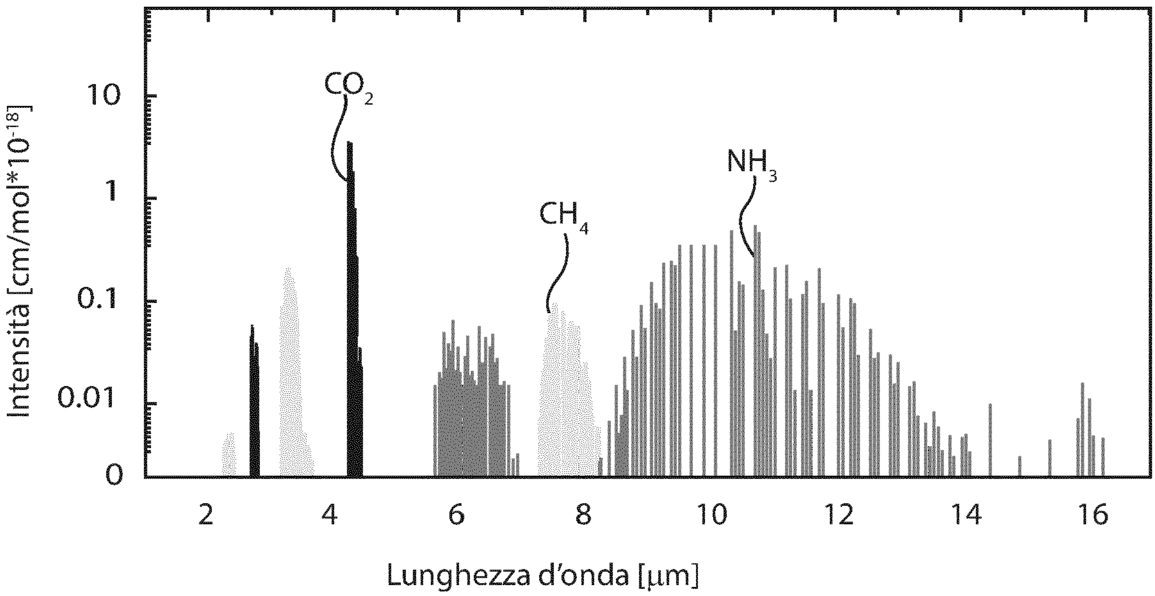
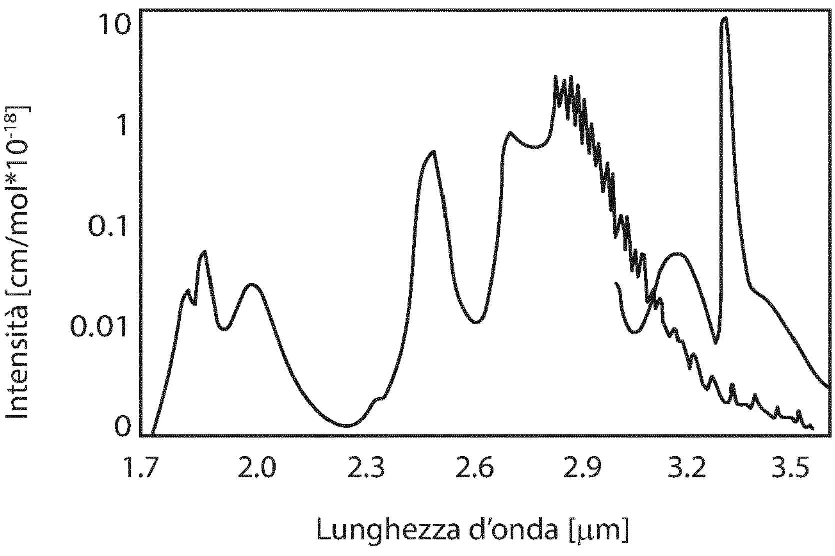


FIG. 3



CO2
CH4
NH3
Intensità [cm/mol*10-18]
10
1
0.1
0.01
0
2
4
6
8
10
12
14
16
Lunghezza d'onda [μm]

FIG. 4



Intensità [cm/mol*10-18]
10
1
0.1
0.01
0
1.7
2.0
2.3
2.6
2.9
3.2
3.5
Lunghezza d'onda [μm]

FIG. 5

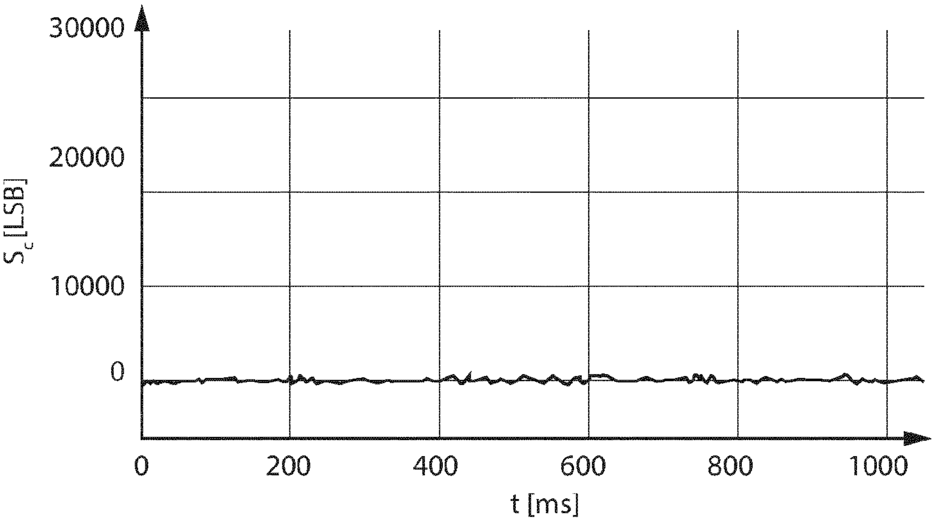


FIG. 6A

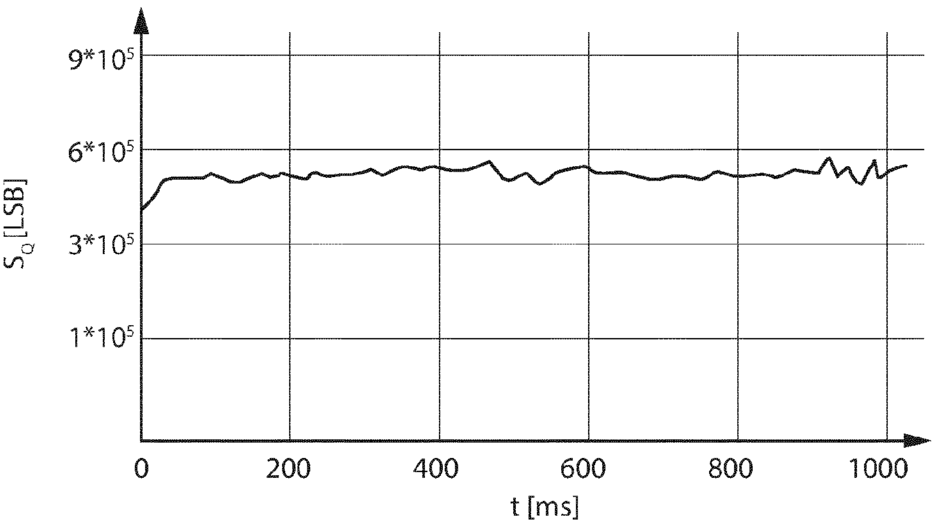


FIG. 6B

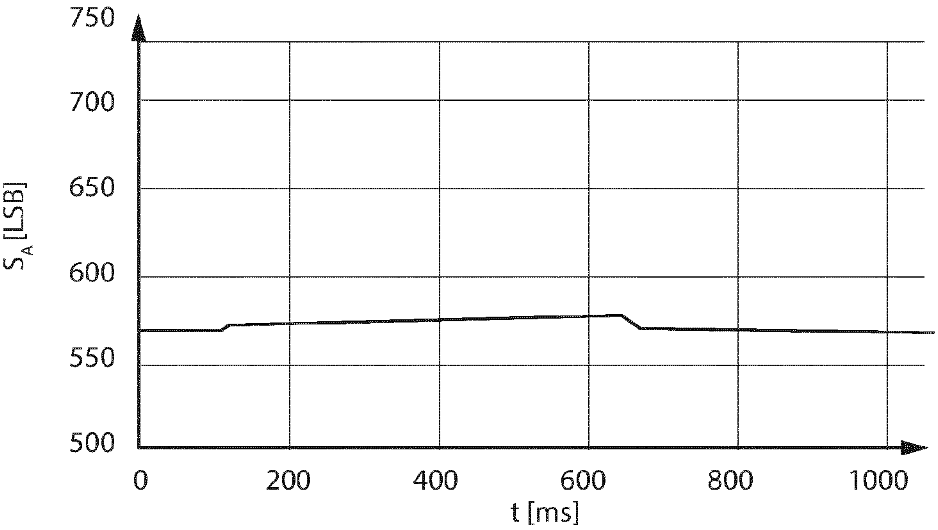


FIG. 6C

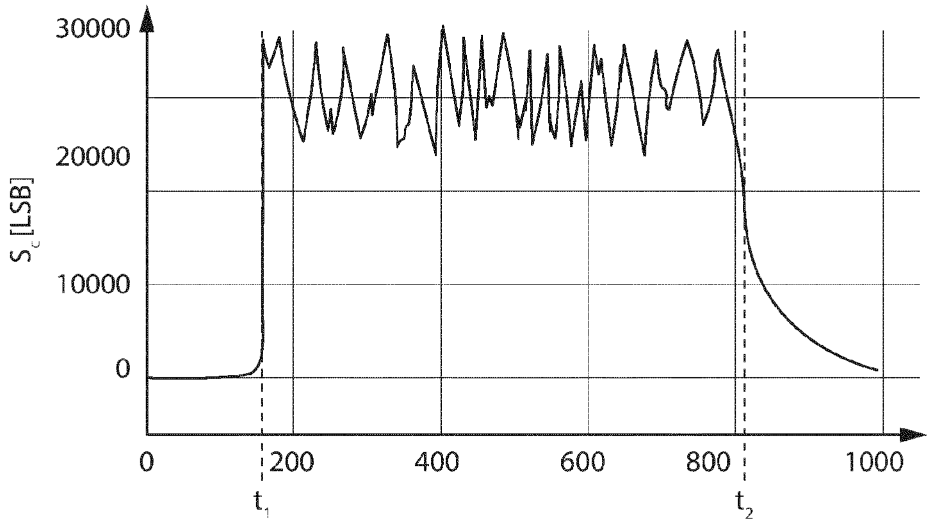


FIG. 7A

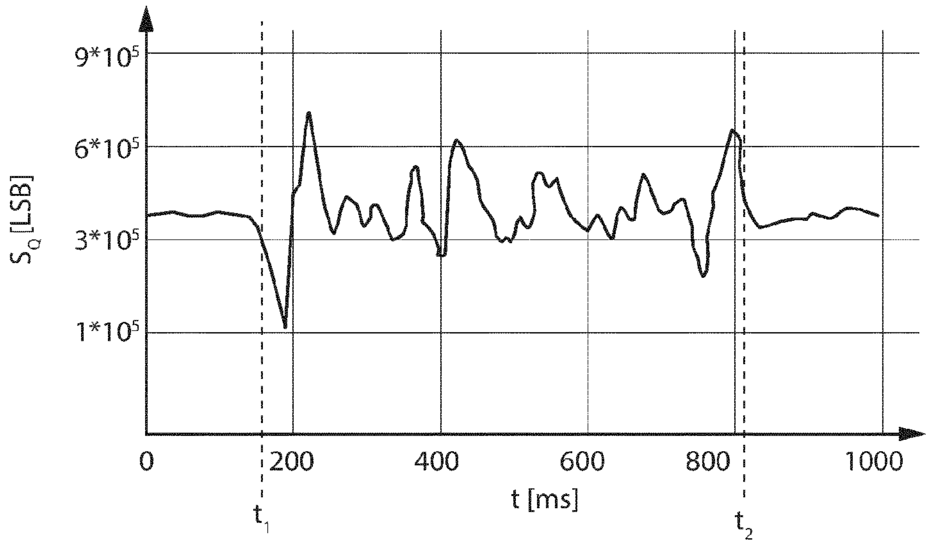


FIG. 7B

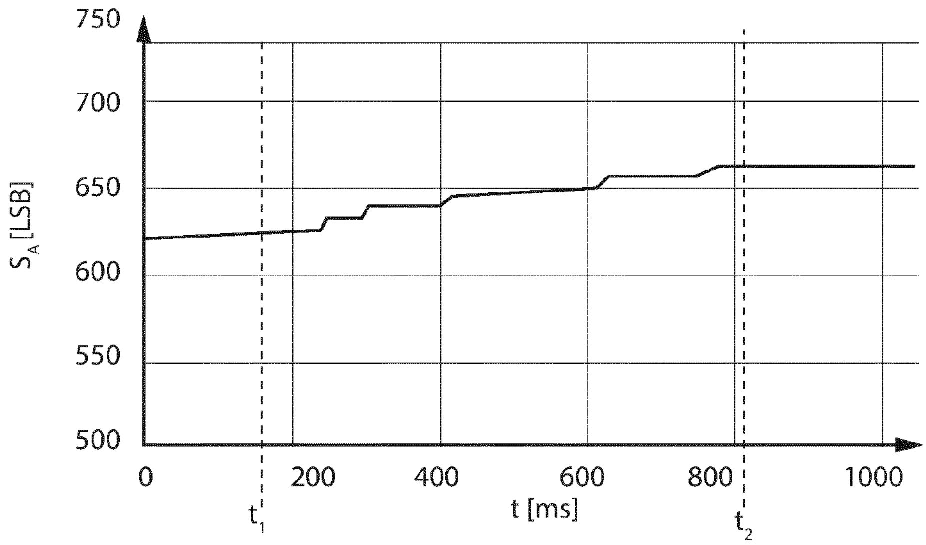


FIG. 7C

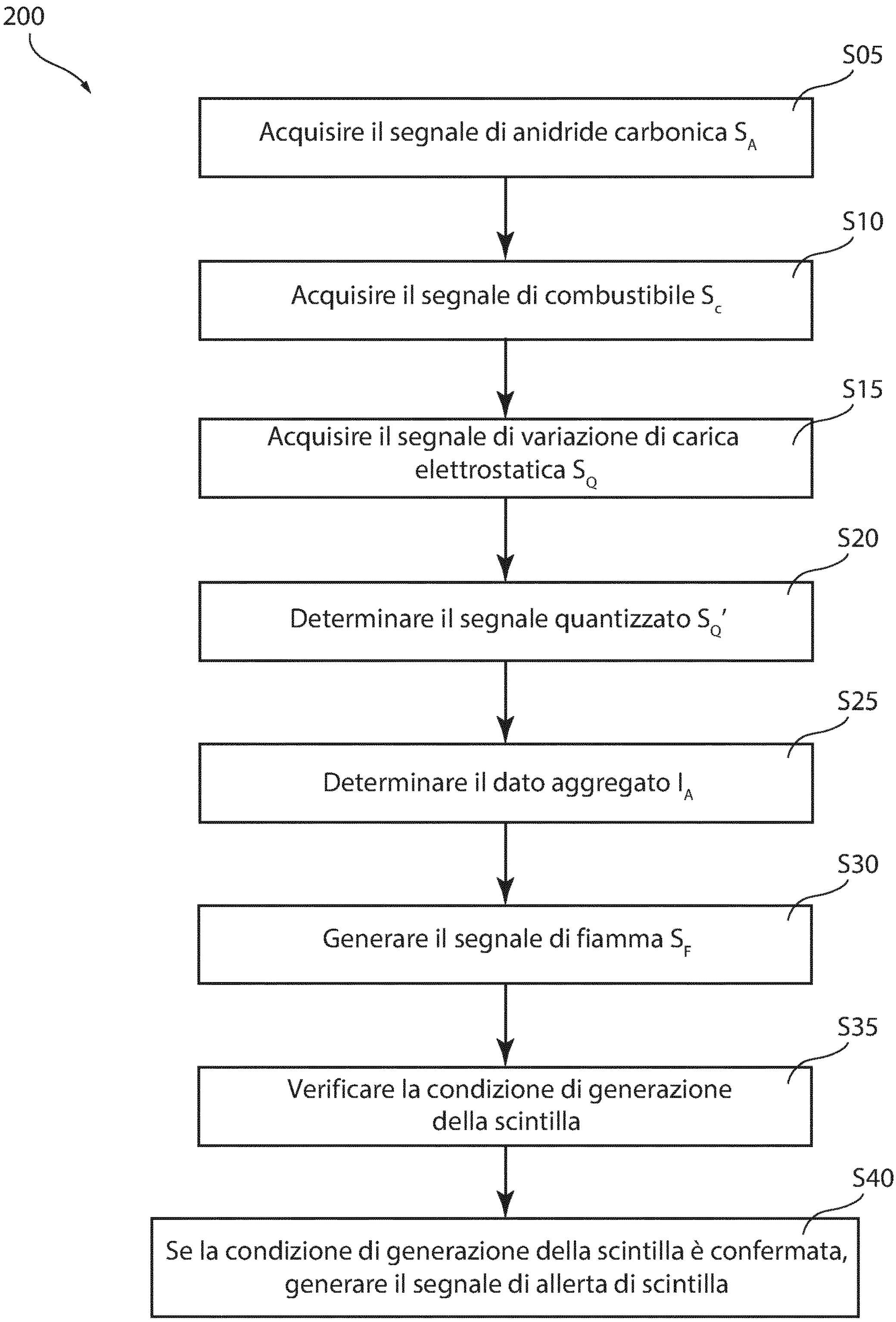

200
S05
Acquisire il segnale di anidride carbonica S_A
S10
Acquisire il segnale di combustibile S_c
S15
Acquisire il segnale di variazione di carica elettrostatica S_Q
S20
Determinare il segnale quantizzato S_Q'
S25
Determinare il dato aggregato I_A
S30
Generare il segnale di fiamma S_F
S35
Verificare la condizione di generazione della scintilla
S40
Se la condizione di generazione della scintilla è confermata, generare il segnale di allerta di scintilla

FIG. 8

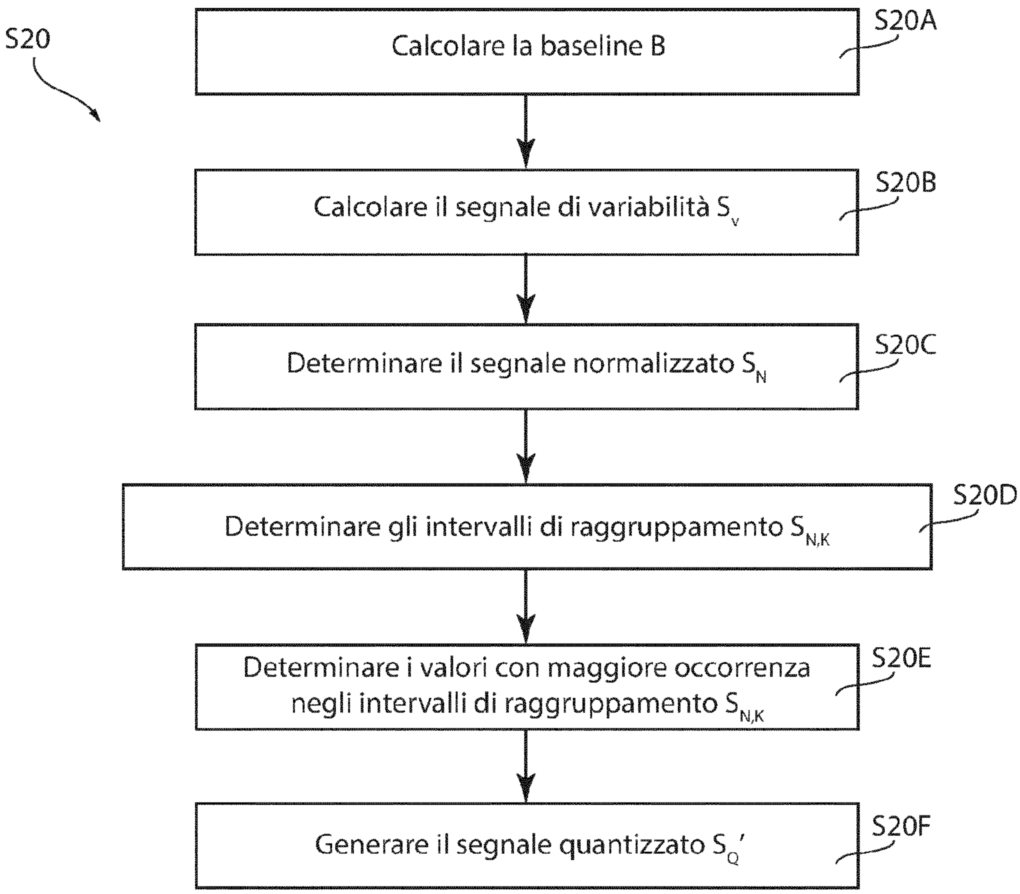

S20
Calcolare la baseline B
S20A
Calcolare il segnale di variabilità S_V
S20B
Determinare il segnale normalizzato S_N
S20C
Determinare gli intervalli di raggruppamento $S_{N,K}$
S20D
Determinare i valori con maggiore occorrenza negli intervalli di raggruppamento $S_{N,K}$
S20E
Generare il segnale quantizzato S_Q'
S20F

FIG. 9

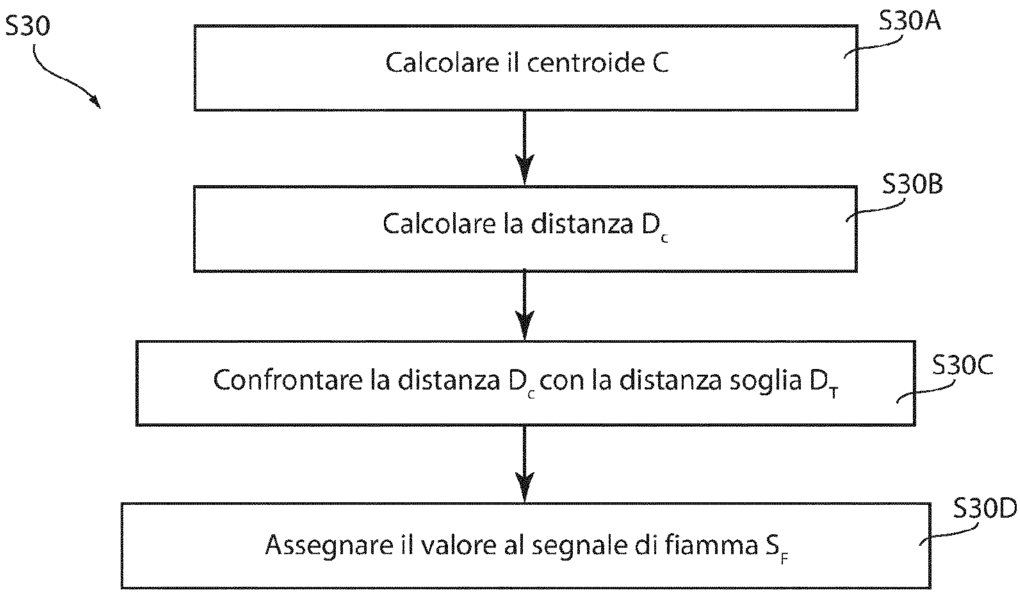

S30
Calcolare il centroide C
S30A
Calcolare la distanza D_c
S30B
Confrontare la distanza D_c con la distanza soglia D_T
S30C
Assegnare il valore al segnale di fiamma S_F
S30D

FIG. 10

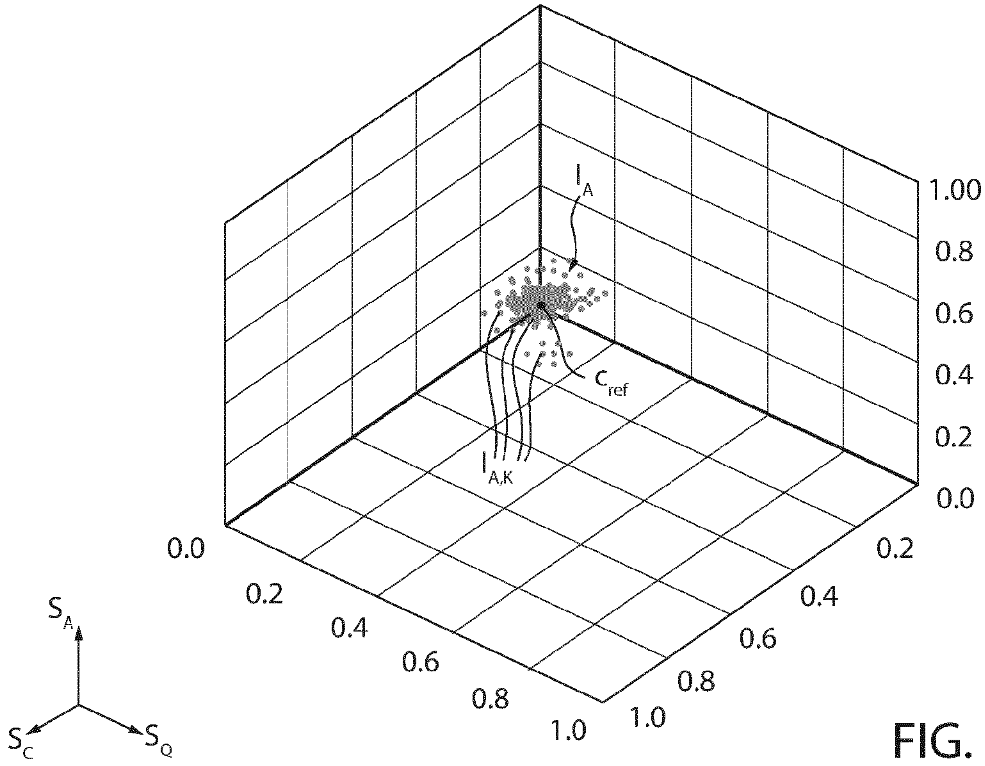


FIG. 11A

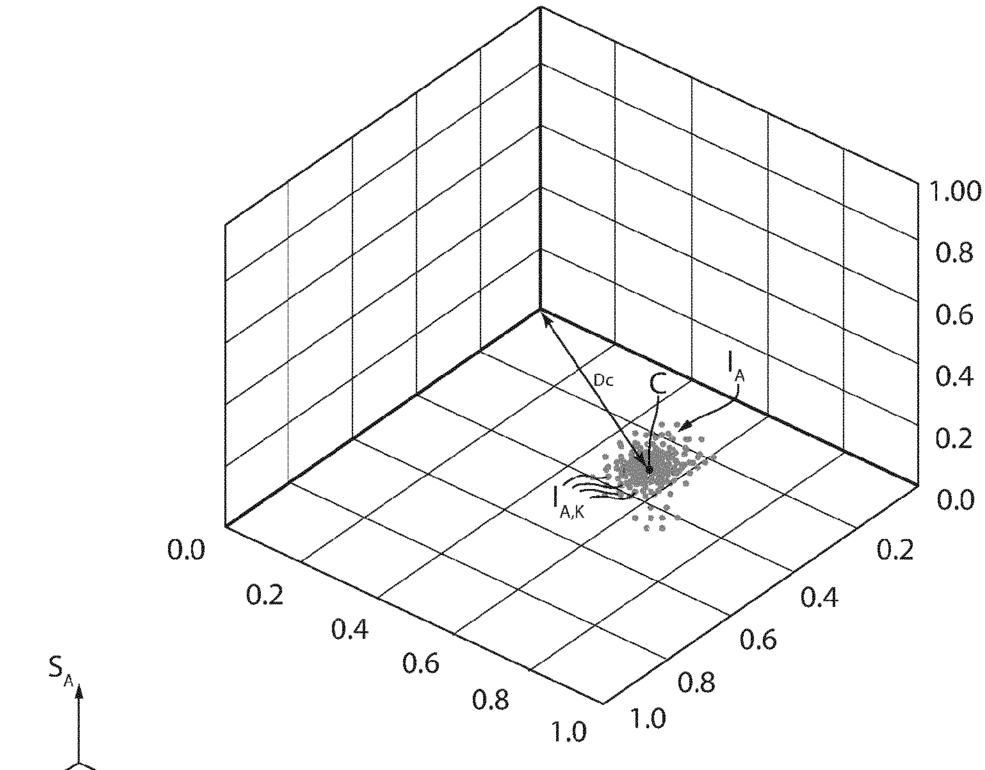


FIG. 11B

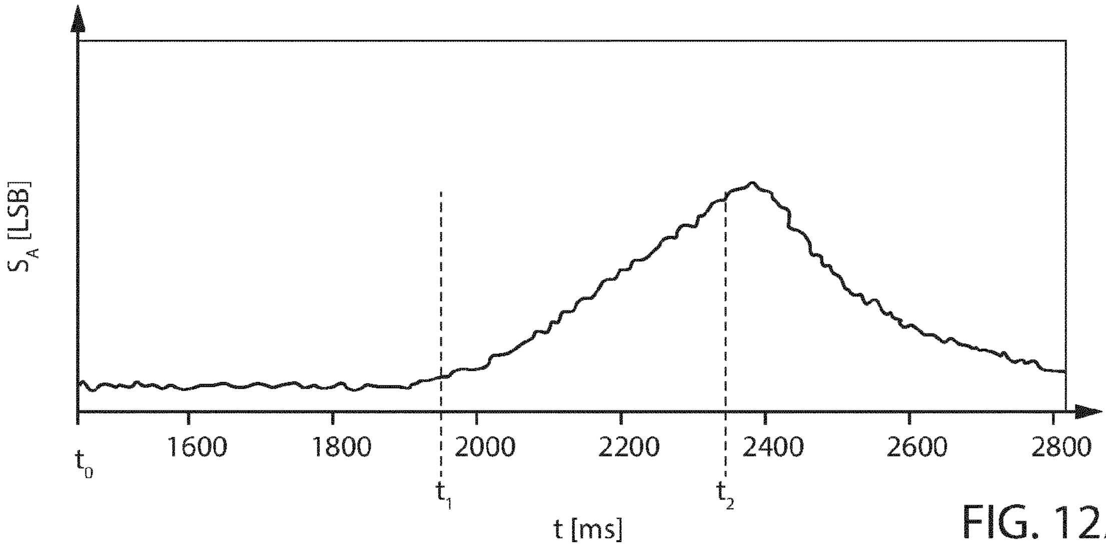


FIG. 12A

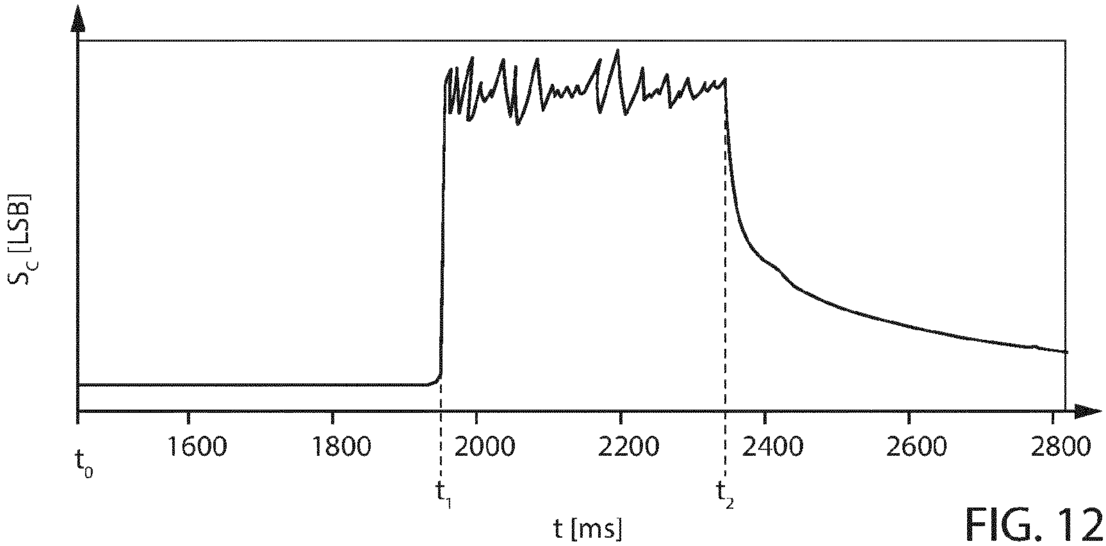


FIG. 12B

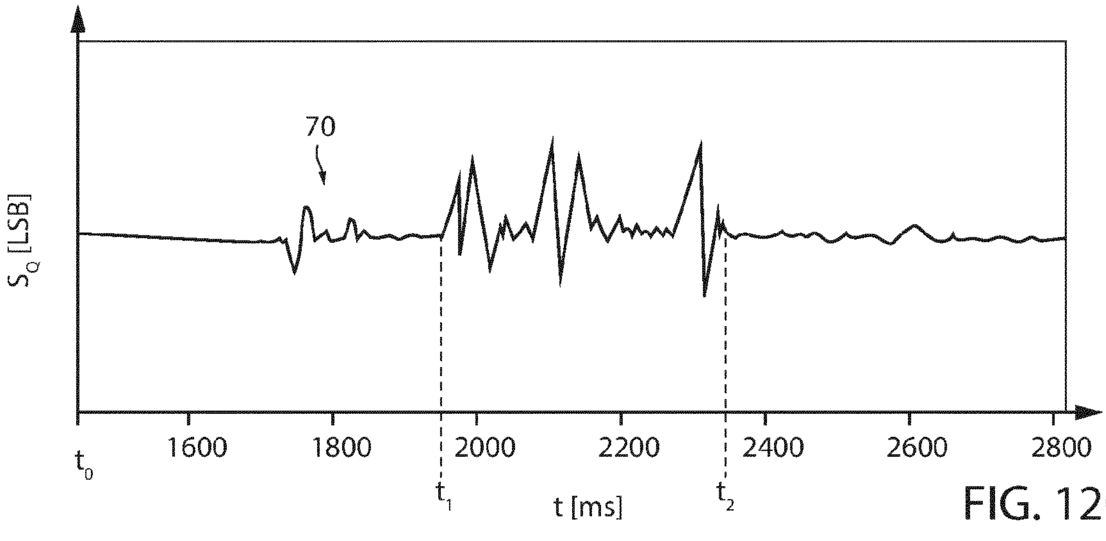


FIG. 12C

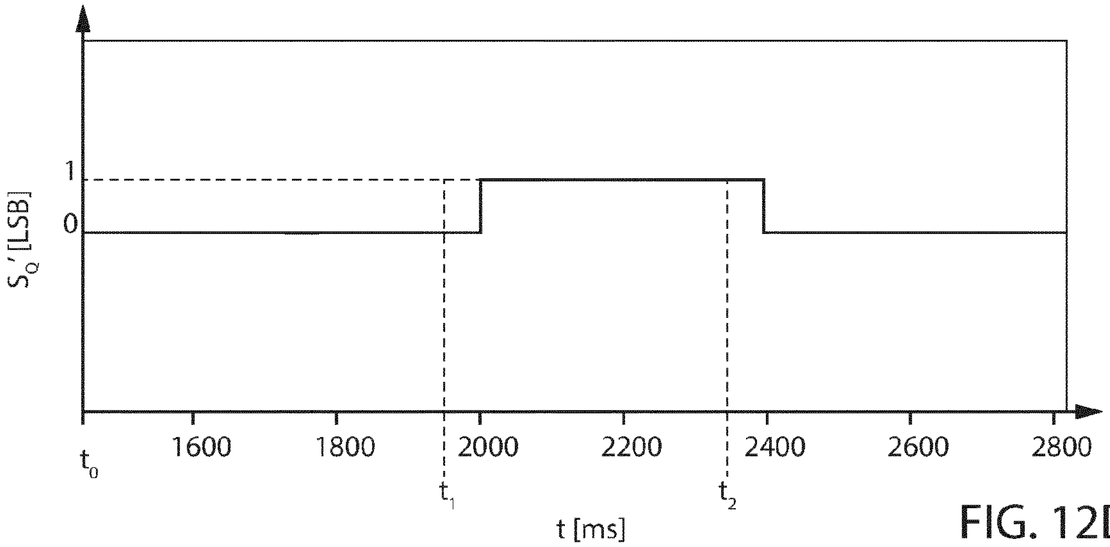


FIG. 12D

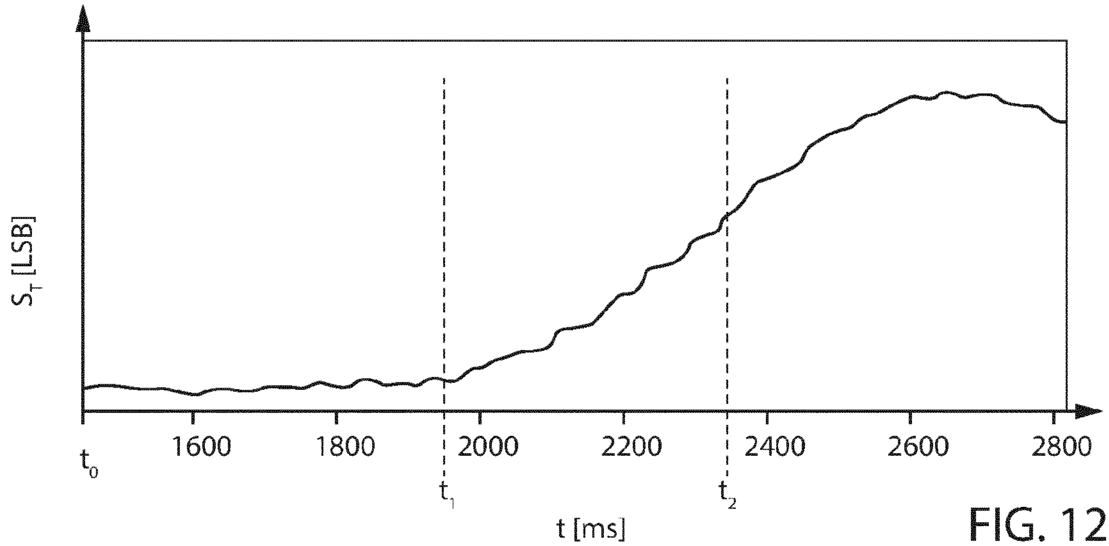


FIG. 12E

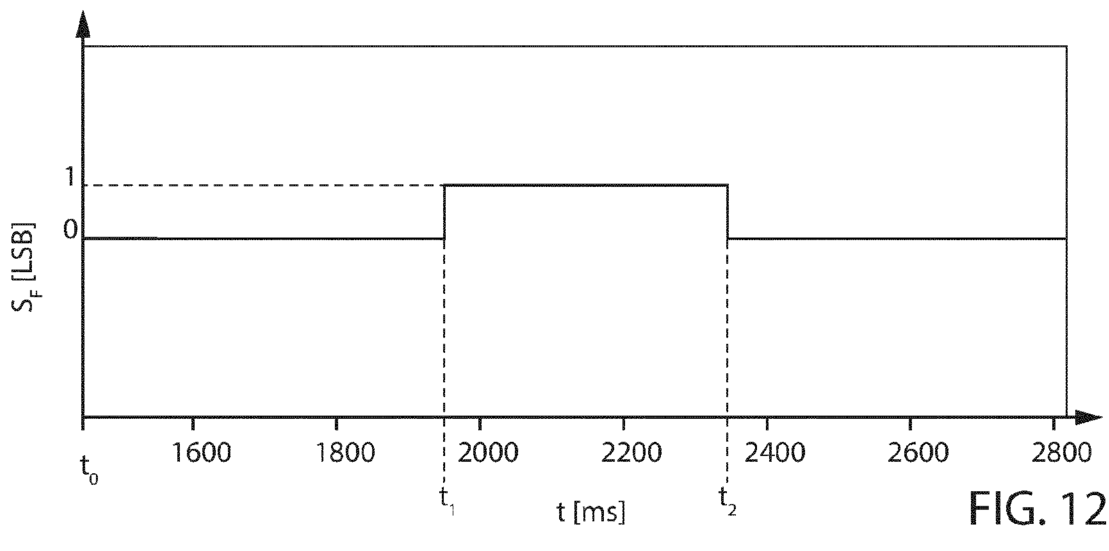


FIG. 12F

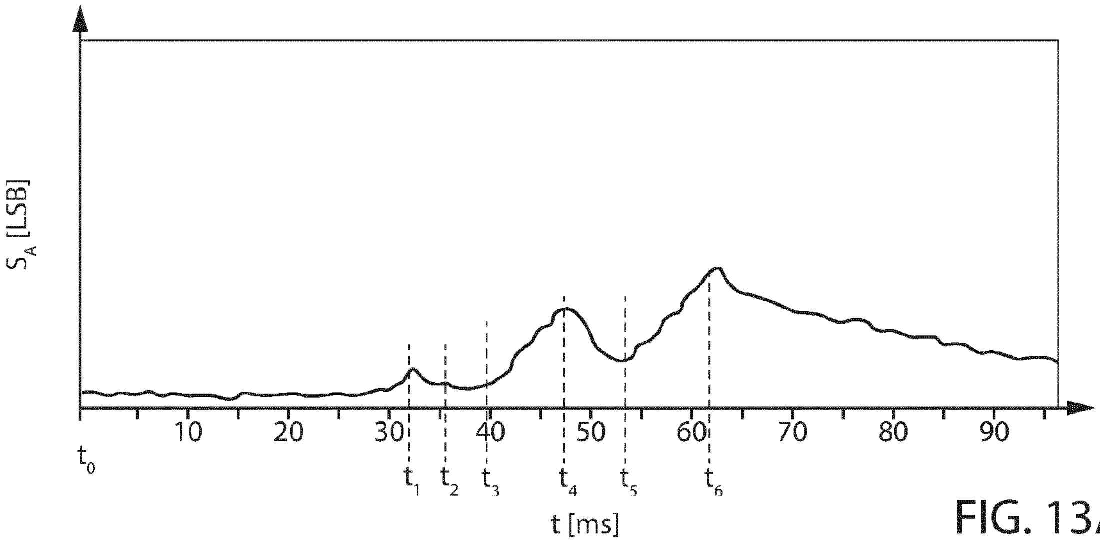


FIG. 13A

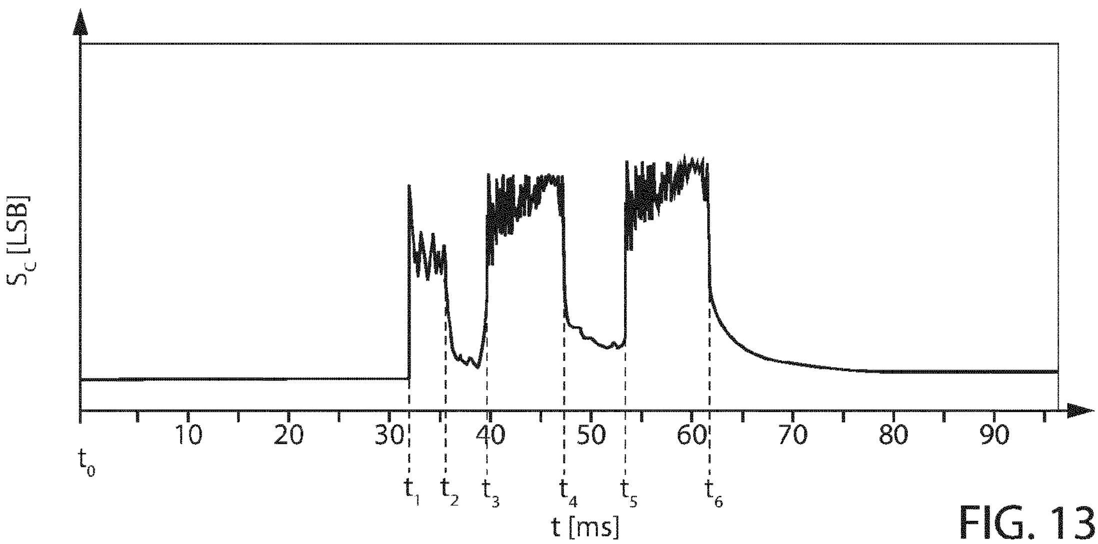


FIG. 13B

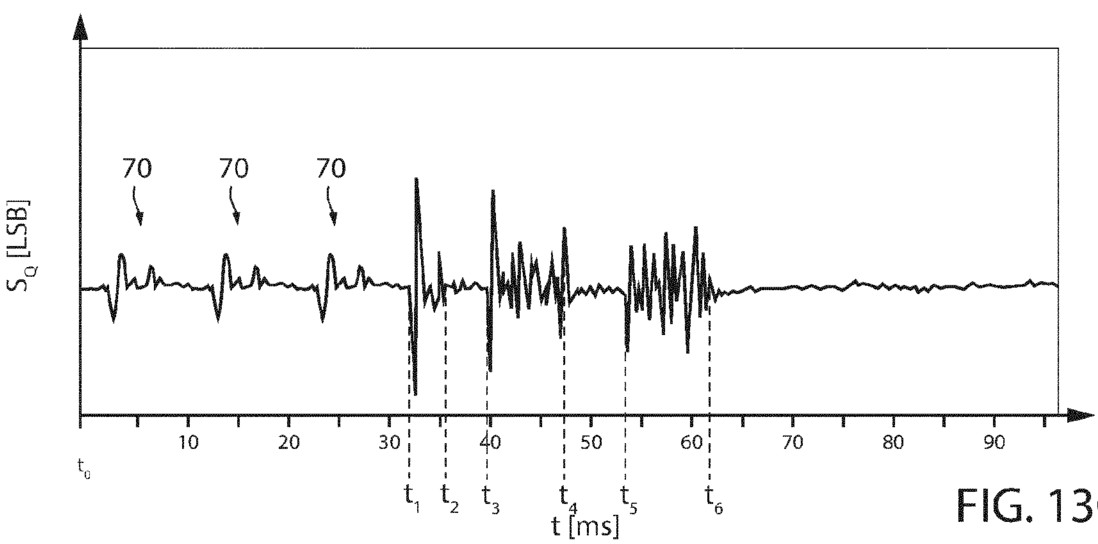


FIG. 13C

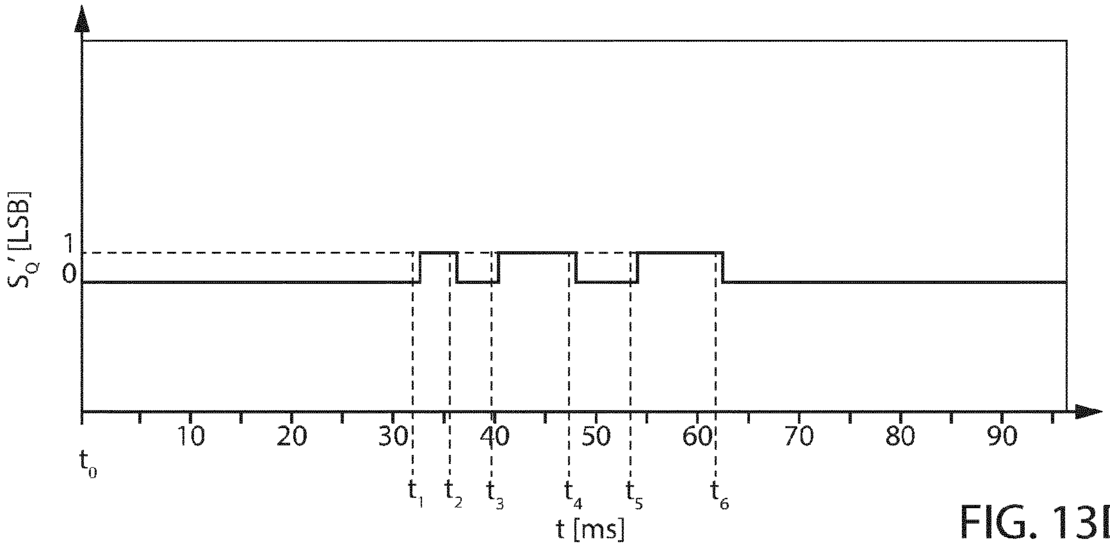


FIG. 13D

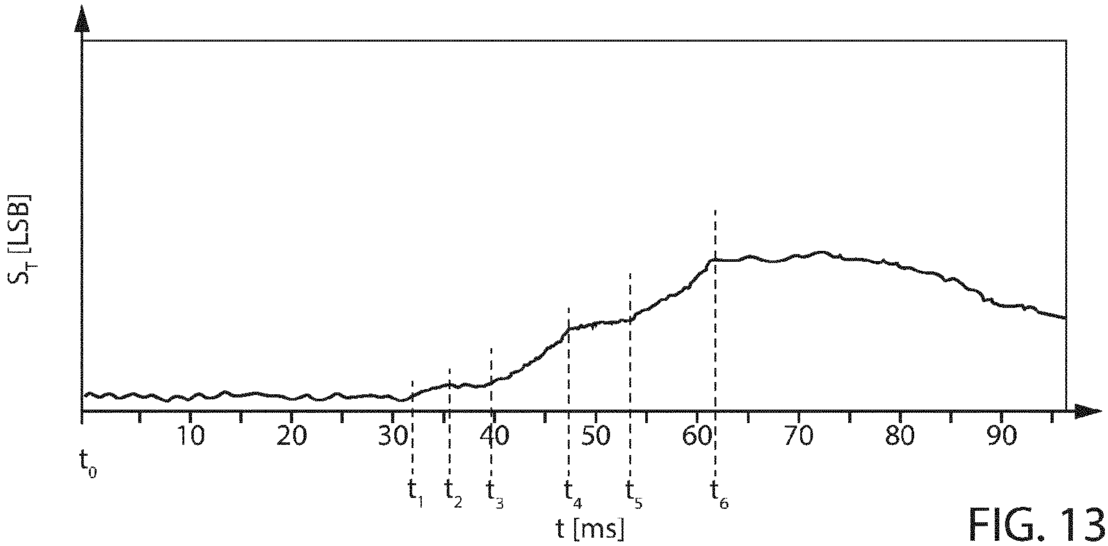


FIG. 13E

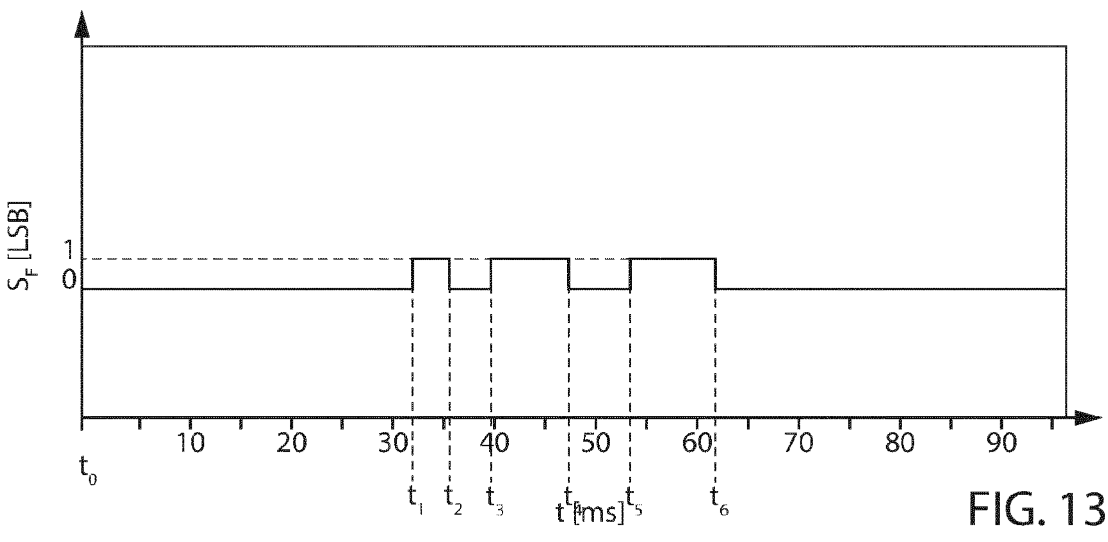


FIG. 13F

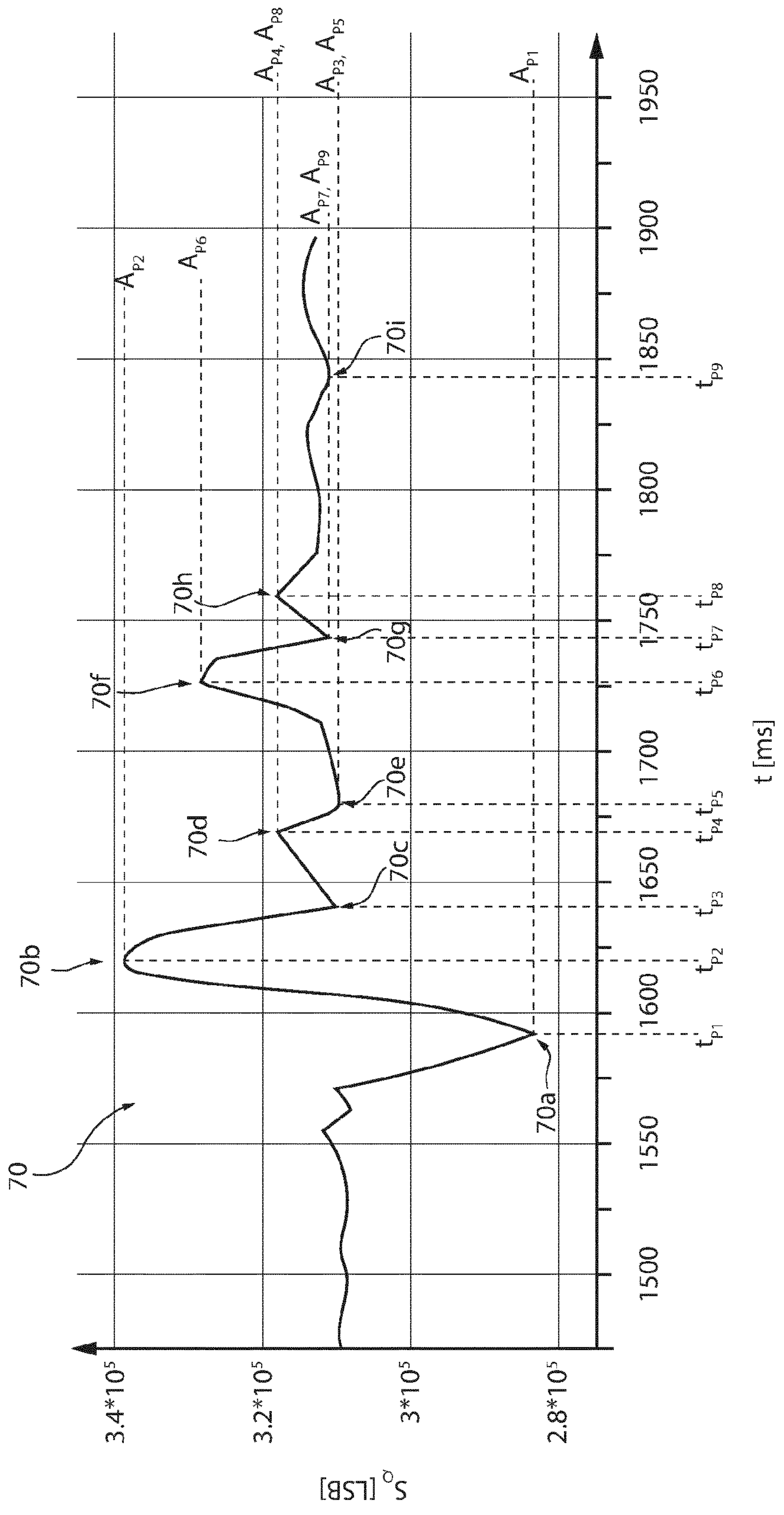

70
70a
70b
70c
70d
70e
70f
70g
70h
70i
3.4*10^5
3.2*10^5
3*10^5
2.8*10^5
S_Ω [LSB]
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
t [ms]
A_P1
A_P2
A_P3, A_P5
A_P4, A_P8
A_P6
A_P7, A_P9
t_P1
t_P2
t_P3
t_P4 t_P5
t_P6
t_P7
t_P8
t_P9

FIG. 14

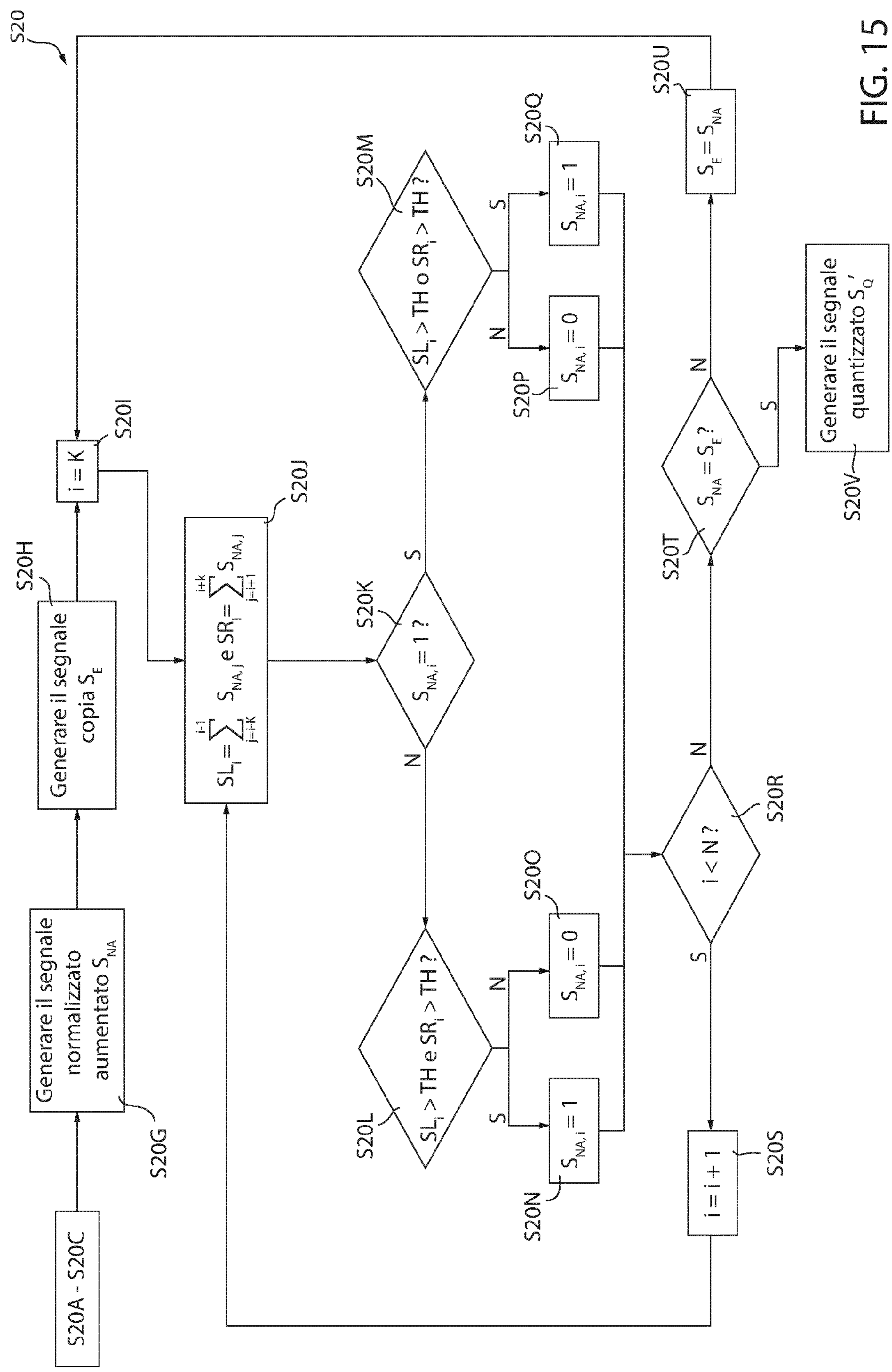

S20
S20A - S20C
Generare il segnale normalizzato aumentato S_{NA}
S20G
Generare il segnale copia S_E
S20H
i = K
S20I
$SL_i = \sum_{j=i-K}^{i-1} S_{NA,j}$ e $SR_i = \sum_{j=i+1}^{i+k} S_{NA,j}$
S20J
$S_{NA,i} = 1$?
S20K
S
N
$SL_i > TH$ e $SR_i > TH$?
S20L
$SL_i > TH$ o $SR_i > TH$?
S20M
$S_{NA,i} = 1$
S20N
$S_{NA,i} = 0$
S20O
$S_{NA,i} = 0$
S20P
$S_{NA,i} = 1$
S20Q
i < N ?
S20R
i = i + 1
S20S
$S_{NA} = S_E$?
S20T
$S_E = S_{NA}$
S20U
Generare il segnale quantizzato S_Q'
S20V

FIG. 15

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EUROPEAN SEARCH REPORT

Application Number
EP 24 15 9069

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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F23N

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	30 June 2024	Theis, Gilbert

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