Attempts at Simplified Measurement of Odors in Japan using Odor Sensors

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Abstract
The simplified odor measurement in Japan is conducted using simplified versions of the conventional sensory tests or by methods using a detection tube. In addition, research has recently been undertaken to create practical odor sensors with a single sensor element and electronic noses with multiple sensor elements.
The odor sensor with a single sensor element, already used for more than 10 years, features the ability to provide measurement results immediately on-site and to conduct continuous monitoring. However, to match the sensitivity of the nose, the odor sensor requires the creation of calibration curve for each odor element. Also care must be taken about interfering gases when using the odor sensor.
To solve these problems, research has been conducted in recent years into electronic noses that incorporate multiple odor sensor elements. Attempts are being made to create electronic noses that automatically evaluate odor category, evaluate the intensity of odor regardless of its category and output odor category information for the identification of odor sources. Future investigation is required to determine if the electronic nose incorporating multiple sensors can act as a replacement for the human sense of odor, as well as to determine the practical limits to its application.

1. Introduction

The Japanese Offensive Odor Control Law prescribes olfactory and instrumental methods to measure odors. While these methods are effective in providing accurate measurement results, they involve complex procedures. These methods also require the preparation of a human panel, as well as specialist operators.

In recent years, however, there are increasing demands for simplified methods to evaluate the strength and category of odors in applications such as the daily performance evaluation of deodorizing units, self-regulation of odors emitted from workplaces, and screening before conducting official measurement methods. Furthermore, in addition to the conventional demand for the measurement of atmospheric odors, there are increasing demands for the evaluation of odors from automobiles, household appliances and fabrics.
To respond to these demands, research has been made into the practical application

of odor sensors for the simplified measurement of odor intensity and of electronic noses to numerically determine both odor intensity and category.

Table 1 shows the current status of these instruments. Thanks to the development of hand-held devices, the odor sensors offer the advantage of conducting odor measurements on-site. Electronic noses feature the ability to determine the category of odor, and to predict the intensity of odor regardless of its odor category. Odor sensors have been in practical use for about ten years. However, the practical application of electronic noses in the evaluation of offensive odors has just started to be suggested. The determination of the effectiveness of electronic noses must wait for further investigation.

Table 1 Odor Evaluation Methods in Japan

			Advantages	Disadvantages
Official methods	Olfactory method	Triangular odor bag method	Official method	Requires a panel of at least 6 members. Complex procedures.
	Instrum-ental method	GC GC-MS Absorptiometry	Official method	Instrument preparation required. May not reflect actual odor intensity.
Simplified methods	Instrum-ental method	Odor sensor	Permits on-site measurements.	Requires calibration for odor element.
		Electronic noses	Can evaluate odor category. Can identify odors and determine the intensity.	Expensive.
		Detector tube	Permits on-site measurements.	Low sensitivity for some odors.
		Monitoring specific components	Permits on-site measurements.	Cannot measure some odors.
	Olfactory method	Comparison using 2 odor bags 6-4 selection method	Simpler than official methods.	Reduced accuracy.

2. Odor Sensors

2.1 Outline

Odor sensors incorporate a sensor element that reacts to odors. The signal from the sensor element is processed to display the odor intensity as a numeric value. The instrument incorporates an internal micro air pump for odor intake. Metal Oxide Semiconductor sensor elements are used to achieve sensitivity and stability. Different types of odor sensor instrument are available: instruments with one sensor element that display the odor intensity only, and instruments with two sensor elements that display simple odor category information in addition to the intensity.

Fig. 1 Odor Sensor with One Sensor Element

2.2 Sensors with One Sensor Element (Fig. 1)

These instruments achieve good correlation with the odor index if they have high sensitivity for the odor components that make a large contribution to the odor index. However, care is required, as the correlation with the odor index may not be obtained if sensitivity is low for these components or if substances are present that interfere with the sensor.

The odor index is determined from a correlation equation (calibration equation) between the odor sensor indicated values and odor indices determined by an official method. This relationship is determined by measuring several different odor concentrations and determining the values of a and b from the following regression equation:

$$SR = a \times OI - b$$

(where, SR is the odor sensor value and OI is the odor index.)

The optimal odor element can be selected to suit the application; elements are available for various fragrance and odor components, hydrogen sulfide, and ammonia.

Fig.2 Odor Sensor with Two Sensor Elements

2.3 Sensors with Two Sensor Elements (Fig. 2)

Apart from the number of sensors, the configuration of these instruments is basically identical to instruments with a single sensor element. The instrument incorporates two sensors: sensor A and sensor B. According to the manufacturer, sensor B reacts sensitively to light odorants, while sensor A is more sensitive to the heavier odorants. "Light" odorants are defined as volatile alcohols, as well as hydrogen sulfide and ammonia with relatively low molecular weights; while 'heavy" odorants are unsaturated aromatic hydrocarbons with relatively large molecular weights, such as toluene, xylene, and methyl mercaptan. Acetic acid and aldehydes are intermediate substances that cause almost identical reactions in both sensors. The sensors are also influenced by the functional groups.

The measurement results are displayed on a two-dimensional Cartesian plane, with the sensor A output along the X axis and sensor B along the Y axis, as shown in Fig. 3. An odor vector is defined as the vector linking the zero-point and A and B Cartesian coordinates. The vector length defines the odor intensity, which is calculated as the square root of the sum of the squares of A and B. The odor quality is defined as the angle (gradient) between the vector and the X axis, which is displayed as an angle from 0° to 90°.

Although this method permits an approximate identification by evaluating the similarity of the measured odor to several pre-measured odors, the identification of complex compound odors is fundamentally difficult. However, the vector does indicate whether a complex compound odor mainly includes heavy or light odor components.

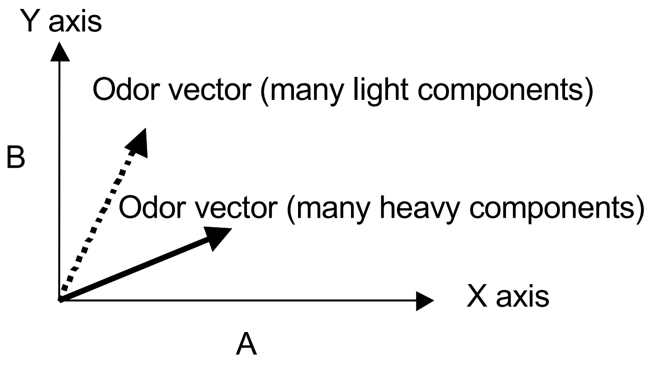

Fig. 3 Odor Sensor Outputs with Two Sensor Elements

3. Electronic Noses

3.1 Outline

An electronic nose is an instrument employing multiple sensor elements that can be operated to offer information on the category, as well as the intensity of odor. In this sense, sensors with two sensor elements described in section 2.3 also belong to electronic noses. Due to the increased number of sensor elements, these instruments are desktop, rather than portable type in many cases. In the subsequent sections, possible applications and additional functions for these instruments will be discussed.

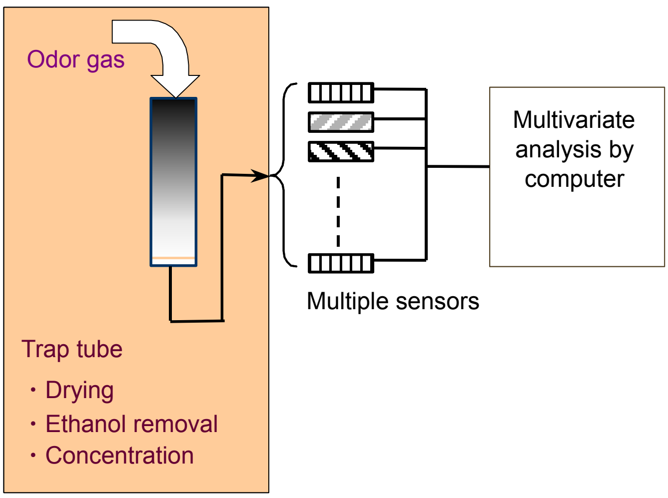

Fig. 4 Electronic Nose Configuration

3.2 Operating Principle

As shown in Fig. 4, the electronic nose resembles a human nose, with the receptor proteins replaced by multiple sensor elements having different properties. The signals generated by these sensor elements in response to an odor are sent as vectors to a computer, which plays the role of the human brain. The computer conducts identification and quantitation of the odors through multivariate analysis or other data processing. (1)

In practice, every sensor responds to different odor substances with different sensitivity, rather than to a specific odor substance. The differences in response between the sensors are subjected to multivariate analysis and other statistical processing, and the disparities between the odor types are displayed graphically for identification and quantitation. (2)

For example, an increase in output intensity with no change in the signal ratio from each sensor is evaluated as a change in odor intensity with no change in odor category. A change in the signal ratio between the sensors is evaluated as a change in odor category.

Fig. 5 Appearance of the Electronic Nose

3.3 Odor Categories using Principal Component Analysis

Principal component analysis is a type of multivariate analysis that can roughly categorize odors.

Fig. 6 shows measurements categorizing normal odors in the environment. Group 1 encompasses odors from printing and painting; Group 2 the odors of exhaust gases (classified by location); Group 3 the sulfur-based odors from piggeries and pulp; and Group 4 the sweet odors of roses and chewing gum.

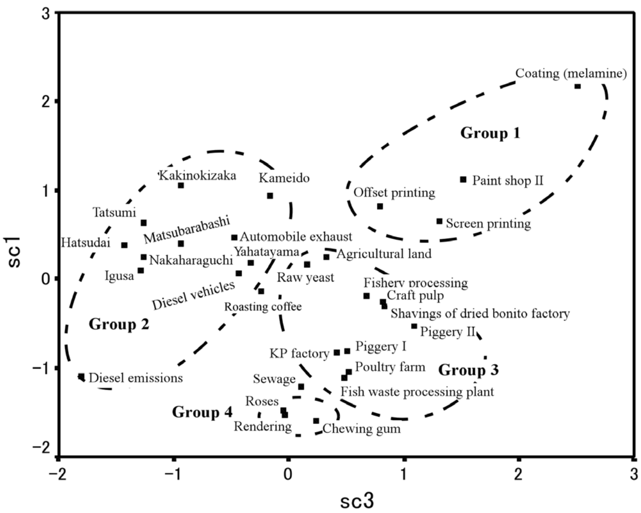

Fig. 6 Principal Component Analysis Results for Environmental Odors

Principal component analysis finds the major direction in which the data group spreads in the odor space formed by multiple sensors. This direction is taken as the principal component axis No. 1 (SC1) and the next major direction of data spreading is taken as the principal component axis No. 2 (SC2). This process is repeated to determine the No. 3 and No. 4 axes. However, for display purposes, two or three of the principal component axes are selected and displayed in a 2- or 3-dimensional representation. (3)

3.4 Odor Intensity Measurements by Multiple Regression Analysis

Multiple regression analysis and the partial least squares (PLS) method determine the correlation between multiple samples of known intensity (odor index) and the output sensor values. The odor intensity (odor index) of unknown samples can then be estimated from this correlation. Fig. 7 shows the multiple regression analysis data from samples taken at three locations with different odor qualities: a printing works, a paint shop and a bone processing plant. The horizontal axis represents the odor index obtained by an olfactory method and the vertical axis represents the odor index estimated from the sensor data using multiple regression analysis. The diagram shows that the method accurately determines the odor index for different odor categories.

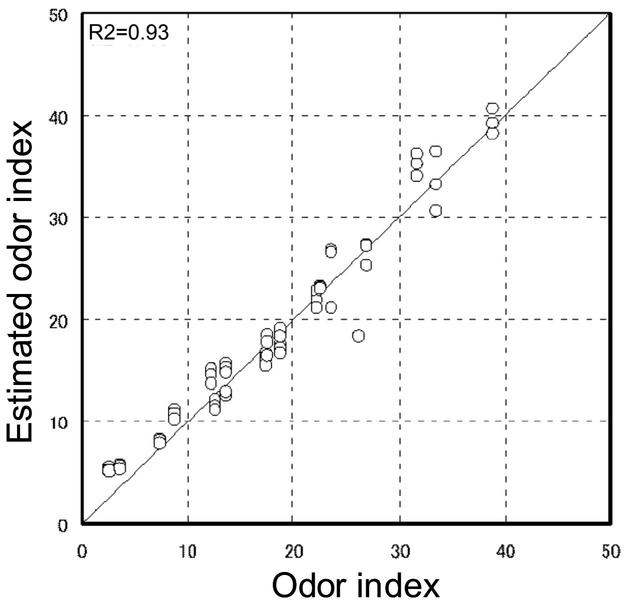

Fig. 7 Odor Intensity Prediction using Multiple Regression Analysis

3.5 New Analysis Methods with the Electronic Nose

Multivariate analysis, such as principal component analysis, is based on the comparison between samples. It obtains no absolute values, making evaluation of the results difficult in the absence of large amounts of comparison data.

Multiple regression analysis offers quantitative information based on large volumes of background data. Therefore, the practical application of this method is difficult, as any change in sensor properties or measurement environment requires a revision of the database.

As a means to resolve these problems, we recently proposed absolute value representation software. This method involves the measurement of multiple category gases and evaluating unidentified samples based on these category gases.

In practice, the odor spectrum is determined for several category gases in the odor space formed by multiple output signals, and the sample gas is expressed as the sum of the contributions to each category gas.

If the expression of the odor quality perfectly matches the direction of a category gas, then the sample gas can be evaluated as a gas in the same category as the category gas. The similarity of the sample gas to the category gas decreases as it deviates from the direction of the category gas. The quality of the sample gas odor can be evaluated by numerically representing its contributions to the category gases.

Fig. 8 shows examples of offensive odor measurements using this method. The odor qualities are roughly expressed as a radar chart to provide a visual representation. In addition, totaling the contributions to each category odor gives a 5-stage representation of the overall odor intensity. This odor intensity compensates for the differences in sensitivity between the sensors and the nose, permitting a determination of the odor intensity that is independent of the odor quality.
We anticipate that further developments of this method in the future will permit the evaluation of the quality and intensity of any odor type with sensitivity equivalent to that of the nose.

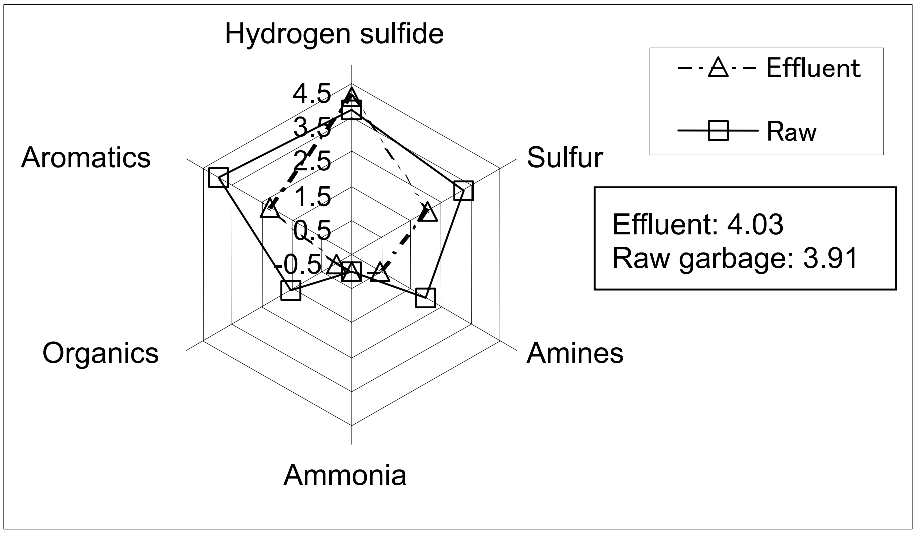

Fig. 8 Offensive Odor Analysis using Absolute Value Representation Software

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