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Odor Sensor System for Early Fire Detection and Its Application to Utility Mobile Robot

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In this paper, an odor sensing system for early fire detection is demonstrated. The odor sensing system consists of a sensor array and a computer. The sensor array consists of five metal-oxide-semiconductor gas sensors. Sensing the generation of hydrogen during incomplete combustion could be effectively utilized to detect the early stage of fire. As an application of the proposed sensor system, it was implemented into a utility robot named "Banryu" (tmsuk, Inc.) which is commercially available.

1. Introduction

Odor sensing systems have attracted much attention in recent years, because developing an objective evaluation method for odors instead of relying on human sensory test is required. The odor sensing systems, called electronic nose (e-nose) systems, have been applied to various areas (*e.g.* food processing, medical clinic, public health, etc.).(1) The areas using e-nose systems have increasingly expanded and several applications of e-nose systems can be found in the literature.(2,3)

In this paper, we show an odor sensing system for early fire detection. Fire alarm systems generally sense smoke, heat and flame to detect fire. The detectors, however, cannot detect the initial stages of a fire. We have developed an odor sensing system for early fire detection using commercially available metal oxide semiconductor (MOS) odor sensors. Here we consider a house fire as the target to be detected by the sensors and we discuss specifically fires caused by cigarettes. The proposed odor sensing system consists of two different sensors: one with broad sensitivity for various odors, and the other with high selectivity for hydrogen. Sensing the generation of hydrogen during incomplete combustion can be utilized to detect the early stages of a fire. The system developed has

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been attached to a commercial utility robot, which is used to detect the fire and warn of changes concerning odors in a room.

2. Experimental

2.1 *Odor sensor system*

Odor sensors based on the change in the resistance in MOS have been studied for many applications. In this experiment, commercial metal oxide odor sensors of two types, CH-Ez and CH-H (New Cosmos Electric, Inc.), were used. The CH-Ez-type odor sensor has broad sensitivity for various odors, which can be used for detecting a change in the atmosphere of the room being measured. The CH-H-type has high selectivity for hydrogen, which can sense the generation of hydrogen in incomplete combustion. A sensor array combining these sensors was used for odor samples.

Figure 1 shows the odor sensing system. The sensor array is connected to the sensor unit, which consists of circuit boards for each sensor and a power supply. Measuring a change in the resistance of the MOS sensor indicates the adsorption of odors on the surface of a sensor. The measured change in the resistance can be observed and visualized using the software on the computer, which is connected through an A/D converter. We considered two conditions for the experiment. First, we prepared an experiment in a sealed chamber. Odors injected into the chamber using a syringe were measured by the two types of MOS sensors located on the top of the chamber. In this experiment using the sealed chamber, sensor response patterns were evaluated for the odors using the CH-Ez and the CH-H sensors. We next carried out an experiment in using the sensors in a room, which was assumed to be a more practical environment.

Three locations of the sensor array relative to the odor source were considered as shown in Fig. 2 and the responses observed at these locations were compared.

3. Results and Discussion

3.1 *Evaluation of responses to burning cigarettes and disturbing odors*

First, we target a fire caused by a cigarette; therefore, the odor of a burning cigarette is used as the sample. The odors assumed to exist normally in the house; that is, odors of hair mousse, hair spray, perfume and fragrances are used as the competing odors. Figures 3 and 4

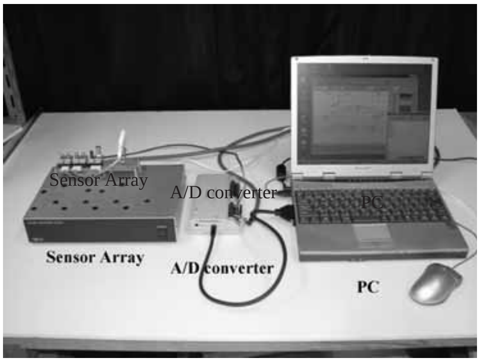


Fig. 1. The odor sensor system.

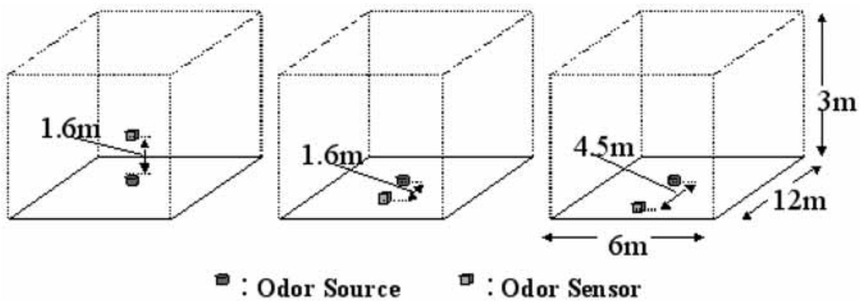
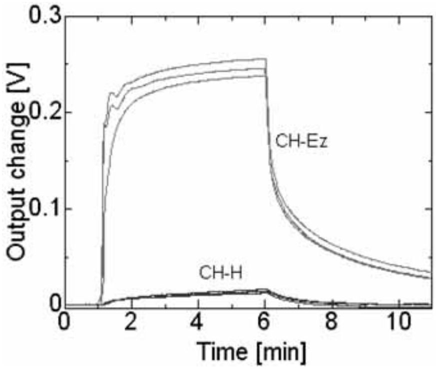


Fig. 2. Relative location of the sensor array and the odor source.



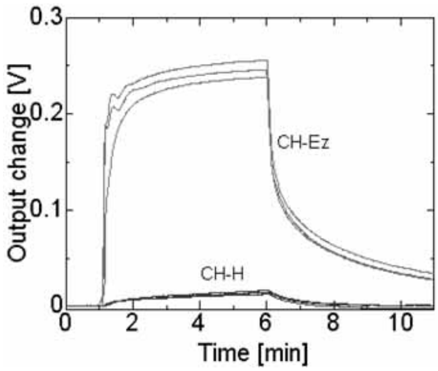


Fig. 3 (left). Response to the odor of a burning cigarette.
Fig. 4 (right). Response to a typical conflicting odor. (Response to the odor of hair spray.)

show typical responses to the burning cigarette and the odor assumed to compete the sensor response, which shows the response to the odor of the hair spray. These concentrations are set at 10,000 ppm.

In Fig. 3, as compared to the response of the CH-Ez sensor, we can see that the CH-H type sensor has an adequate response to the target odor. It also shows that the generation of hydrogen can be detected using the CH-H sensor. On the other hand, the response pattern to the competing odor is different from the response to the odor of the burning cigarette; the CH-Ez sensor responds only to the odor of the hair spray and the generation of hydrogen could not be detected. For the other odors assumed to compete the responses are similar to these results as shown in Fig. 4.

Using these results of the responses we can discriminate the burning cigarette from the other odors, and the detection of the generation of hydrogen can be used for discrimination. Figure 5 shows the discrimination of the odor of the burning cigarette from the odors assumed to compete and influence the sensor responses.

Burning cigarettes are separated from other odors, and even cigarette brands can be distinguished. However, the odors of burning cigarettes at low concentrations appear the plots near other odors. Here, the sensors directly sense the burning cigarettes that do not denote the concentrations; therefore, their odors are injected at very high concentrations in the experiment. From the result shown in Fig. 5, the change in the concentration of the odors influences the separation of the odors on the plots. Therefore, to avoid the influence of the change in the concentration of the odors, we normalized the sensor output response. Figure 6 shows the discrimination of the odors of burning cigarettes from the odors assumed to compete with and influence the sensor responses using normalized sensor outputs sampled at 240 s after starting the measurements. Each symbol indicates the same odor in Fig. 6. The discrimination among the odors improved from that in Fig. 5, and the plots of the same odors at different concentrations are closer. Thus the proposed method enables us to discriminate the odor of burning cigarettes.

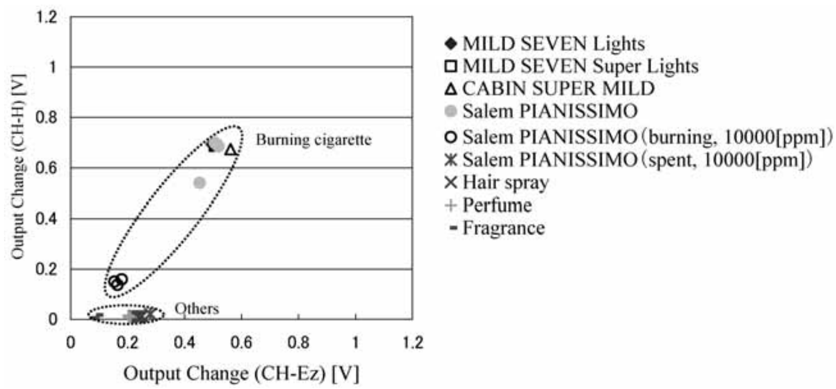


Fig. 5. Discrimination of the odors of burning cigarettes, using the outputs of the sensors (CH-Ez and CH-H) at 240 s after starting the measurement.

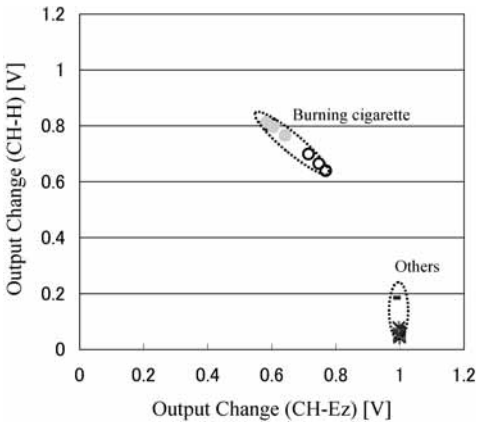


Fig. 6. Discrimination of the odor of burning cigarettes, using the normalized outputs of the sensors (CH-Ez and CH-H) 240 s after starting the measurements (symbols are same as in Fig. 5).

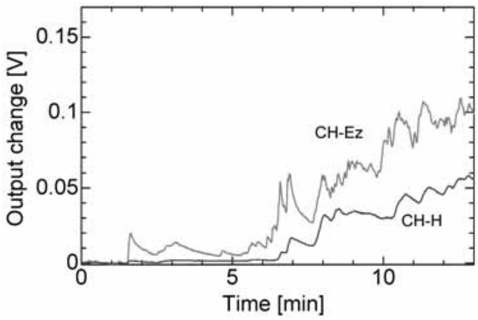
3.2 *Experiments in a closed room*

Assuming that the proposed odor sensing system will be used in a house, we considered and evaluated the response to burning cigarettes and the competitions in a closed room as shown in the Fig. 2 as more representative environment. Here we choose the odor of hair spray as the competing odor, and we show only the results of a case in which the sensor array is located over the odor source. Figure 7 shows the response to the odor of a burning cigarette in the room, where the sensor array is located over the odor source.

In Fig. 7, we can see that the CH-H type sensor responds sufficiently, similar to the measurement in the sealed chamber. The generation of hydrogen is also detected in this case. Note that the output of the CH-Ez sensor correlates with that of the CH-H sensor. Figure 8 shows the response to a typical competing odor, hair spray, when the sensor array is located over the odor source. The generation of hydrogen could not be detected, similar to the response in Fig. 4. The response pattern obtained by the sensors is similar in the experiment in the sealed chamber. Therefore, sensing the generation of hydrogen can be used to discriminate the odor of burning cigarettes.

It is remarkable that results for the other relative locations between the sensor and the odor source show the same result; the generation of hydrogen can be detected and the responses between the CH-Ez and the CH-H sensors correlate to the odor of burning cigarettes. Since it is expected that the response to the odor generated in incomplete combustion can be shown to be similar to burning cigarettes, the proposed system may be useful for early detection of fires.

We next expand the target odorants. The responses to odors generated when other materials burn, which are generated by heating items with a soldering iron, are added and evaluated. The senor array used in the previous experiments is constructed using the same two types of sensors, CH-Ez and CH-H. The key to discriminating the odorants is the sensor response to hydrogen, which is obtained using the CH-H sensor. But hydrogen can not be detected in some odorants obtained from burning materials, as shown in Fig. 9. Therefore, we expand the sensor components on the array. Each sensor on the array is



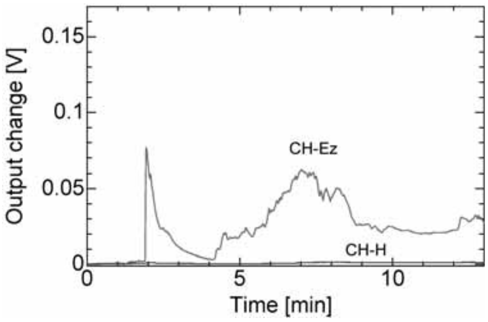


Fig. 7 (left). Transient response to the odor of a burning cigarette in the room. (The sensor array is located over the odor source.)
Fig. 8 (right). Response to a typical competing odor (the response to the odor of hair spray), when the sensor array is located over the odor source.

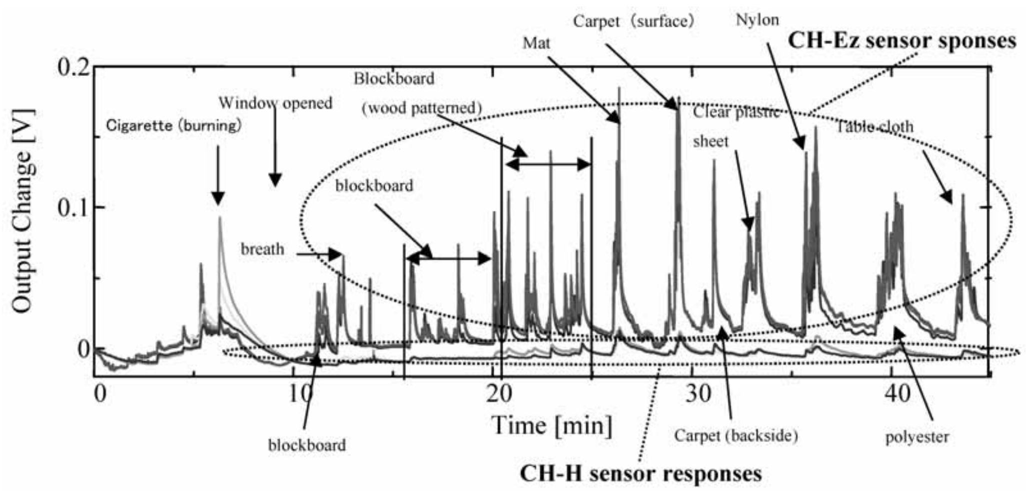


Fig. 9. Response to odorants generated by burning cigarette and several materials.

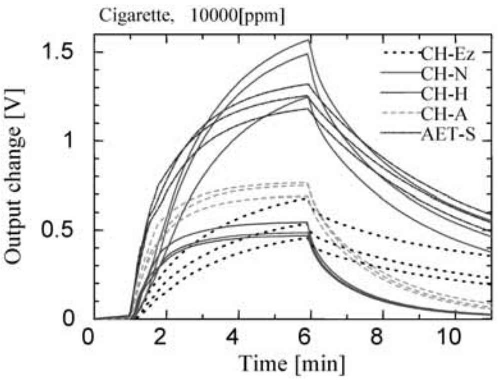
characterized by its sensitivity to hydrogen, ammonia, hydrogen sulfide, volatile organic compounds (VOC) and various other odors. The sensor array is reconstructed with these sensors.

First, we evaluate the previous odorants again with a sensor array consisting of five sensors. The odors are generated in two ways. One method generates a single odor separately. The other generates two odors sequentially at an interval of several minutes. The sensor array generates a response pattern to the odors; typical response patterns are shown in Figs. 10 and 11, when the responses to the target odorants can be characterized by the response of the CH-H type sensor primarily selective for hydrogen.

Next, we consider the influence of the rest of the competing odorants by a principal component analysis (PCA) plot using the array output at each time. Figure 12 shows the result of PCA using the sensor response pattern constructed by the sensor array output sampled 420 s after stating the experiments. The data were obtained by experiments in the room. The measurements using two odors were obtained by generating a second odor 60 s after generating the first odor. The result shows that the target odor, cigarette, can be discriminated from the competitive odors. The response patterns to the target odor, which was characterized by the response to hydrogen, were different from the responses to the competitive odors. Although the concentration of the target odor increased, responses to the competing odors were constant or decreased. Thus, the response pattern to the mixtures was similar to the response to the target. Therefore, the mixtures containing the target odor can also be isolated from the other odorants. The detection of the generation of hydrogen could be utilized to discriminate the odors of fire from that of the competing odors.

3.3 *Discrimination of the odorants generated by burning materials*

We also applied the proposed system to detect the odorants generated by burning materials such as cellulose, polyethylene and nylon. Figure 13 shows the typical transient response to the odor obtained by burning nylon. It shows that the CH-H type sensor can not



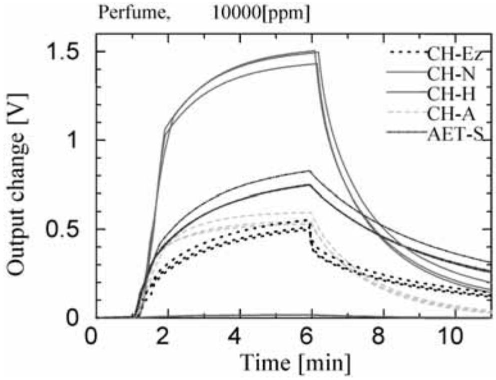


Fig. 10 (left). Response to the odor of burning cigarette in the chamber.
Fig. 11 (right). Response to the odor of perfume in the chamber.

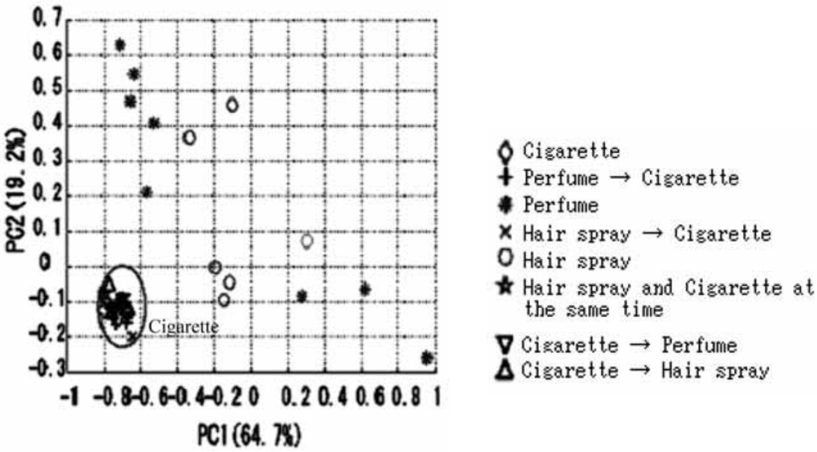


Fig. 12. PCA plot of the data measured in the room. The odors are generated in two ways. One method generates a single odor separately. The other method generates two odors sequentially at an interval of several minutes (shown as A→B).

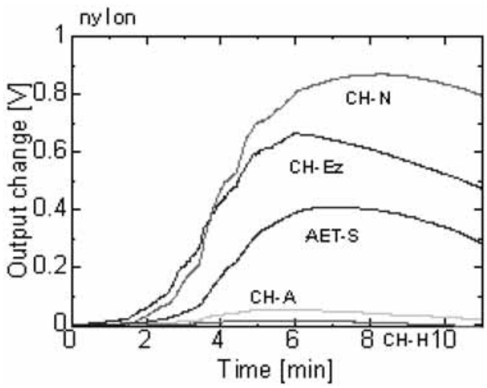


Fig. 13. Response to the odor of the burning nylon.

respond to the odor sufficiently. Therefore, as an indicator, the generation of hydrogen cannot be used to detect the fire. Therefore we consider the response pattern of the odorants obtained by the sensor array output. The response patterns are utilized to construct data vectors for PCA. We applied PCA to the discrimination of the sensor array responses to the odorants generated by burning materials.

The pattern vectors corresponding to the odors were normalized to reduce the influence caused by changes in the concentration of the odorants. In Fig. 14, PCA is performed on unit gases with changing concentration. The result shows the method can discriminate the gases even if concentrations change. We next apply the method to the odorants shown in Fig. 15. Figure 15 shows the proposed system can also discriminate the odorants generated by burning materials from the competing odorants. The proposed sensor array system can be utilized to detect fires.

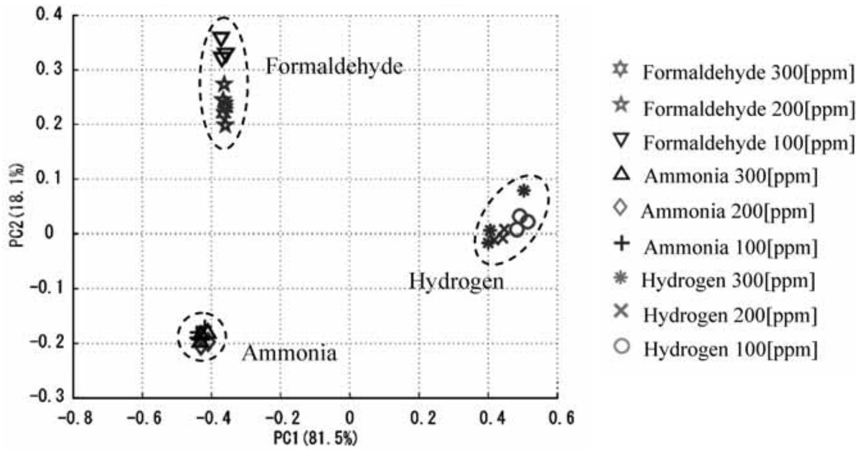


Fig. 14. PCA plot of the data from responses to the gases at different concentrations.

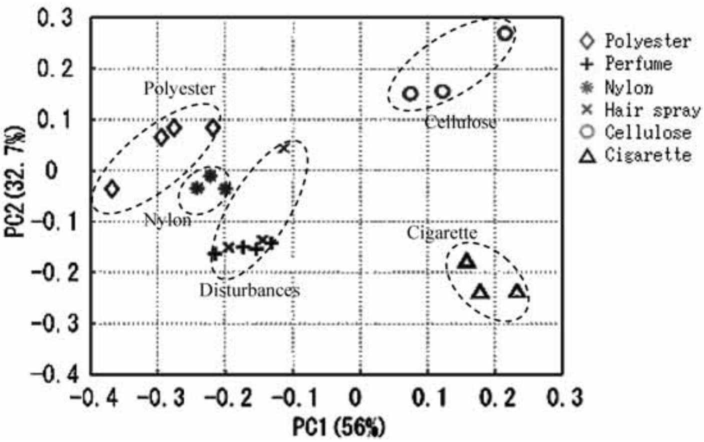


Fig. 15. PCA plot of the data from the chamber.

Fig. 16. The utility robot “Banryu” (tmsuk, Inc.).

4. Conclusions

An odor sensing system for early fire detection was developed and demonstrated. We have shown that sensing the generation of hydrogen in incomplete combustion could be utilized to detect the early stages of fire effectively. Some odorants generated by burning materials can be isolated from the competitors using the sensor array system with PCA. As an application of the proposed system, the sensing system has been attached to the commercial utility robot “Banryu” (tmsuk, Inc.) shown in Fig. 16.

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