Approach to Detection of Fires in Their Very Early Stage by Odor Sensors and Neural Net

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Abstract

Two odor sensors having SnO_2 film layers of different thickness were used for detection of different odors and their outputs were plotted on X and Y axes respectively. There was a clear difference between the traces of their outputs drawn as they were exposed to odors from smouldering materials and from organic solvents used everyday. So, these outputs of the sensors were given to a neural net with which a system capable of discriminating different odors was developed. This system was able to distinguish odors from smouldering materials among others with high accuracy.

Key words: fire detection, smouldering fire, odor sensor, Tin dioxide, neural net, odor recognition

1. Introduction

As in buildings of other occupancies, it has become difficult nowadays to detect fires in offices or factories where a variety of ventilation systems are installed and constant air flow exists by means of conventional smoke sensors [1]. In view of this and the recent report on fires in computers and electronic apparatus[2] ,there is a strong demand that such fires be discovered and controlled before smoke spreads in the rooms,i.e. at the smouldering stage of fire in the electronic circuit board in the equipment. If there is an effective method of quickly finding such an abnormal environment as a sign of fire,the chances of fire outbreak would be much reduced. As flammable materials are heated gradually, they give out odors before smouldering. Therefore, it will be possible to detect fires in the very early stage if sensors are selectively perceptive to the burnt odors.

Extensive studies on discrimination of odors have been made, using odor sensors

[3,4,5]. There is also a report on successful improvement of their selectivity to odors by pattern-matching method using plural sensors [6]. In 1986 Rumelhart et al proposed a neural net employing the back propagation method which is very much suited for handling analog data[7]. Moriizumi et al reported that neural net was well suited for recognition of alcohol[8]. A primitive study was also made on the use of neural nets with plural sensors to make fire judgement, which reportedly proved to be very effective for this purpose [9].

In this study two odor sensors having different SnO_2 film thickness were used to investigate their responses to different odors. The output levels of each sensor were plotted on the X and Y axes, from which it was found that the odors given out by smouldering fires and the ones from organic compounds such as alcohol could definitely be classified into separate groups. Accordingly,a system which discriminates between those odors given out in the very beginning of fire and those existing in the normal environment was developed by using two sensors having different film thickness in conjunction with the neural nets, and its efficiency was investigated. It has been found that nearly all odors which are given out by smouldering fires and to which the odor sensors are sensitive can be regarded as odors from fires and that this system is capable of detecting the smouldering fires in their very early stage without fail.

2. Measuring Methods

Two sensors were built with SnO_2 deposited on aluminium substrates to form film Layers of different thickness, i.e. 1000 Å and 2500 Å respectively, and Pt was spattered on their opposite sides as heaters. The sensors were heated up to 350℃. The measuring circuit is shown in Fig.1.

2. 1 Method of Measuring Sensitivities to Burnt Odors

Eighteen kinds of materials were prepared. They were heated at a rate of 10℃/min until a temperature of 350℃ was reached, and in the mean time the sensor sensitivities to odors were measured. At the same time, smoke densities, number of particles and smoke generating temperatures were also measured, using the VESDA of I.E.I.(AUST). and the particle counter of Met One(USA). As shown in Fig.2, the measuring apparatus was equipped with a HEPA filter and deodorant filter to control the number of particles of 0.3 micron and larger in size to 10^4 particles or less and to remove the odors. The materials for testing were put into a vessel in the clean duct and heated up to 330℃. Two kinds of vessels were used for different tests. A 1.8-liter glass bell-jar was used in TEST 1. In this test, two different sensors were placed in the bell-jar, from which air was drawn and introduced into the particle counter at a flow rate of 300 mL/min. A 65-liter stainless steel box was prepared for TEST 3. At this time no sensor was placed in the box,but air drawn therefrom by pump was led into the VESDA and the sensors in the 1-liter box at a rate of 3L/min.

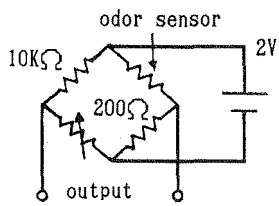

Fig.1 Measuring circuit

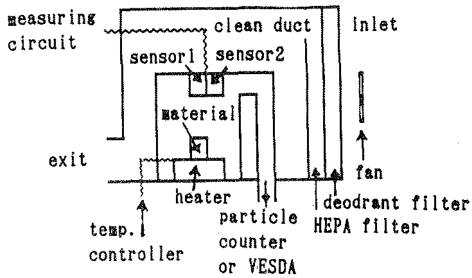

Fig.2 Measuring diagram of odor sensors

2. 2 Method of Measuring Sensitiviies to Environmental Odors

In TEST 2, two sensors were placed in the 1.8-liter bell-jar with odorant materials in sealed condition. Their sensitivities to different odors were measured as odors were generated.

3. Results

3. 1 Sensitivities to odors from smouldering materials (TEST 1)

As shown in Table 1, the sensors were highly sensitive to odors from smouldering cellulosic materials, e.g. copying paper and pine tree chip, but less sensitive to the one from cardboard. It was assumed that this slower response of the sensor in the test with the cardboard was due to lower quality paper which allowed the adhesive to dissipate as smoke at a lower temperature of 190℃. Paper containing less impurities gave out odors and smoke at higher temperatures. Even at a temperature of 330℃,cotton did not generate smoke but only odor. The sensors showed a high sensitivity in the test with cotton. Glass epoxy chip and paper epoxy chip used for electric circuit boards were heated to measure the sensor sensitivities. The paper epoxy chip gave out odor and smoke at 150℃ and 180℃ respectively. The glass epoxy chip with printed resist generated odor and smoke at 210℃ and 300℃ respectively.

Test results showed that the sensor was as sensitive to the odor from the glass epoxy chip as it was to the odors from the cellulosic materials while they were less sensitive to the odor from the paper epoxy chip. The sensitivities of the sensors to the odors from plastic and rubber materials were as follows.

Acryl resin > Polyethylene > Polystylene > Rubber > ABS resin

It became clear from these test results that the sensors were more sensitive to the odors from the materials having a large difference between the odor generating temperature and the smoke generating temperature. Furthermore,the sensor can sufficiently detect the odors from the cellulosic materials and the glass epoxy chip before smouldering when heated at a rate of 10℃/min.

Table 2 shows the sensor sensitivities to the burnt odors from seven different materials as a function of the sensor temperature. In the tests with the copying paper, newspaper and ABS resin the sensors showed increase in sensitivity but slower response time with decrease of the heater temperature. On the contrary a marked improvement was noted in the sensor sensitivity at higher heater temperature in the test with the acryl resin. In the test with the glass epoxy chip, the sensor having the film of 1000 Å thick showed the same tendency as in the test with the acryl resin while the sensor having the 2500 Å thick film showed a maximum sensitivity at a heater temperature of 317℃.

3. 2 Sensitivities to odors existing in normal environment (TEST 2)

There are a great variety of odors generated in the normal environment. The materials used in this test and the sensor sensitivities to the odors measured are shown in Table 3. It was noted that the sensors showed very high sensitivities to odors given out from coffee powder and cigarette butts. It might be natural that the sensors were very sensitive to these odors because these materials had once been roasted or burnt. The sensors also showed high sensitivities and quick response to the odors from the materials including alcohol and volatile compounds. They were also very sensitive to odorants containing high grade alcohol. On the other hand the sensors were less sensitive to confectionary having strong flavors.

Table 1 Sensitivity and Materials

(sensor was 2500Å thick and heated at 350℃)

Material (heating rate 10℃/min) weight: 20 mg	odor generating temp [℃] (A)	smoke generating temp [℃] (B)	B−A [℃]	smoke sensitivity [mV]
Copying paper	225	290	65	800
Newspaper	200	260	60	770
Filter paper	240	300	60	780
Cardboard	175	190	15	120
Pine tree	205	310	105	920
Cotton	210	−	−	980
Vinyl chrolide	170	170	0	240
Poly ethylene	200	220	20	350
Poly styrene	230	250	20	340
Acryl resin	170	290	120	640
Rubber	140	170	30	170
Paper epoxy	150	180	30	160
ABS resin	150	190	40	100
Glass epoxy*1	210	300	90	850
Glass epoxy*2	185	300	115	920

*1 with resist *2 without resist

Table 2 Sensitivity as a function of sensor temperature

Material (10℃/min)	Sensor type	Heater Temp. 350℃ [mV]	Heater Temp. 317℃ [mV]	Heater Temp. 267℃ [mV]
Copying paper	Thin	800	950	1000
	Thick	700	770	850
Newspaper	Thin	770	950	1000
	Thick	450	900	960
Filter paper	Thin	780	930	840
	Thick	580	850	780
ABS resin	Thin	100	—	200
	Thick	70	—	120
Acryl resin	Thin	640	590	250
	Thick	900	860	600
Glass epoxy chip (no resist)	Thin	850	850	820
	Thick	720	760	720
Glass epoxy chip (resist)	Thin	920	860	850
	Thick	600	1000	650

* thin type:1000 Å thick type :2500 Å

Each material is 20 mg.

Table3 Sensitivity to environmental odors (Sensor Temp. 300°C)

Materials	Quantity	Sensor type	Sensitivity [mV]
Coffee powder	2.0 g	Thin	1100
		Thick	1040
Potato chip	2.4 g	Thin	0
		Thick	100
Cigarette butt	5cm	Thin	1000
		Thick	940
Perfume	1μℓ	Thin	720
		Thick	760
eau du Cologne	1μℓ	Thin	740
		Thick	800
Iso-propyl alcohol (IPA)	1μℓ	Thin	520
		Thick	680
Ethyl alcohol	1μℓ	Thin	720
		Thick	800
Toluene	1μℓ	Thin	520
		Thick	510

Thin type :1000 Å thick type :2500 Å

Table4 Sensor sensitivity at smoke density 0.1%/m

	A	B	B/A
Materials	Sensitivity of 1000 Å sensor [mV]	Sensitivity of 2500 Å sensor [mV]	ratio of sensitivity
Copying paper	300	750	2.50
Filter paper	75	105	1.41
Newspaper	150	450	3.00
Pine tree	300	666	2.22
Glass epoxy*1	182	345	1.90
Glass epoxy*2	250	700	2.80
Paper epoxy	62	7	0.11
Polyethylene	57	178	3.12
Cotton	1000	900	0.90
Acryl resin	778	300	0.39
Vinylchloride	25	25	1.00
ABS resin	20	40	2.00
Cigarette *3	70	100	1.43

Materials except cigarette were heated at 350℃.
*1 with resist
*2 without resist
*3 smoking a cigarette in 40 m³.

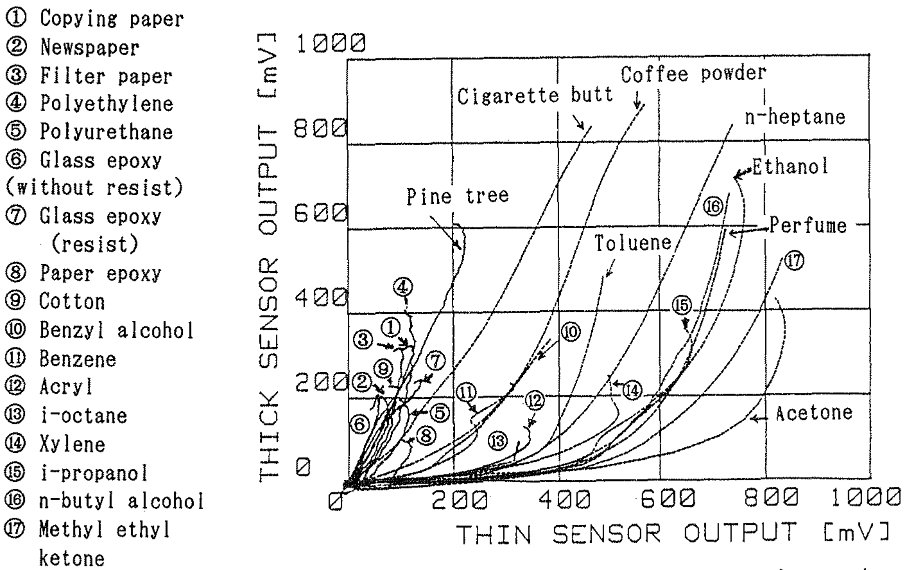

Fig. 3 Output traces of two sensors to various odors

3. 3 Sensor sensitivities at smoke density of 0.1%/m (TEST 3)

In order to measure sensitivities of the sensors at the smoke density of 0.1%/m, the different materials were heated to smoulder, giving out odors and smoke in the 65-liter test box. Quantities of the materials were controlled so that a maximum smoke density of 0.15%/m would not be exceeded. Table 4 shows the output changes of the sensors when subjected to the smoke density of 0.1%/m attained by smouldering of the different materials. Principal materials are listed below in the order of sensitivity shown by the sensor having the 2500 Å thick film.

Cotton > Copying paper> Glass epoxy chip (without resist) > Pine tree chip > Newspaper > Glass epoxy chip (with resist) > Acryl resin.

The sensor with its threshold level set at 300 mV, for example, is capable of giving an alarm before the smoke density of 0.1%/m is reached. However, the sensors showed only slight response to odors given out while vinyl chloride or ABS resin was heated. The sensor having the film of 1000 Å thick was more sensitive to the odors from the acryl resin and cotton than the sensor with the film of 2500 Å thick.

3. 4 Output traces of two sensor subjected to different odors

Outputs of the sensors with films of 1000 Å and 2500 Å thick were plotted on the horizontal axis and the vertical axis respectively. Fig.3 shows the traces of their responces to the odors given out from the different smouldering materials and to organic compounds existing in the normal environment such as alcohol and perfume. In the beginning,the traces of their responses to the odors from almost all the smouldering materials concentrated in the same region in Fig.3. In contrast with this , the sensor with the 1000 Å thick film showed quick responses to the odors from ethyl alcohol,iso-propyl alcohol(IPA), toluene and perfume, and the sensor with 2500 Å thick film responded slowly thereafter, and accordingly the traces of their responses showed an upward tendency on the right side. The traces of the sensor responses to the odors from the smouldering acryl resin were similar to those attained with respect to the organic compounds. It was assumed that acryl nitrile having a low boiling point was produced due to thermal decomposition of acryl resin, and the sensor showed the same response as in the case with alcohol. The traces of the sensor responses to the odors from coffee, odorant materials and cigarette butt were located between those for the above two groups. This means that discrimination between those odors generated by fire and the ones existing in the normal environment is possible.

4. Discrimination of Odor by Neural Net

It was found that the traces of the sensor responses to different odors could be classified into specific groups due to kinds of odors. Therefore, a system which determines the kinds of odors was developed and evaluated, using a neural net suited for pattern matching of sensors' analog data.

Table 5 Definition table

No	Input		Organic odor		Smouldering odor	
	SENSOR 1 (thin)	SENSOR 2 (thick)	definition value	calculated value	definition value	calculated value
1	0.05	0.03	0.05	0.09	0.00	0.00
2	0.05	0.10	0.05	0.04	0.10	0.00
3	0.05	0.30	0.05	0.01	0.40	0.40
4	0.05	0.50	0.00	0.01	0.80	0.87
5	0.10	0.05	0.40	0.31	0.00	0.00
6	0.10	0.10	0.20	0.19	0.00	0.00
7	0.10	0.40	0.00	0.02	0.80	0.76
8	0.10	0.70	0.00	0.01	0.95	0.94
9	0.15	0.05	0.50	0.62	0.00	0.00
10	0.20	0.10	0.70	0.65	0.00	0.00
11	0.20	0.20	0.25	0.28	0.05	0.01
12	0.20	0.40	0.00	0.04	0.70	0.69
13	0.20	0.60	0.00	0.02	0.95	0.92
14	0.40	0.10	0.95	0.94	0.00	0.00
15	0.40	0.20	0.80	0.74	0.00	0.00
16	0.40	0.30	0.35	0.35	0.00	0.00
17	0.40	0.40	0.20	0.13	0.20	0.25
18	0.40	0.70	0.00	0.02	0.95	0.93
19	0.60	0.20	0.95	0.93	0.00	0.00
20	0.60	0.40	0.30	0.36	0.10	0.01
21	0.60	0.60	0.00	0.05	0.75	0.77
22	0.60	0.80	0.00	0.02	0.95	0.93
23	0.80	0.20	0.95	0.98	0.00	0.00
24	0.80	0.40	0.70	0.71	0.05	0.00
25	0.80	0.60	0.20	0.14	0.40	0.37
26	0.80	0.80	0.00	0.03	0.85	0.90

Table 6 Probability for discrimination smouldering odor and organic odor

No	Kind of odor	probability of smouldering odor (max. %)	probability of organic odor (max. %)
1	Copy paper	94.6	0.0
2	Pane tree	97.3	0.0
3	Newspaper	90.3	0.0
4	Filter paper	95.9	0.0
5	Glass epoxy	92.5	0.0
6	〃 (resist)	82.5	0.0
7	Paper epoxy	18.4	0.0
8	Polyurethane	76.6	0.0
9	Polyethylene	96.8	0.0
10	Cotton	90.9	0.0
11	Acryl	4.7	90.1
12	Coffee powder	38.2	26.1
13	Cigarette butt	75.6	1.9
14	Ordorant	27.2	26.5
15	Ethanol	2.7	97.6
16	i-propanol	2.0	97.4
17	Acetone	1.5	98.3
18	Benzene	14.6	23.6
19	Toluene	9.1	90.0
20	n-heptane	5.5	95.8
21	Xylene	2.4	96.0
22	i-octane	2.9	67.6
23	n-butylalcohol	3.6	97.3
24	Benzyl alcohol	13.2	43.4
25	Methyl Ethyl Ketone	2.2	98.1
26	Perfume	2.4	97.5

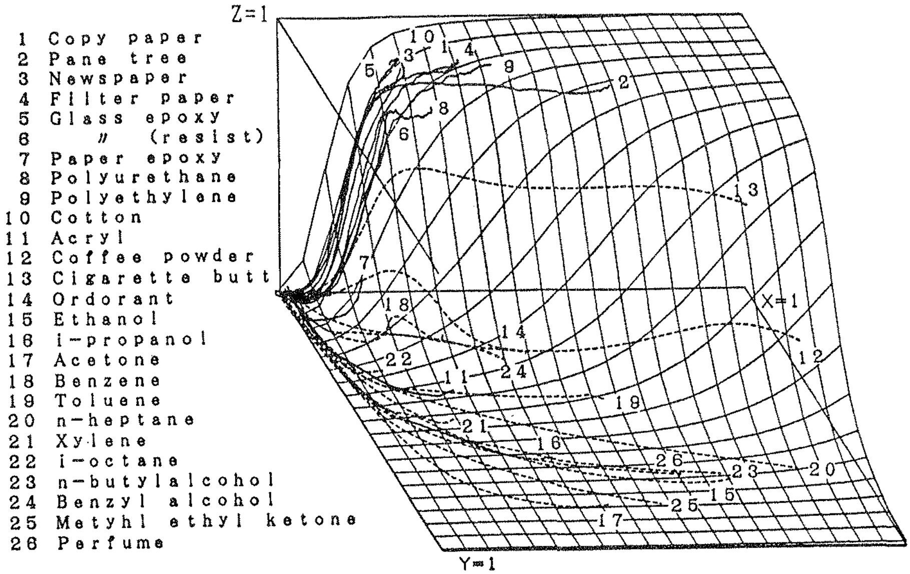

Fig. 4 Probability for smouldering odor
---- organic odor — smouldering odor
(Probability is shown with height on Z axis.)

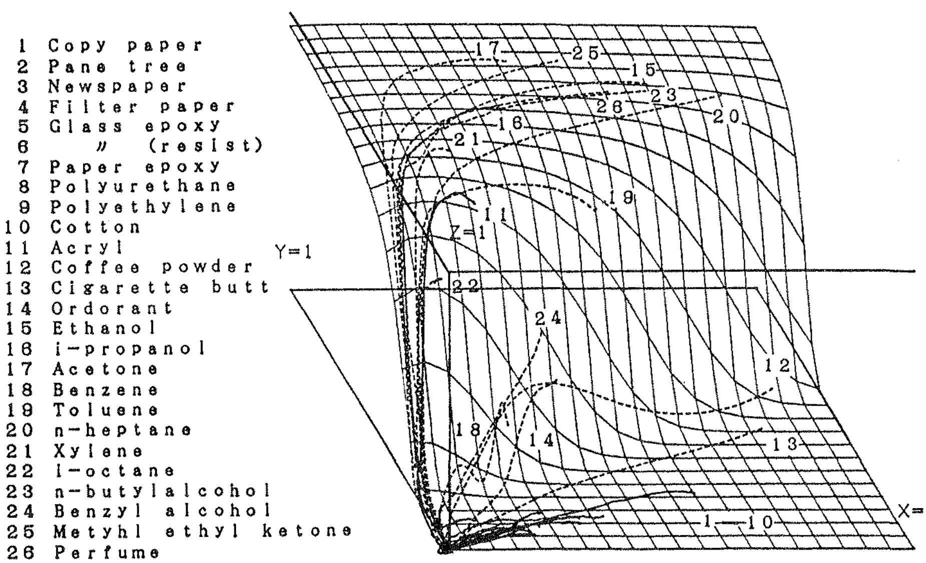

Fig. 5 Probability for organic odor
---- organic odor — smouldering odor
(Probability is shown with height on Z axis.)

4. 1 Definition of Input/Output of Neural Net

Probability for discriminating odors from the smouldering materials and from the organic compounds as outputs was calculated by giving the outputs of the sensors having different film thickness to the neural net. The actual Definition Table has been made with reference to the traces of the sensor responses shown in Fig.3. The neural net was composed of two input neurons, five hidden neurons and two output neurons. Table 5 shows actual outputs achieved with the inputs from the sensors after the neural net learnt the Definition Table by the back-propagation method [7].

4. 2 Results of Judgement by Neural Net

Plotting the outputs of the sensors having thin and thick film on the X and Y axes respectively, probability for the odors from the smouldering materials can be displayed with height on the X axis as shown in Fig.4. The mesh shows the scale of defined probability. As the actual outputs of the sensors are given to the neural net for calculation, their traces can be drawn with plotted lines on the mesh. It can be seen that the neural net showed very high probability for the odors from the smouldering materials except the acryl resin. Probability for the odors from smouldering coffee and odorant materials remained with slight increase. A 75.6 % of probability was attained with the odor from cigarette butt. On the other hand, the neural net showed extremely low probability, about 15% at the highest, for the group of organic compounds such as iso-propyl alcohol(IPA), ethyl alcohol, and acetone.

Likewise, probability for the odors from the organic compounds as calculated in the neural net is shown in Fig.5. The acryl resin had an exceptionally high probability and marked a maximum of 90% while the one of the other odors was zero. Table 6 shows probability for odors from different smouldering materials and organic compounds, by which difference in quality of the odors could be discriminated.

It has become apparent that affinity of odors can accurately be determined by using two odor sensors having different film thickness in conjunction with the neural net. It is also possible to distinguish difference between the odors generated in the very early stage of fire and the ones from the organic compounds used in the normal environment without fail.

6. Conclusion

The investigation on sensitivities of the two odor sensors having different SnO_2 film thicknesses to different odors revealed that:

(1) The sensors were highly sensitive to odors from smouldering materials including cellulose and glass epoxy chip.

(2) The film thicknesses of the sensors had a great influence upon their sensitivities. The sensor with the thicker film layer was more sensitive to the odors from the smouldering materials while the one with the thinner film

layer was more sensitive to the odors from the organic compounds.

(3) The sensor showed increased sensitivities to the odors from the smouldering materials with the lower heater temperature, but an opposite tendency to the odors from the organic materials.

It is possible to discriminate difference in quantity between odors from the smouldering materials and organic materials by obtaining their probability with outputs of the two sensors having different film thickness. By selectively detection the particular odors generated in the very early stage of fire by this system, it is possible to quickly and effectively smell out abnormality in the environment. If the neural net is combined with many odor sensors, it would be possible to discriminate difference between delicate odors or to identify what is smouldering more precisely. It is further expected that any abnormality in the environment be detected through odors in the future.

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