

METHOD FOR COMPLEX WAVEFORM DETECTING AND IDENTIFYING CHEMICAL ODORS AND ODOR MIXTURES

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application claims benefit of United States Provisional Application 63/545,388
filed October 24, 2023, the complete contents of which are incorporated herein by reference.

BACKGROUND

Technical Field

10 The invention generally relates to detecting and identifying chemical odors and
mixtures of odors and, more particularly, to electronic nose based detection and identification
different odors and/or mixtures of odors.

Description of Related Art

15 Devices generally referenced as “electronic noses” or “e-noses” use gas sensors,
which output electric signals at levels indicating concentration of certain chemical vapors and
use the electric signals for detecting and identifying of specific odors. However, current
techniques of electronic odor detection and identification have shortcomings. Some arise from
20 the fact that although current gas sensors can generate signals in response to millions of
different chemicals that exist another fact remains; unlike signal outputs of light sensors,
which can be characterized in terms of the light spectrum bands for colors, e.g., orange, yellow,
green, blue, indigo, and violet, there is no known “odor spectrum” for characterizing or
classifying outputs of gas sensors.

25 One example of such shortcomings is current odor identification and classification
techniques can have insufficient selectivity for some applications, which can be problematic
for generalized odor recognition.

30 Another shortcoming in current odor classifying techniques is insufficient accuracy
and resolution for inspecting certain odor mixtures and aromas such as given off by certain
natural substances such as coffee beans and certain other foods and beverages. Another
shortcoming of current techniques of classifying and identifying odors is insufficient accuracy
for identifying or classifying a quality in certain odors wherein the quality has a nature that

can change over time. This shortcoming can arise, for example, in relation to freshness of foods. Another shortcoming with current odor sensing and classification techniques is lack of unique correspondence between sensor output level and odor concentration, i.e., a specific output level of a sensor is not necessarily indicative of a specific concentration of a specific odorant.

Accordingly, there is need for improved an method and system for electronic detecting and identifying of odors.

SUMMARY

This Summary identifies example features and aspects and is not an exclusive or exhaustive description of disclosed subject matter. It will be understood that whether or not features or aspects are included in or omitted from this Summary is not intended as indicative of relative importance of such features or aspects. Additional features and aspects are described in the following detailed description and drawings that form a part thereof.

Systems and methods according to various embodiments provide, among other features and advantages, novel generating of complex waveform electrical signatures in response to, corresponding to, and unique different odors and mixtures of odors. According to one or more embodiments, the novel generating can produce complex waveform electrical signatures unique to the odor and to the odor concentration.

One example system according to one or more embodiments can comprise a first odor sensor and a second odor sensor, respectively configured to convert exposure to an odorant to electrical signals that exhibit respectively different electrical response characteristics.

An example system according to one or more embodiments can further comprise complex waveform generating resource, e.g., a circuitry or processing logic or both, configured to generate, using both the first sensor modulated first oscillatory signal and the second sensor modulated second oscillatory signal a complex waveform.

Methods according to one or more embodiments feature novel generation, in response to different odorants, of complex waveform signatures, the complexity provided through combinations of features including odorant exposure to two or more sensors that generate different electrical responses to the odorants, followed by conversion of the different electrical responses to corresponding, differently formed oscillating signals and then, via process combining the differently formed oscillating signals, forming the complex signature.

A system according to one or more embodiments can further include a conversion or translating resource, e.g., circuitry or processing logic or both, configured to translate the first sensor signal to a first sensor modulated first oscillatory signal and to convert or translate the second sensor signal to a second sensor modulated second oscillatory signal. According to one or more embodiments, the conversion or translating can include generating a first frequency carrier signal and a second frequency carrier signal, modulating the first frequency carrier signal with the first sensor signal, and modulating the second frequency carrier signal with the sensor signal. In one or more embodiments the modulating can be, for example and without limitation, amplitude modulation.

Steps in an example method according to one or more embodiments can include a sensor array, comprising at least a first sensor and a second sensor, configured with different electrical response characteristics, receiving an increased concentration of an odorant, and the sensors outputting in response, respectively, a first sensor signal and a second sensor signal. Further according to one or more embodiments, the first sensor signal can exhibit a first signal versus time characteristic and, based at least in part on the differences between the first electrical response characteristic and the second electrical, the first signal versus time characteristic the second signal versus time characteristic can differ from one another. shape can differ from the first signal versus time shape based at least in part on the odorant type combined with the difference of the second electrical response characteristic from the first electrical response characteristic. Steps in the method's processes can further include generating a complex waveform signal, which can be based at least in part on both the first sensor signal and the second sensor signal, and can have a complex waveform shape that, based at least in part on both the first signal versus time shape and the second signal versus time shape, can be the complex waveform signature of the odorant.

An example system according to one or more embodiments, can provide a generating of a complex waveform that corresponds to an odor, and features can include a sensor array having at least two sensors, wherein a first sensor among the at least two sensors can be configured, with respect to the first sensor's sensing response to at least one target odorant, with a first electrical response characteristic, and to output, in response to being exposed to a target odorant, a first sensor output signal, having a first change with respect to time characteristic that is based at least in part on the target odorant and the first electrical response characteristic. The system can also include a second sensor among the at least two sensors

being configured, with respect to sensing response to the at least one target odorant, with a second electrical response characteristic, and to output, in response to being exposed to the target odorant, a second sensor output signal, having a second change with respect to time characteristic that differs from the first change with respect to time characteristic by a difference that is based at least in part on the target odorant and the difference between the first electrical response characteristic and the second electrical response characteristic. The system can further include a processor programmed to modulate a first oscillatory signal, using the first sensor output signal, to generate a first sensor signal modulated first oscillatory signal, and modulate a second oscillatory signal, using the second sensor output signal, to generate a second sensor signal modulated second, and combine the first sensor signal modulated first oscillatory signal and the second sensor signal modulated second oscillatory signal plurality to form a complex waveform, corresponding to the odorant.

Further features and benefits can include but are not limited to processing blocks or steps configured to compare the complex waveform signal generated in response to an unknown odorant or mixture of odorants against a stored database of reference complex waveform signatures, for a “best match” identification of the odor(s) and mixtures of odors.

Further, according to one or more embodiments the step or processing block for generating the complex waveform signatures unique to different odors and mixtures of odors can be configured to place the signatures within human-audible bandwidths.

BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the nature and advantages of the embodiments may be realized by reference to the following drawings. It will be understood that the drawings show illustrative, not limitative examples. It will also be understood that graphics in the drawings are scaled for readability and that graphic representations of functions and features are not necessarily drawn to a scale consistent with their physical implementations. Further, in the drawings similar components or features may have the same reference label.

Figure 1 presents a functional block schematic of one example system according to one or more embodiments for real time generating, responsive to different odors and/or mixtures of odors, corresponding complex waveform signatures, each unique to the sensed odor and/or mixture of odors, using novel generating and combining plural sensor signal modulated oscillatory signals.

Figure 2 presents a functional block schematic of another example system according to one or more embodiments for real time generating complex waveform signatures corresponding to and unique to different odorants and/or mixtures of odorants, using an exemplary larger number of sensors modulating a larger population of basis frequencies.

5 Figure 3 presents graphic illustration of operations in generating and combining a plurality of oscillatory signals, and such operations can be used in providing, according to various embodiments, complex waveform signatures unique to different odorants and/or mixtures of odorants.

10 Figure 4 presents a functional block schematic of another example system according to one or more embodiments, providing real time generating of different complex waveform signatures, unique to different odorants and/or mixtures of odorants, using novel generating and combining plural sensor modulated oscillatory signals, and further featuring reference complex waveform database configured odorant identification and classification.

15 Figure 5 presents a functional block schematic of another example system according to one or more embodiments providing plural sensor modulated oscillatory signal frequency generation of complex waveform signatures and further featuring complex signature-based audio notification or alarms responsive to one or more specific odorants and/or or mixtures of odorants.

20 Figure 6 presents a functional block schematic of one example plural gas sensor amplitude modulated (AM) frequency configuration for system or method operations in real-time generating, according to one or more embodiments, complex waveform signatures unique to different odorants and/or mixtures of odors.

25 Figure 7 presents a functional block schematic of one example computer system configured to provide system logic and perform process step in accordance with one or more disclosed embodiments.

Figure 8 presents a circuit schematic for one example hardware implementation of one or more systems in accordance with the Figure 6 functional block.

30 Figure 9 shows a photograph of one constructed and inventor-tested hardware prototype implementation of one example system according to one or more embodiments for generating different complex waveform signatures corresponding to and unique to different odors and/or mixtures of odors.

Figure 10 graphically presents observed signals from the Figure 9 inventor-tested

prototype system, responsive to presenting a same odor to a first sensor and a second sensor of the system, the signals including (i) a first sensor signal amplitude modulation of a first channel frequency, (ii) a second sensor signal amplitude modulating of a second channel frequency, and (iii) a complex waveform signature produced by combining the two amplitude modulated channel frequencies.

Figure 11 graphically presents, on a two-dimension (2D) signal level versus time graph, three separate signal level versus time plots, showing inventor measured outputs from one commercial, off-the-shelf (COTS) NH₃ sensor, one COTS CO (RED) sensor, and one COTS NO₂ (oxygen or "OX") sensor, in response to exposure to different concentrations of ethanol vapor.

Figure 12 graphically presents on a 2D signal level versus time graph, signal level versus time plots, showing inventor measured outputs from the COTS NH₃ sensor, the COTS CO (RED) sensor, and the COTS NOS₂ (OX) sensor, in response to exposing the sensors to a succession of ethanol, citral (chemical formula C₁₀H₁₆O), Windex(TM) brand window, and phenethyl alcohol (PEA).

Figure 13 graphically presents operations and magnitude versus time plots of certain signals generated in a process of generating, according to one or more embodiments, a complex waveform signature responsive to and unique to a selected concentration of Listerine(TM) vapor, operation including exposing the vapor to the NO₂ (OX), CO (RED), and NH₃ sensors, the resulting sensor outputs amplitude modulating corresponding frequencies, producing AM modulated frequencies, and combining the AM modulated frequencies to produce the complex waveform signature.

Figure 14 graphically presents operations and magnitude versus time plots of signals generated in a process similar to that presented in Figure 13 generating, according to one or more embodiments, using a plurality a generated AM modulated frequencies, a respective complex waveform signature responsive to and unique to a selected concentration of ethanol.

Figure 15 presents the graphics of Figure 14, overlayed with representation of the testing apparatus and showing enlarged view of the complex waveform signature.

Figure 16 graphically presents complex waveform signatures for a particular concentration of Listerine(TM) vapor and ethanol vapor, generated by a constructed prototype in accordance with one or more embodiments.

Figure 17 shows an illustrative example of a multiple sensor, sensor output signal frequency modulated oscillatory signal generation of complex waveform signature in accordance with one or more embodiments.

DETAILED DESCRIPTION

5 The present disclosure provides novel, improved techniques of detecting, identifying, classifying and quantifying odors. Systems and methods according to various embodiments feature, in combination with other elements and aspects, novel processes include exposing an odorant or mixture thereof to a plurality of differently configured gas sensors, and generating, based on the plurality of sensor outputs, a plurality of sensor modulated oscillations, then
10 combining the sensor-modulated oscillations to create a corresponding complex waveform signature that can be unique for each odor or mixture of odors.

As used in this disclosure, the terms “sensor,” “gas sensor,” and “odor sensor” have identical meaning, i.e., are interchangeable without change in meaning.

The term “electrical response characteristic” and its abbreviated form recitation “as
15 ER characteristic,” which is used herein, in the context of describing or referring to a sensor, will be understood to mean the particular change with respect to time characteristics of the sensor’s electrical output signal in response to the sensor receiving an increase in concentration of an odorant to which the sensor is sensitive, and it will be understood that “characteristic” encompasses a transient signal versus time characteristic and a steady-state
20 signal versus time characteristic.

“Odor,” as used in this disclosure, encompasses a smell or scent caused by a vapor state or gas state of a physical substance, e.g., a chemical compound, carried by an ambient atmosphere.

“Odorant,” as used herein means airborne molecules or particles that, at least at a
25 threshold concentration, produce or exhibit a respective odor.

“Volatile” as used herein means a tendency to evaporate at room temperature, where “evaporate” means to undergo a phase change from a liquid state or a solid state to a gas state without substantive change of the molecule itself.

One example system according to one or more embodiments can comprise at least two
30 different sensors, “different” meaning having mutually different ER characteristics, with respect to at least one odor or combination of odors. One example arrangement of “at least two different sensors” comprise, but is not limited to, at least a first sensor having a first ER

characteristic with respect to a first target odorant, in combination with a second sensor having a second ER characteristic with respect to the first target odorant. Another example arrangement of “at least two different sensors” can comprise, but is not limited to, at least a first sensor having a first ER characteristic with respect to a first target odorant, in combination
5 with a second sensor having a second ER characteristic with respect to the first target odorant, in further combination with a third sensor that has, for example, a third ER characteristic with respect to the first target odorant or, for example, a third sensor that with respect to sensor function is a duplicate of the first sensor.

It will be understood that “sensor array,” as used in this disclosure, means a plurality
10 of sensors arranged in a spatial distribution that, absent explicit description or other statement to the contrary, is not intended as or as implying any limitation on spatial pattern or patterns, or define any spatial pattern or patterns or any alignment.

According to one or more embodiments, the sensor array may be supported in a structure configured to enclose a volume that may be referred to, for purposes of description,
15 as an “interior volume.” In one or more embodiments, the housing can be configured with or to provide, for example, an inlet port into and for flow purposes an outlet port out from the interior volume.

According to one or more embodiment, spatial distribution and arrangement of the sensors within the sampling space can be such that when an odor is to be analyzed, all the
20 sensors may be concurrently exposed to the odor, with the concentration of the odorant being constant throughout the sampling space.

In implementations according to one or more embodiments, a single sensor may be employed, e.g., to establish a single corresponding waveform as a control.

In certain implementations of systems and methods according to one or more
25 embodiments it can be preferable to configure two or more of the sensors in the multiple sensor array to have different respective detection properties. For example, one sensor of the array configured to detect NH_3 , another configured to detect CO_2 , and so forth. Alternatively, or in addition, multiple identical sensors may be present in the array, for purposes such as but not limited to operation as a control, e.g., via comparing the signals from the nominally
30 identical sensors. Another purpose for or benefit of including multiple identical filters in the array is the correspondingly attained option of selectively applying different modifications to different ones of the identical sensors, e.g., attaching different filters, as described in more

detail in later paragraphs.

Each sensor can be configured to detect and respond to at least one molecule or group of molecules (an odor stimulus or odor stimuli) that share certain chemical properties in vapor form and may be referred to herein as a “target vapor,” as “target molecule(s),” a “target odor molecule,” a “target vapor molecule,” and so forth. It will therefore be understood that a “nontarget vapor,” as the term is used herein, can be any collection of airborne molecules or particles which have no significant effect upon the response or behavior of the sensor array. As such, a “target vapor may be a pure vapor comprising a plurality of molecules all having the same chemical formula, or it may be a mixed vapor comprising a plurality of molecules of different chemical formulae, the combination of which produces a sensor array response which is different from the sensor array response to one or more of the chemical formulae provided individually. A group of target molecules may share, for example, similar binding/ligand properties or rates of diffusion through a filter. When target molecules interact with the surface of a sensor, they change the conductivity of the sensor and alter the amount of current that is detected.

Each sensor or grouping of sensors of a sensor array may be configured to be sensitive only to a particular target vapor. In an embodiment, a sensor array can comprise a plurality of groupings of one or more sensors, where each grouping is configured to detect a different vapor. Alternatively, each sensor may have sensitivity to a plurality or range of vapors.

In implementations according to various embodiments, one or more of the sensors can be configured for selectivity to a particular target vapor by arranging a target-selective pass filter, e.g., over the sensor’s detection layer. The target-selective pass filter can operate, for example, by impeding vapors of chemical composition other than the target vapor from reaching the sensor’s detection layer. Installing and removing such filters may be used to modify the selectivity of the sensors. For example, all the sensors of an array, or a section or portion of the sensors of an array can comprise identical sensors that can be selectively or optionally modified to each include a different filter to distinguish different vapors. In such implementations each of the filters can differentially affect the passage or flow of molecules across the filter, e.g., by an active regulation or alternatively, a passive regulation, such as absorption or diffusion at different rates for different vapor molecules. Each sensor can therefore have a different reaction/sensitivity to the same vapor molecule. As a result, one or more otherwise identical sensors may give a different response profile for a given vapor. The

different response profiles correspondingly which can be associated with a unique odor fingerprint.

According to one or more embodiments the plurality of sensors can be configured to output analog signals. Accordingly, an array of sensors with different sensitivity characteristics can output, in response to all receiving a particular odorant or mixture of odorants, a plurality of different analog signals, each sensor's analog signal having a respective magnitude and exhibiting changes in its magnitude with respect to time associated with or corresponding to the sensor's sensitivity to the odorant or mixture of odorants. According to one or more embodiments, the respective analog output signals of each of two or more of the sensors can be transformed into a respective domain waveform prior to being combined with n, thereby producing a plurality of initial waveforms. The plurality of initial waveforms is then combined to produce a domain complex waveform signature in the domain that corresponds to the odor or mixture of odors that was detected.

Figure 1 shows a functional block schematic of one configuration of one example system 100 according to one or more embodiments that, via functional blocks configured to translate multiple gas sensor signals into corresponding sensor-modulated modulated oscillatory signals, and functional blocks configured to combine the sensor-modulated oscillatory signals, can provide complex waveform signatures for each of a plurality of different odors, or mixtures of odors, or both.

Referring to Figure 1, the system 100 can include a first sensor 102-1 and a second sensor 102-2. According to one or more embodiments the first sensor 102-1 may be configured for sensitivity to gas state or vapor state molecules of substances, e.g., chemical compounds, within a first group or list and the second sensor 102-2 may be configured for sensitivity to gas or vapor state molecules of substances within a second group or list. For purposes of description, molecules of substances within the first group or list will be alternatively referred to as "first target molecules" and molecules of substances within the second group or list as "second target molecules. According to various embodiments the first sensor 102-1 and the second sensor 102-2 can be arranged in a housing 103, within an enclosed interior volume 103-V. The housing 103 can be provided, according to one or more embodiments, with a first opening or first air passage 103-A and a second opening or second air passage 103-B, to enable, e.g., flow of odorant vapor from an exterior of the housing 103 into the interior volume 103-V and out. Optionally, according to one or more embodiments the first air passage 103-1 and

second air passage 103-2 may be provided with selectively actuatable open-closed state passage covers or shutters that be controlled, for example and without limitation, by a computer-generated command, a user-interface actuatable button, or equivalent. It will be understood that according to one or more embodiments and in various applications the housing
 5 103 may be omitted.

In accordance with one or more embodiments, the first sensor 102-1 can be configured with a first electrical response characteristic and the second sensor 102-1 with a second electrical response characteristic that differs from the first.

Figure 1 shows in graphics an example signal magnitude versus time form of the first sensor signal “GS1(t),” and an example signal magnitude versus time form of the second sensor signal “GS2(t).” According to one or more embodiments, system 100 can include a first sensor signal modulated first oscillatory signal generator 104-1 that can be configured to receive the first sensor signal and generate, in response, a first sensor signal modulated first oscillatory signal or first frequency, such as the Figure 1 example MB1(t), in accordance with
 10 the following Equation (1):

$$MB1(t) = GS1(t) \bullet SG(\omega_1(t)) \quad \text{Equation (1)}$$

where

SG can be, for example, a sine or cosine function, and

ω_1 can be, for example, radians per second.

The system 100 can also include a second sensor signal modulated second oscillatory signal generator 104-2 that can be configured to receive the second sensor signal and generate, in response, a second sensor signal modulated second oscillatory signal or frequency. According to one or more embodiments, the second sensor signal modulated second oscillatory signal generator 104-2 can be configured to generate the second sensor signal
 20 modulated second oscillatory signal as a second sensor signal amplitude modulated second oscillatory signal, such as the Figure 1 example MB2(t), in accordance with Equation (2):

$$MB2(t) = GS2(t) \bullet SG(\omega_2(t)) \quad \text{Equation (2)}$$

where ω_2 can be, for example, radians per second.

According to various embodiments, the SG function of Equation 2 can be the same as the SG function of Equation (2), e.g., both can be a sine function.

The system 100 can further include a combiner 106 that can combine $MB1(t)$ and $MB2(t)$ to produce a complex waveform such as the example $CSS(t)$ appearing in the figure, e.g., by a summation in accordance with Equation (3) as follows:

$$CSS(t) = MB1(t) + MB2(t) \quad \text{Equation (3)}$$

Figure 2 presents a functional block schematic of another example system 200 according to one or more embodiments for real time generating complex waveform signatures corresponding to and unique to different odorants and/or mixtures of odorants, using a larger population of gas sensors modulating a larger population of oscillating signals or frequencies. The Figure 2 system 200 implements the larger population of gas sensors by adding a third sensor 202-1 and up to an Nth sensor 202-N, which for purposes of description are also collectively referred to as “sensors 202”).

The third sensor 202-1 can be configured with a third electrical response characteristic, up to the Nth sensor 102-N with an Nth electrical response characteristic.

Responsive to exposure to one or more odorants within a group, or range of odorant types in accordance with the electrical response characteristics of the sensors 202, each outputs a respective sensor signal, as specified below for the third sensor signal $MB3(t)$ in accordance with

$$MB3(t) = GS3(t) \bullet SG(\omega_3(t)) \quad \text{Equation (3)}$$

$$MBN(t) = GSN(t) \bullet SG(\omega_N(t)) \quad \text{Equation (4)}$$

where ω_3 and ω_N can each be, for example, radians per second.

As described above for Equation (1) and Equation (2), according to various embodiments, the SG function of Equation (4) and Equation (3) can be identical to one another and can be the same as the SG function of Equations (1) and (2)..

Figure 3 schematically illustrates certain aspects in and operations in generating, responsive to different odorants and mixtures therefore one or more embodiments in generating complex waveforms by generating a plurality of different frequencies such as the illustrated example plurality comprising a first frequency carrier wave 302-1, a second frequency carrier wave 302-2, and a third frequency carrier wave 302-3, which will be

collectively referenced herein as “carrier waves 302.” Operations further include combining
304 the different frequency carrier waves. generating a summing a plurality of different
frequencies, in this example integer three. The Figure 3 example is simplified, as the
combining (e.g., summing) is of non-modulated oscillating signals. The Figure 3 example
5 configures the carrier waves 302 as non-modulated sine waves in accordance, for example,
Equations (5), (6), and (7).

$$F1(t) = M1\sin(\omega_4 t) \quad \text{Equation (5)}$$

$$F2(t) = M2\sin(\omega_5 t) \quad \text{Equation (6)}$$

$$F3(t) = M3\sin(\omega_6 t) \quad \text{Equation (7)}$$

10 where,

M1, M2, and M3 can be scalar weights that can be, but are
not necessarily equal to one another, and

$\omega_4, \omega_5, \omega_6$ can be, e.g., in radians per second.

The combining 304 that forms the complex waveform FC(t) can combine F1(t), F2(t),
15 and F3(t) as a summing operation, in accordance with Equation (8) below.

$$FC(t) = F1(t) + F2(t) + F3(t) \quad \text{Equation (8)}$$

Generation of the complex waveform signatures as described in reference to Figure 1
and Figure 2 differs from odor to odor, or from chemical to chemical. The complex waveform
signatures can therefore be used to establish the identity of an unknown odor sample based,
20 for example, on comparisons of the unique signature to existing known (control) signatures in
a database. Accordingly, a system such as the system 100 or the system 200 can include a
database of previously acquired digital images of complex waveforms corresponding to
known vapors and mixtures of vapors and the methods of identifying an unknown odorant
include a step of a performing best match comparison between existing, the predetermined
25 complex waveforms of known vapors to identify a sample (e.g., an unknown) vapor.

Various embodiments can further include processing resources and processes for
establishing and for storing the database of complex waveform signatures. The complex
waveform database can be produced for example by performing the steps of one or more of
the methods described above but using samples of known odorants. Optionally, according to

various embodiments, various “blank” or other control waveforms can be stored with or separate from the examples of known odorants.

The establishing of the database can further include performing data acquisition with the same odorant but at different concentrations. In this manner, a unique complex waveform
5 can be generated and included in the database for each among a plurality of different concentrations of the odorant.

Figure 4 presents a functional block schematic of one configuration of one example system 400 providing, according to one or more embodiments for real time generating of different complex waveform signatures in response to different odorants and/or mixtures of
10 odorants, using novel generating and combining plural sensor modulated frequencies, and further providing generated complex waveform signature to reference complex waveform database “closest match” based odorant identification and classification.

The Figure 4 illustrated configuration of system 400 comprises an adaptation of the Figure 2 system 200, so as to avoid obfuscating concepts and operations of the system 400
15 features of reference complex waveform database identification and classification with description of details not particular to such features. As illustrated, an example system 400 can comprise a system such as the system 200 combined, in various configurations, with an A/D converter resource such as the A/D 402 to digitize the complex waveform (abbreviated in Figure 4 blocks as “CPXW”) signatures output by the complex waveform generating block
20 208, and a CPXW Signature Identifier-Classifer Database 404 operatively, e.g., logically coupled to a CPXW Signature Identifier-Classifer logic 406, and to a CPXW Signature Identifier-Classifer Database Management logic 408.

As will understood by persons of skill in the pertinent arts, after reading this disclosure in its entirety, systems providing functional capabilities such as described for the system 400
25 can be implemented, for various applications, with computer resources for generating the complex waveforms and for creating and maintaining the complex waveform database creations and management, being resident in a server that connects, via server interface(s) to the sensors, e.g., to the system 400 sensors 102 and 202. Hardware implementation of resources for creating and/or maintaining of the CPXW Identifier-Classifer Database 404 can
30 comprise, for example and without limitation a storage resource of a computer system such as described in more detail in later sections of this disclosure, e.g., in reference to Figure 7.

In like manner, according to various embodiments the CPXW Signature Identifier-

Classifier Database Management logic 408 can be implemented by particular computer processing instructions stored, e.g., in a non-volatile, non-transitory memory that is communicatively connected to a programmable processing resource, in combination with an available processing capacity of a computer resource such as described in more detail in later sections herein, e.g., in reference to Figure 7.

Figure 5 presents a functional block schematic of a configuration of one system 500 according to one or more embodiments for multi-sensor modulated frequency-based generation of complex waveform signatures unique to one or more specific odorants and/or mixtures of odorants, and further comprising complex waveform signature triggering of audio notification or alarm. The Figure 5 example system 500 is shown configured as an adaptation of the Figure 2 system 200 to avoid obfuscating features of the system's audio notification embodiment with description of details not particular to such features. Adaptation of the system 200 can include, for example, adding an acoustic loudspeaker 504 and, optionally, depending at least in part on specifications of the acoustic loudspeaker 504 and the desired audio level, an audio amplifier 502. Adaptation can also include, because of the audible nature of the alarm, configuring the first sensor signal modulated first oscillatory signal generator 104-1, the second sensor signal modulated second oscillatory signal generator 104-2, the third sensor signal modulated third oscillatory signal generator 204-1, ..., and the Nth sensor signal modulated Nth oscillatory signal generator 204-N such that $\omega_1, \omega_2, \omega_3, \dots, \omega_N$ and therefore ω_6 are in an audible sound frequency band. Adaptation may also include, e.g., in configurations wherein the combiner or combining operations 206 output the complex waveform as discretized, digital data, addition of a digital to analog converter (DAC).

Figure 6 presents a functional block schematic of one configuration of one system 600 for multiple sensor signal amplitude modulated (AM) basis frequency generating, according to one or more embodiments, of complex waveform signatures unique to different odorants and/or mixtures of odors.

Arrangements of the system 600 can include a first sensor 602-1, second sensor 602-2, third sensor 602-3, and fourth sensor 602-4, and subsequent description will alternatively reference these, collectively, as "the sensors 602." Each of the sensors 602 can be configured, according to various embodiments, with a particular ER characteristic to output, in response to exposure to a target vapor, a respective sensor signal having a respective signal change with respect to time characteristics. Figure 6 shows, as examples of such generating, a first sensor

signal GN1(t) output from the first sensor 602-1, a second sensor signal GN2(t) output from the second sensor 602-2, a third sensor signal GN3(t) from the third sensor 602-3, and a fourth sensor signal GN4(t) from the fourth sensor 602-4, which subsequent description herein can alternatively reference, collectively, as “sensors signals 602.”

5 The system 600 can further include, according to one or embodiments, a first basis oscillatory signal/frequency generator 604-1, second basis oscillatory signal/frequency generator 604-2, a third basis oscillatory signal/frequency generator 604-3, and a fourth basis oscillatory signal/frequency generator 604-4. Subsequent description herein can alternatively reference these, collectively, as “the basis oscillatory frequency generators 604.”

10 The basis oscillatory frequency generators 604 can be configured to generate, for example, respective non-modulated oscillating carriers such as, for example, a first sinusoidal carrier signal $SF(\omega_1 t)$, a second sinusoidal carrier signal $SF(\omega_2 t)$, a third sinusoidal carrier signal $SF(\omega_3 t)$, and a fourth sinusoidal carrier signal $SF(\omega_4 t)$. The “SF” can be, for example, a sine function, and ω_1 , ω_2 , ω_3 , and ω_4 can be, for example, respective values in radians-per-second. It will be understood that ω_1 , ω_2 , ω_3 , and ω_4 in the context of Figure 6 may differ from ω_1 , ω_2 , ω_3 , and ω_4 appearing in Equations (1) through (7).

The system 600 can further include a first AM mixer 606-1, that can be configured to receive $SF(\omega_1 t)$ and the first sensor signal GN1(t), apply the first sensor signal GN1(t) as an amplitude modulator of the first sinusoidal carrier signal $SF(\omega_1 t)$, and output on line 608-1 a first sensor signal GN1(t), amplitude modulated first sinusoidal carrier signal $SF(\omega_1 t)$. The second AM mixer 606-2, can similarly receive $SF(\omega_2 t)$ and GN2(t) and output on line 608-2 a second sensor signal GN2(t), amplitude modulated second sinusoidal carrier signal $SF(\omega_2 t)$. The third AM mixer 606-3 and fourth AM mixer 606-4 can likewise output on lined 608-3 and 608-4, respectively, a third sensor signal GN3(t) amplitude modulated third sinusoidal carrier signal $SF(\omega_3 t)$ and fourth sensor signal GN4(t) amplitude modulated fourth sinusoidal carrier signal $SF(\omega_3 t)$.

In subsequent description herein the outputs of the first AM mixer 606-1, second AM mixer 606-2, third AM mixer 606-3, and fourth AM mixer 606-4 can be alternatively referenced, collectively, “sensor signal GNX(t) amplitude modulated sinusoidal carrier signals $SF(\omega_x t)$.” According to various embodiments, example of system 600 can further

include a combiner or summing device 610 that, through combining the sensor signal $GNX(t)$ amplitude modulated sinusoidal carrier signals $SF(\omega_x t)$, can generate the complex waveform signature $CSWS(t)$.

5 The analog signals generated or produced from each of the sensors can be provided as analog sensor output signals. In one aspect, the analog sensor output signals from a plurality of sensors can be individually processed to produce a modulated amplitude frequency waveform for each output. This can produce a plurality of modulated amplitude frequency waveforms. initial waveforms acquired during a single exposure of the array to an odor are combined by, for example, a voltage summing device to generate a unique complex waveform. 10 Processing of sensor analog output signals may include the steps of detecting a first electrical profile from the sensor. Electrical profiles may be of current flow, resistance, voltage, or impedance over time, for example.

For reasons such as aging of the sensors, there may be occurrences, over the apparatus lifespan of certain implementations of systems according one or more embodiments of 15 fluctuations or deviations of signal readings (i.e. “sensor drift”). Accordingly, systems according to various embodiments can include particular monitoring features that can identify fluctuations or gradual changes in the behavior/signal outputs of the sensors over time. The monitoring feature can be configured to compare one or more of the analog sensor output signals, the digitized sensor output signals stored in a sensor input buffer, and/or any other 20 response parameter value stored in a response parameter buffer, for a target vapor, with a memory-stored odor data for that target vapors A processor of the system may further comprise a calibrator logic that can correct or compensate for certain fluctuations or certain gradual changes in the electrical characteristics and/or sensitivity of the sensors of the sensor array.

25 Persons of skill in the pertinent arts, upon reading this disclosure in its entirety, will understand that implementation of systems in accordance with the appended claims, can include known sensors and/or known sensor arrays and even processing for existing sensor arrays, may be used. In an alternative embodiment, a commercially available sensor array for detecting vapor molecules may be adapted for use with the present invention. For purposes of 30 illustration, one example of such a commercially available sensor array can be, e.g., and without limitation, the Cyranose Electronic Nose manufactured and sold by Intelligent Optical Solutions (California, USA). The Cyranose® Electronic Nose is a handheld apparatus that can

be configured with a plurality of different types of sensors, e.g., and without limitation, CO₂, H₂S, O₂, or VOCs (Volatile organic compounds) sensors.

According to one or more embodiments, processing resources for performing steps of processes described herein may be implemented at least in part as processor-executable instructions embodied in a non-transitory computer-readable medium communicatively connected to a processor logic, the instructions being configured to cause the processor logic to perform described operations. The computer-readable medium can comprise any non-transitory medium such as, for example, including, but not limited to non-volatile media. Processing resources can also include volatile media. Non-volatile media may include, for example, optical or magnetic disks and other persistent memory. Volatile media may include, for example, dynamic random access memory ("DRAM"), which typically constitutes a main memory. Common forms of computer-readable media include, for example, a disk, hard disk, magnetic tape, any other magnetic medium, a compact disc read-only memory ("CD-ROM"), a digital video disc ("DVD"), any other optical medium, random access memory ("RAM"), programmable read-only memory ("PROM"), electrically erasable programmable read-only memory ("EPROM"), FLASH-EEPROM, any other memory chip or cartridge, or any other non-transitory, tangible computer-readable medium.

Figure 7 shows a function block schematic of one example computing resource 700, that may include one or more programmable processor(s) 702, a general storage 704 and an instruction memory 706 communicatively connected to the one or more of the processing resources 702 via a communication infrastructure, e.g., bus 708.

Processor(s) 702 can be provided by, for example, type or form of processing unit capable of processing data or interpreting, executing, and/or overseeing execution of one or more of the instructions, processes, and/or operations stored in the Instruction Memory 706. Processor(s) 702 may also direct or manage execution of operations by external processing resources.

General storage device 704 may include one or more data storage media, devices, or configurations and may employ any type, form, and combination of data storage media and/or device. For example, general storage device 704 may include, but is not limited to, a hard drive, network drive, flash drive, magnetic disc, optical disc, RAM, dynamic RAM, other non-volatile and/or volatile data storage units, or a combination or sub-combination thereof.

Electronic data, including data described herein, may be temporarily and/or permanently stored in the general storage 704.

Instruction memory 706 can store, e.g., on a non-transitory storage medium, processor executable instructions, for example, a basis frequency modulation control module, sensor select module, sensor configuration module, sensor monitoring module, sensor calibration module complex waveform signature to reference database match module, and alarm configuration module.

The computer system can include sensor interface 710 that can interface, to the sensors 712, and for purposes of receiving sensor output signals, the system 700 can include A/D 714. The sensor interface 710 can also provide a sensor control configuration connection 715 to the sensors 712. According to one or more embodiments the computer system 700 can include a reference complex signature database 716 and a user interface 718.

Implementations of the user interface 718 can include, for example and without limitation, hardware and/or software for capturing user input, including, but not limited to, a keyboard or keypad, a touchscreen component (e.g., touchscreen display), a receiver (e.g., an RF or infrared receiver), motion sensors, and/or one or more input buttons.

User interface device 718 may include one or more devices for presenting output to a user, including, but not limited to, a graphics engine, a display (e.g., a display screen), one or more output drivers (e.g., display drivers), one or more audio speakers, and one or more audio drivers. The computer system 700, according to one or more embodiments, can also include an alarm audio device 720 implemented, for example, by hardware such as audio speaker 504 or audio speaker 504 and audio amplifier 502 of the Figure 5 example system 500, which the processor(s) 702 may activate, via the alarm interface 722 and D/A converter 204.

According to one or more embodiments, the computer system 700 can include capability, for example, a cloud interface 728 for connecting to a cloud resource 730.

EXEMPLARY USES AND APPLICATIONS

The unique sound signatures can be used in many different applications to alert and inform the user. Electronic nose instruments are used (e.g., in the home or a vehicle) by consumers, by research and development laboratories, quality control laboratories and process & production departments for various purposes, examples of which include but are not limited to:

In the home, for example, uses of systems and methods according to one or more applications and/or adaptations, can include not only detecting spoilage of perishables in a refrigerator but, through the higher resolution signature provided by the novel generation of complex waveforms in accordance with one or more embodiments, can further detect and quantify a changes in the signature indicating the degree of the food spoilage in the refrigerator and/or on the shelf. Sound signatures might alert the user to a gas leak, high levels of CO, CO₂ or smoke (e.g., from food burning in an oven or on a stove, or from a fire in the structure, and so forth).

In quality control laboratory uses include but are not limited to monitoring conformity of raw materials, intermediate and final products; batch to batch consistency; detection of certain types of contamination, spoilage, and/or adulteration; origin or vendor selection; monitoring of storage conditions; rapid classification of food; meat, fish and poultry quality monitorin, and so forth.

In process and production departments, uses can include but are not limited to managing raw material variability; comparison with a reference product; measurement and comparison of the effects of manufacturing process on products; following-up cleaning in place process efficiency; scale-up monitoring, and so forth.

In product development phases uses can include but are not limited to sensory profiling and comparing various formulations or recipes; benchmarking of competitive products; evaluating impact of changes of process or ingredient on sensory features, and so forth.

In the fields of health and security uses can include but are not limited to: detection of dangerous and harmful bacteria, such as the smell of the MRSA (Methicillin-resistant *Staphylococcus aureus*) and methicillin susceptible *S. aureus* (MSSA), among others, e.g. by placement in hospital (or airplanes buses, etc.) ventilation systems to detect and therefore prevent contamination of other patients or equipment by many highly contagious pathogens; the detection of medical conditions including cancers by detecting the VOC's (volatile organic compounds) that indicate the medical condition; the detection of viral and bacterial infections in COPD exacerbations; the quality control of food products e.g. to indicate when food has started to spoil or, when used in the field, to detect bacterial or insect contamination; etc.

In the field of crime prevention and security, uses can include but are not limited to detection of “odorless” smells to detect the odors of bombs, explosives and gun residue despite other airborne odors capable of confusing police dogs; for drug detection; etc.

In environmental monitoring uses can include but are not limited to or identification of volatile organic compounds in air, water and soil samples; and so forth.

In manufacturing uses include but are not limited to monitoring e.g., flavor and/or fragrance of foods and beverages; packaging material (e.g., to detect leakages);
5 pharmaceutical products; cosmetics and perfumes; chemical manufacturing e.g., to monitor volatile chemical types and levels; and the like.

Odor-print complex waveform signature based odor identification in accordance with various embodiments can also assist in numerous personal and commercial applications. On a personal level, hygiene-related odors for which individuals are either insensitive or to which
10 they have become adapted could be uniquely signaled by audio outputs. The complex waveforms would have basic frequencies and undertones which could be recognized with training. Individuals with anosmia or dysosmia or complete olfactory adaptation could be alerted to environmental hazards such as smoke, ammonia or natural gas leaks with audio alerts that can be immediately recognized. Other less threatening occurrences such as a
15 significant other applying perfume could be signaled

In a commercial environment quality control setting spoilage of products can be signaled with unique sound waveforms. Environmental hazards such as smoke, natural gas leaks, and refrigerant leaks could be identified with unique aural patterns.

Normal compositions of flavorings, seasonings, meat searing levels with olfactory
20 components could be recorded and compared with standards.

Environmental hazards that involve, for example, gases that cannot be smelled or to which persons can tend to adapt, and therefore overlook, can be detected and, optionally, signaled with what can be a recognizable specificity.

Another feature and advantage provided by one or more embodiments is the capability
25 to co-present a mixture of odor components, responsive to which the plural sensors generate respective outputs, which processes according to one or more disclosed embodiments translate into a plurality of sensor-modulated, e.g., amplitude modulated, oscillating carriers and which then combine the plurality of sensor-modulated oscillating carriers, producing a complex waveform wherein the complexity contains the presence of the components. The complexity
30 thereby provided via but, e.g., with practice, recognizable complex waveform. through a bypassing of odor recognition. This can be generalized to odor mixtures by odor recognition allowing for co-presentation of mixture components.

EXAMPLES

Various embodiments and aspects thereof are further described by and will be further understood from the following non-limiting examples. These examples will be understood as being illustrative of various embodiments' concepts and aspects, and are not intended as any limitation on the scope of the invention.

Operational Hardware Prototype

Figure 8 presents a circuit schematic for one for several inventor-constructed, tested operational hardware prototypes, implementation of one or more systems in accordance with the Figure 6 functional block.

Figure 9 shows a photograph of one constructed, working, inventor-tested hardware prototype, implementing one example system according to one or more embodiments for generating complex waveform signatures corresponding to and unique to different odors and mixtures of odors, generally configured according to the Figure 8 circuit schematic.

The Figure 9 illustrated working prototype device included two gas sensors, having respectively different ER characteristics, and each connected to a respective channel. The channels were referred to as channel 1" and "channel 3." The prototype was powered by a universal serial bus (USB) connection (visible in the lower right of the photograph) and output a complex waveform or odor signature (phone jack in upper right) when an odor or odor mixture was presented to the gas sensors.

Sensor Characteristics

The Figure 9 illustrated working prototype used, as described above, a plurality of individual, physically separate hardware, volatile organic compound (VOC) sensors.

Figure 10 shows sensor output amplitude modulated carrier frequencies and complex waveform signals from the Figure 9 prototype. An odor was presented to a first one among three VOC sensors, and the first VOC sensor's output signal was used to modulate the amplitude of the channel 1 frequency, producing a first sensor modulated channel 1 frequency, which appears in the figure as item number 1002, and is shown in more detail in the enlarged view region "A.". When the same odor was presented to second among the sensors, the second

VOC sensor output was used to modulate the amplitude of the channel 2 frequency, producing the second sensor's modulation of the channel 2 frequency, which appears as item number 1004 and is shown in more detail in the enlarged view region "B." When both the sensors were exposed to the odor, the amplitude of the channel 1 frequency was modulated by the first sensor output concurrent with the amplitude of the channel 2 frequency being modulated by the second sensor output. The combining the first sensor amplitude modulation of the channel 1 frequency with the third sensor amplitude modulation of the channel 2 frequency was a complex mixture of the two channels which formed a complex waveform sound signature, which appears in Figure 10 as item 1006, which was unique for that odor and is visible in more detail in the enlarged viewing area "C."

Experimental Methods

In the inventors' experimental implementation, odorants were presented to the sensor elements as a diffusion of the odorants from a headspace of a water or other non-odorous carrier solution. Products such as the glass cleaner Windex (TM) and other common products were presented similarly. Solid or semi-solid products such as peanut butter were presented in close proximity to the sensor surface. The sensors were positioned at a distance from the processing unit, connected with a cable. The cable was a printed ribbon cable that contained conductive traces for the sensors and ground. The sensors were connected between ground and a respective load resistor on the processor board. The load resistors were in turn connected to a regulated voltage. The varying resistance of the sensor in response to the odorant caused a corresponding voltage change.

In the later constructed, working hardware prototypes that included a microcontroller, said device generally included analog to digital conversion (ADC) resources. For example, one microcontroller was an ESP32, which included an ADC device converted the signal into a digital signal that was recorded and processed in a microcontroller (ESP32). The stimulus waveform was recorded in memory where it was retrieved for later processing. Alternatively, the processing was performed directly on the microcontroller which used a neural network to analyze the waveform and used principal component analysis to recognize stimulus dimensions and assign magnitude and frequency components which were then output through an onboard digital to analog converter.

Later working prototypes constructed by with authorization by the inventors and/or

the applicant, used packages multi-sensor arrangements including multiple sensors and programmable microcontroller. One example of such sensor package was a MICS6814 sensor, which is a microelectromechanical sensor consisting of three sensor elements, each specified by the vendor as having a chemical response characteristic different from the other two. The differences included one of the three sensor elements being specified by the vendor as a RED sensor element, another specified as an OX sensor element, and the other specified an NH₃ sensor element.

The sensor prototype included structure that housed all three sensor elements together in the same case. The case dimensions were 5 mm by 7 mm. Each of the three sensor elements was specified by the vendor as coated with a respective sensing layer and the sensing layers differed from one another in correspondence with the sensors' respectively different chemical response characteristics. The specific composition of the sensing layers was not specified in the data sheet from SGX-Sensortech (TM). Both n-type (WO₃, SnO₂, ZnO, TiO₂, V₂O₅) and p-type (NiO, CuO, Co₃O₄,) metal oxide semiconductors are commonly used. These have different spectrums of chemical sensitivity and are marketed usually for use in the detection of those chemicals where the sensor has highest sensitivity. In description herein of the operational prototype responses to non-targeted chemicals are alternatively referred to as "interferences."

The RED sensor in the MICS6814 sensor package was specified by its vendor-supplied documentation as sensitive to CO, H₂S, ethanol, hydrogen, ammonia, methane, propane and isobutane, the OX sensor was specified as sensitive to NO, NO₂ and hydrogen, and the NH₃ sensor as sensitive to ammonia, ethanol, hydrogen, propane and iso-butane. Where sensitivity overlaps, a difference in concentration range commonly exists. In practice, we have found that many other different chemicals and odorants could be sensed by each sensor.

Figure 11 graphically presents, on a two-dimension (2D) signal level versus time graph, three separate signal level versus time plots, showing inventor measured sensor outputs from a commercial, off-the-shelf (COTS) NH₃ sensor, a COTS RED sensor, and a COTS OX sensor, in response to exposure to different concentrations of ethanol vapor.

Figure 12 graphically presents on a 2D signal level versus time graph, signal level versus time plots, showing inventor measured outputs from the same COTS sensors used for the Figure 11 graphs, in response to exposing the sensors to a succession of ethanol, citral

(chemical formula $C_{10}H_{16}O$), Windex(TM) brand window, PEA, and ethanol.

Figure 13 graphically presents example operations in one process 1300 according to one or more embodiments for generating a complex waveform signature in response to and unique to a particular concentration of Listerine(TM) vapor. Operations in the process 1300 include commencing 1302 at time *to* an exposing the Listerine vapor to an NH₃, a CO sensor, and to an NO₂ sensor, and the sensors in response outputting 1304, over a sensing interval, respective sensor signals, visible in the figure as an NH₃ sensor output, a CO sensor output, and an NO₂ sensor output. Process 1300 operations further included amplitude modulating 1306 a first a response to the concentration of Listerine vapor, producing NH₃ sensor modulated first frequency 1308A, CO sensor modulated second frequency 1308B, and NH₃ sensor modulated third frequency 1308C, collectively labeled on the figure as item 1308. Process 1300 further included a combining 1310 the three sensor signal output amplitude modulated frequencies to form resulting complex waveform signature 1312 unique to the particular concentration of Listerine vapor.

Figures 14 graphically presents operations in an example process according to one or more embodiments providing, in response to and unique to a particular concentration of ethyl alcohol vapor, a complex waveform signature. The process 1400, in the Figure 14 example, uses the same sensors used for the Figure 13 process.

Figure 15 presents the graphics of Figure 14, overlayed with representation of the sensor testing module and apparatus and showing enlarged view "D" of the complex waveform signature.

Figure 16 graphically presents complex waveform signatures for a particular concentration of Listerine(TM) vapor and ethanol vapor, generated by a constructed prototype in accordance with one or more embodiments.

Figure 17 shows an illustrative example arrangement 1700 of process of multiple sensor, multiple frequency modulated carrier signal based generating of complex waveform signature in accordance with one or more embodiments. The example arrangement of the process 1700 differs from the processes 1300 and 1400 in that it uses the sensor outputs to frequency modulate 1702 the carrier frequencies, producing a first sensor frequency modulated first carrier signal 1704A, a second sensor frequency modulated second carrier signal 1704B, and a third sensor frequency modulated third carrier signal 1704C (collectively

“ sensor signal frequency modulated carrier signals 1704”), then combining these to produce a respective FM-based complex waveform signal 1706.

It is to be understood that this invention is not limited to particular embodiments described, as embodiments described herein are susceptible to various modifications and alternative forms. Embodiments have been shown by way of example in the drawings and will be described in detail herein. However, the exemplary embodiments described are not limited to the particular forms disclosed. Rather, the instant disclosure covers all modifications, equivalents, and alternatives falling within the scope of the appended claims.

It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims.

Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is encompassed within the invention. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges and are also encompassed within the invention, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the invention.

Ordinal terms such as “first,” “second,” “third,” etc., as used in this specification and the appended claims to modify, e.g., step(s), functional block(s), signal(s), instruction(s), element(s) are to be understood as a labelling to individually reference separate step(s), functional block(s), signal(s), instruction(s), and/or element(s), and are not to be understood, except where stated otherwise, to be any indication of temporal or spatial ordering, or of priority.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Representative and illustrative methods and materials are described herein. Methods and materials similar or equivalent to those described herein can also be used in the practice or testing of the present invention.

All publications and patents cited in this specification are herein incorporated by reference as if each individual publication or patent were specifically and individually

indicated to be incorporated by reference and are incorporated herein by reference to disclose and describe the methods and/or materials in connection with which the publications are cited. The citation of any publication is for its disclosure prior to the filing date and should not be construed as an admission that the present invention is not entitled to antedate such publication
5 by virtue of prior invention. Further, the dates of publication provided may be different from the actual dates of public availability and may need to be independently confirmed.

It is to be understood that as used herein and in the appended claims, the singular forms "a", "an", and "the" include plural referents unless the context clearly dictates otherwise. It is further noted that the claims may be drafted to exclude any optional element. As such, this
10 statement is intended to serve as support for the recitation in the claims of such exclusive terminology as "solely," "only" and the like in connection with the recitation of claim elements, or use of a "negative" limitations, such as "wherein [a particular feature or element] is absent", or "except for [a particular feature or element]", or "wherein [a particular feature or element] is not present (included, etc.)..."

As will be apparent to those of skill in the art upon reading this disclosure in its entirety, each of the individual embodiments described and illustrated herein has discrete components and features that may be readily separated from the embodiment or combined with features of any of the other several embodiments without departing from the scope or spirit of the present invention.
15

It is to be understood that various methods and operations are described as a plurality of separate actions, steps, or operations but it will be understood that such description can be for further assisting the reader in gaining an understanding of, for example, concepts and/or logic relationships and should not be understood as limiting the order in which the actions, steps, or operations can be performed and that these can be carried out in the temporal order
20 or spatial arrangement recited or in any other order or arrangement that is logically possible.

While the invention has been described in terms of its several exemplary embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims. Accordingly, the present invention should not be limited to the embodiments as described above, but should further include all
25 30 modifications and equivalents thereof within the spirit and scope of the description provided herein.

CLAIMS

We claim:

1. A method of generating, in response to an odorant, a corresponding complex waveform signature, the method comprising the steps of:

5 distributing a new concentration of a vapor state of the odorant to a sensor array that includes a first sensor and a second sensor, wherein each is sensitive to the odorant, the first sensor has a first electrical response characteristic, the second sensor has a second electrical response characteristic that differs from the first electrical response characteristic, and the new concentration is greater than a concentration of the odorant at the sensor array at a time of a
10 commencement of the distributing;

 the first sensor, responsive to the first sensor receiving the new concentration of the odorant, producing a first sensor signal having a first signal versus time characteristic based at least in part on the odorant, the new concentration, and the first electrical response characteristic;

15 the second sensor, responsive to the first sensor receiving the new concentration of the odorant, producing a second sensor signal having a second signal versus time characteristic that differs from the first signal versus time characteristic, by a difference based at least in part on the odorant, the new concentration, and the second electrical response characteristic differing from the first electrical characteristic;

20 generating, based at least in part on both the first sensor signal and the second sensor signal, a complex waveform signal, wherein the generating is configured to generate the complex waveform signal with a complex waveform shape that corresponds to the odorant, the configuration of the generating including:

 translating the first sensor signal to a first sensor signal modulated first
25 oscillating signal and translating the second sensor signal to a sensor signal modulated second oscillating signal, and

 forming the complex waveform signal by combining of at least the first sensor signal modulated first oscillating signal and the second sensor signal modulated second oscillating signal.

30

2. A method according to claim 1, wherein:

 the first sensor and the second sensor are arranged in an interior of a housing, and the

housing includes a switchable fluid path from an exterior of the housing to the interior of the housing, and

the distributing the new concentration comprises a switching of the switchable fluid path from the closed state to the open state, at a switching time,

5 the first sensor receiving the new concentration commences at a first start time relative to the switching time, and the second sensor receiving the new concentration commences at a second start time relative to the switching time,

the complex waveform shape is further based at least in part on a temporal ordering and a temporal spacing of the first start time with respect to the second start time

10

3. A method according to claim 1 wherein the configuration of the generating the complex waveform signal further includes steps of:

generating a first oscillating carrier signal;

generating a second oscillating carrier signal,

15

wherein

the generating the first sensor signal amplitude modulated first oscillating signal comprises amplitude modulating the first oscillating carrier signal by the first sensor signal, and

the generating the second sensor signal amplitude modulated second oscillating signal comprises amplitude modulating the second oscillating carrier signal by the second sensor signal.

20

4. A method according to claim 3, wherein the first oscillating carrier signal oscillates at a first frequency, which is a first audio frequency and the second oscillating carrier signal oscillates at a second frequency, which is a second audio frequency.

25

5. A method according to claim 4, wherein the method further comprises outputting to a user, via an audio speaker, an audible odor indicative sound that is based at least in part on the complex waveform signal.

30

6. A method according to claim 5, wherein:

the first frequency, the second frequency, the amplitude modulating the first oscillating carrier signal by the first sensor signal, and the amplitude modulating the second oscillating

carrier signal by the second sensor signal are mutually configured such that,

in response to the odorant being a target substance at a first concentration level,
the audible odor indicative sound output to the user has a first audible characteristic,
in response to the odorant being the target substance at a second concentration
5 level, which is higher than the first concentration level, the audible odor indicative
sound has a second audible characteristic that differs from the first audible
characteristic by a quality and/or a quality that is discernible by the user.

7. A method according to claim 1, further comprising identifying the odor by matching the
10 complex waveform of the complex waveform signal against a database comprising a plurality
of different reference complex waveforms, each of which corresponds to a respective
reference odor or mixture of odors.

8. A method according to claim 1, wherein
15 the first sensor is a member of a first group of one or more first type sensors, and the
second sensor is a member of a second group of one or more second type sensors, wherein
each of the one or more first type sensors is configured with a first sensitivity
to the odor,
each of the one or more second type sensors is configured with a second
20 sensitivity to the odor, and
the first sensitivity is different from the second sensitivity.

9. A method according to claim 1,
the first sensor comprises a first sensor device that includes a first sensor sensing layer
25 and, arranged over the first sensor sensing layer, a first filter,
the second sensor comprises a second sensor device that includes a second sensor
sensing layer and, arranged over the second sensor sensing layer, a second filter,
the first filter affects a passage or flow of molecules across the first sensor sensing
layer in a manner that provides the first electrical response characteristic.

30 10. A method according to claim 1, wherein the first sensor signal comprises a first sensor
digital signal, and the second sensor signal comprises a second sensor digital signal.

11. A method according to claim 1, wherein the first sensor signal comprises a first sensor analog signal, and the second sensor signal comprises a second sensor analog signal.

12. A system for generating a complex waveform that corresponds to an odor, comprising:

5 a sensor array comprising at least two sensors, wherein

a first sensor among the at least two sensors is configured, with respect to sensing response to at least one target odorant, with a first electrical response characteristic, and to output, in response to being exposed to a target odorant, a first sensor output signal, having a first change with respect to time characteristic that is
10 based at least in part on the target odorant and the first electrical response characteristic,

a second sensor among the at least two sensors is configured, with respect to sensing response to the at least one target odorant, with a second electrical response characteristic, and to output, in response to being exposed to the target odorant, a second sensor output signal, having a second change with respect to time characteristic that differs from the first change with respect to time characteristic by a difference that is based at least in part on the target odorant and the difference between the first electrical response characteristic and the second electrical response characteristic,
15 a processor programmed to:

modulate a first oscillatory signal, using the first sensor output signal, to
20 generate a first sensor signal modulated first oscillatory signal,

modulate a second oscillatory signal, using the second sensor output signal, to generate a second sensor signal modulated second, and

combine the first sensor signal modulated first oscillatory signal and the second sensor signal modulated second oscillatory signal plurality to form a complex
25 waveform, corresponding to the odorant.

13. A system according claim 12, wherein said sensor array comprises a plurality of groupings of one or more sensors, each grouping configured to detect a different odor.

30 14. A system according to claim 12, wherein said sensor array comprises at least two of the same sensor, wherein a different filter is associated with each of at the least two of the same sensor, differentially affecting a passage or flow of different molecules across the filter.

15. A system according to claim 12, wherein the processor is programmed to:

modulate the first oscillatory signal, using the first sensor output signal, by modulating an amplitude of the first oscillatory signal using the first sensor signal, and outputting as a result a first sensor signal amplitude modulated first oscillatory signal,

5 modulate the second oscillatory signal, using the second sensor output signal, by modulating an amplitude of the second oscillatory signal using the second sensor signal, and outputting as a result a second sensor signal amplitude modulated second oscillatory signal, and

10 perform a summing of at least the first sensor signal amplitude modulated first oscillatory signal and the second sensor signal amplitude modulated second oscillatory signal plurality to form the complex waveform, corresponding to the odorant.