Paper

Study on the development of a practical system for discrimination and concentration-estimation of domestic gases

Non-member Kazunori Sugahara (Tottori University)
Member Ryosuke Konishi (Tottori University)
Member Byeongdeok Yea (Korea Maritime University)
Non-member Tomoyuki Osaki (Tottori University)

A gas discrimination system which can estimate the concentration of the discriminated gases are proposed in this paper. TMS320C50 DSP by Texas Instruments and semiconductor gas sensor TGS823 by FIGARO Electronic are utilized for a data processing unit and a sensing probe, respectively. As for software, an artificial neural network and a fuzzy-neural network are used for the discrimination and the concentration-estimation of introduced gases, respectively. Hydrogen, vapor of alcohol and cigarette smoke are selected as domestic gas examples in the experiment, and the efficiency of the proposed system is confirmed according to the experimental results.

Keywords: neural network, fuzzy-neural networks, concentration-estimation, semiconductor gas sensor, periodic operation

1. Introduction

It is important in several fields such as environment control and disaster prevention to identify the inflammable gas and dangerous gas. Semiconductor gas sensors based on tin oxide (SnO_2) are widely used in many applications because of their advantages such as small size, light weight, high sensitivity and long durability. However, the gas selectivity of the sensors still remained as an unsolved problem in spite of numerous researches that have been invested to improve it. Recently, to obtain the gas selectivity, the researches of intelligent sensor systems have been investigated. In these researches, methods of integrating several sensors with different characteristics and/or the new concepts of pattern recognition, such as fuzzy logic, neural network, are introduced (1) (2). But such methods using multiple sensors complicate sensing system and their signal processing.

On the other hand, the improvement of the gas selectivity of sensors can be expected if more information can be obtained from the response patterns of the sensors. In order to obtain much more information from one sensor, we have proposed the method in which the heater voltages of the sensors are controlled to change their values periodically. And according to the proposed method, we have developed the domestic gas discrimination system (3). In this paper, the gas discrimination and gas concentration-estimation system by using an artificial neural network and a fuzzy neural network. The proposed system has been developed as a practical system, where hydrogen, vapor alcohol, and in the experiment, cigarette smoke were considered as domestic gas examples.

As for hardware, a system with small size and real-time processing is constructed by using DSK (DSP Starter Kit), which contains TMS320C50 Digital Signal Processor (DSP, Texas Instruments) on board. A commercial semiconductor gas sensor TGS823 (FIGARO Electronic) is used as a sensor. As for software, an artificial neural network and a fuzzy neural network are utilized for the discrimination and the concentration-estimation of introduced gases, respectively.

2. Structure of system

2.1 Hardware structure

The block diagram of Fig. 1 shows the hardware structure of the proposed system.

As shown in the figure, the proposed system is constructed with a DSK, extended memories, semiconductor gas sensor circuits and LED's. The DSK, which contains a DSP, an AIC (Analog Interface Circuit), a serial port and an emulator port, plays an important roll in the system. DSP accomplishes 16 bits fixed point calculations and has processing ability of 40MIPS. AIC involves a 14 bit A-D and a D-A converter, a LPF (Low Pass Filter)/BPF (Band Pass Filter) by SCF (Switched Capacitor Filter) and a DSP serial port. The serial port and emulator port are prepared to carry out data transfer between personal computer and the DSK.

In this study, the serial port and the emulator port are used for running test of system program and for development of program, respectively. Memory area of DSP is composed of program memory area, data memory area and I/O area. Because of the practical memory area on the DSK is equipped only 10KW, the external memories are extended to load gas discrimination and concentration estimation programs.

2.2 Software structure

The software of proposed system is constructed with an interrupt routine and a main routine. The interrupt routine is executed to obtain the value of output voltage of sensor at every one second. In the proposed system, the heater voltage of sensor is controlled to have 16-second period, i.e. the heater voltage changes its value at every 8 seconds. And the high and low level voltages of sensor heater are set to be 5[V] and 3[V], respectively. Processing flow chart of the interrupt routine is shown in Fig. 2.

Main routine is composed of a program for judgement of gas introduction, a neural network program for gas discrimination and a fuzzy neural network program for concentration estimation. In the program of gas introduction judgements, difference between the current sensor output voltage and the average value of last 10 of sensor output voltages is evaluated and if it is bigger than the certain threshold value, gas introduction will be detected. Once the gas introduction is detected, the number of obtained data is set to zero and the interrupt routine keeps executing during one period of the heater voltage. In this operation, 16 samples of sensor outputs are obtained. After one set of data is sampled, gas discrimination and concentration estimation by using neural network program and fuzzy neural network program are accomplished. Flow chart for the main routine is shown in Fig.3.

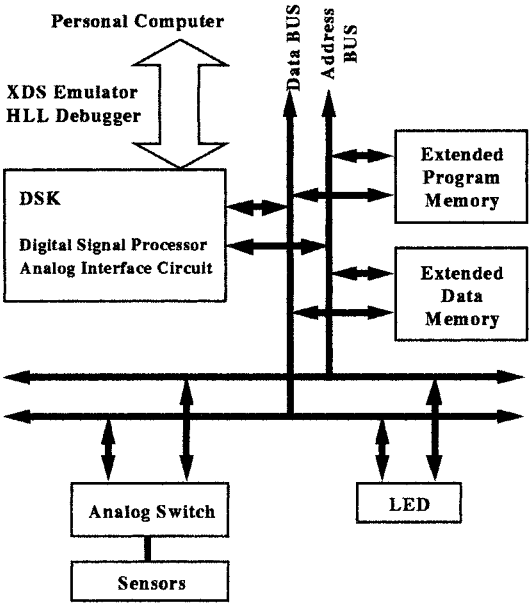

Fig. 1. Block diagram of the discrimination system.

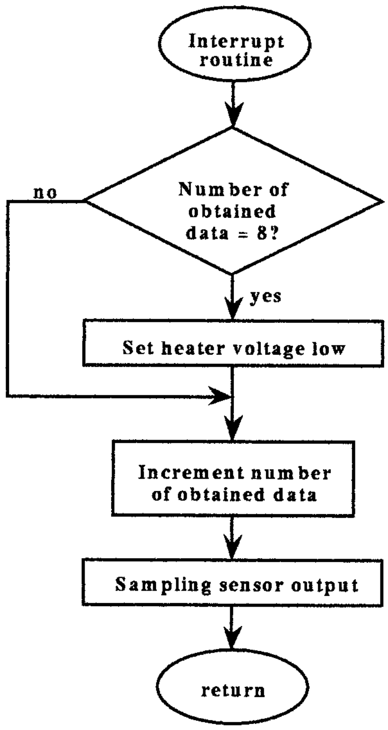

Fig. 2. Interrupt routine.

3. Discrimination of gas species

3.1 Gas discrimination method The schematic diagram of the experimental apparatus is shown in Fig. 4. In this experiment, hydrogen, vapor alcohol and cigarette smoke are introduced with a syringe to a gas chamber with $2400cm^3$ volume considering as a representative examples of dominant gas species. DC components of the output patterns of sensor are used to judge whether gas is introduced or not. When gas introduction is detected, a program for gas discrimination is executed automatically. The DC component of sensor output is removed from output pattern and it is used for discrimination of introduced gas species with a neural network. Here, the neural network is trained by using the back propagation algorithm. Figure 5 shows the typical output pattern of the sensor TGS823 for the standard concentration of gases. Here, the standard concentration is set as same manner as in Ref. (4). The 16 data of the 3-rd period (from 32 second to 47 second) are selected as training patterns of the neural network.

3.2 Gas discrimination experimental The neural network employed for gas discrimination has a three-layer BP network with 16 input nodes, which is correspond to the number of data in one period, and has 10 nodes in hidden layer and 4 nodes in the output layer. The number of nodes in the output layer is determined with the number of objective gas species including air. Here, the air output is included to show that any gases are not introduced. Training of the neural network is performed until the error between the training pattern and the output pattern of neural network becomes smaller than certain threshold value. Table 1 shows the discrimination results when the standard amount of gases is induced.

Table 1. Discrimination results when the standard amount of gases are introduced.

Introduced Gas	Discriminated as			
	air	alcohol	cigarette	hydrogen
air	20	0	0	0
alcohol	0	20	0	0
cigarette	1	0	19	0
hydrogen	0	0	0	20

20 characteristic patterns of each gas are measured,

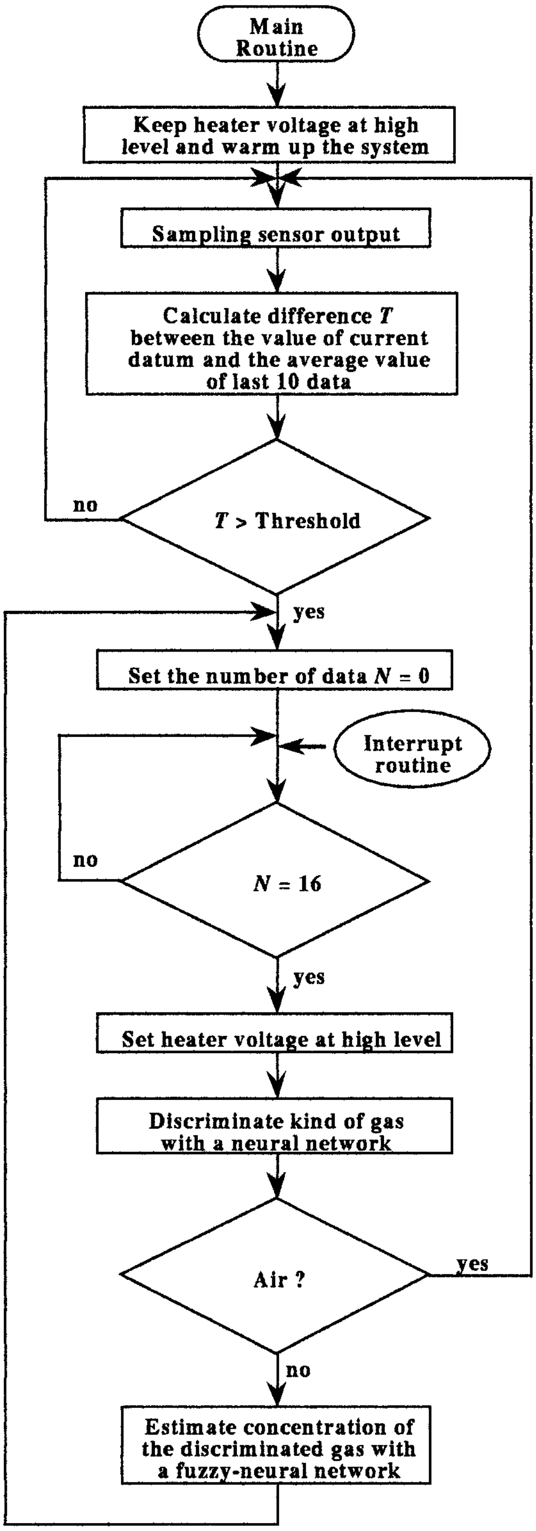

Fig. 3. Main routine.

i.e. 80 measurements for 3 kinds of domestic gas species and the air are performed in this experiment. From the results of this experiment, it can be easily seen that almost perfect discrimination was accomplished. Only one experiment of cigarette smoke gives wrong discrimination result to the air.

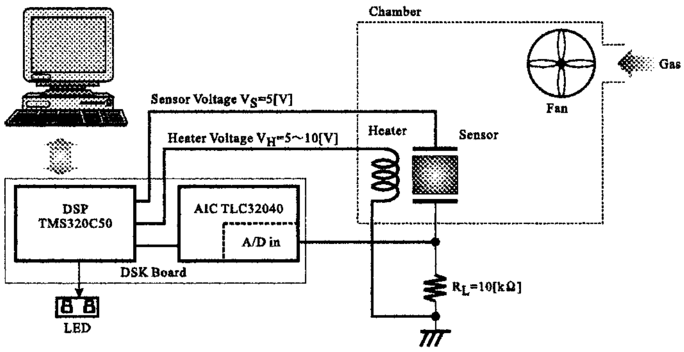

Fig. 4. Schematic diagram of experimental apparatus.

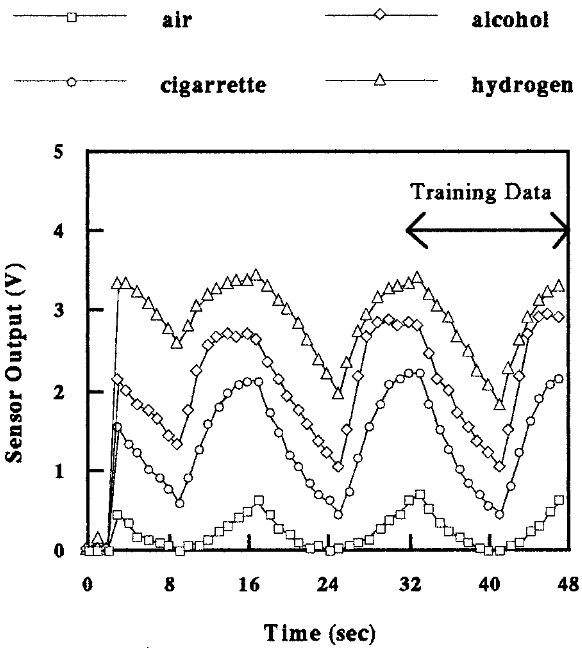

Fig. 5. Typical output pattern of the sensor TGS823 for the standard concentration of gases. The 16 data of the 3-rd period (from 32 second to 47 second) are selected as training patterns of the neural network.

4. Concentration estimation

4.1 Concentration estimation method In order to develop a gas concentration estimation system, the relations between the sensor output and the concentration of introduced gases are tried to represent in fuzzy rules in this paper. Based on the discrimination result, the concentration estimation is performed with fuzzy neural networks (FNN) [5]. The structure of the FNN is determined by the normalized DC components of the sensor outputs and fuzzy IF-THEN rules involved. Five IF-THEN rules are extracted based on the data as follows.

```
IF the DC is very small
      THEN the PPM is very low
IF the DC is small THEN the PPM is low
IF the DC is medium THEN the PPM is medium
IF the DC is large THEN the PPM is high
IF the DC is very large
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THEN the PPM is very high

Figure 6 shows the configuration of a FNN that is constructed based on the above IF-THEN rules. This type of FNN was firstly proposed by Horikawa et al. [6]. As shown in the figure, the FNN has one input node to obtain the DC component x of the objective gases and it has one output node to produces the results of concentration estimation *ppm* of the introduced gases. In the proposed system, by using the normalized value of DC components, the structure of the original FNN is modified adequately to fit for our purpose. The weights w_c and w_g determine the positions and gradients of the membership functions according to the following equation, respectively;

$$f(x) = \frac{1}{1 + exp\{-w_g(x + w_c)\}}, \quad \cdots\cdots\cdots\cdots (1)$$

where $f(x)$ means the output values of the (C)-layer units in Fig. 6. The weights are determined approximately at the initial stage, that is, before learning. After the training was completed, the connection weights of the FNN are renewed to represent the relations between inputs and targets, and, therefore, the outputs of the (D)-layer of FNN with various DC inputs correspond to the membership functions of the antecedent part.

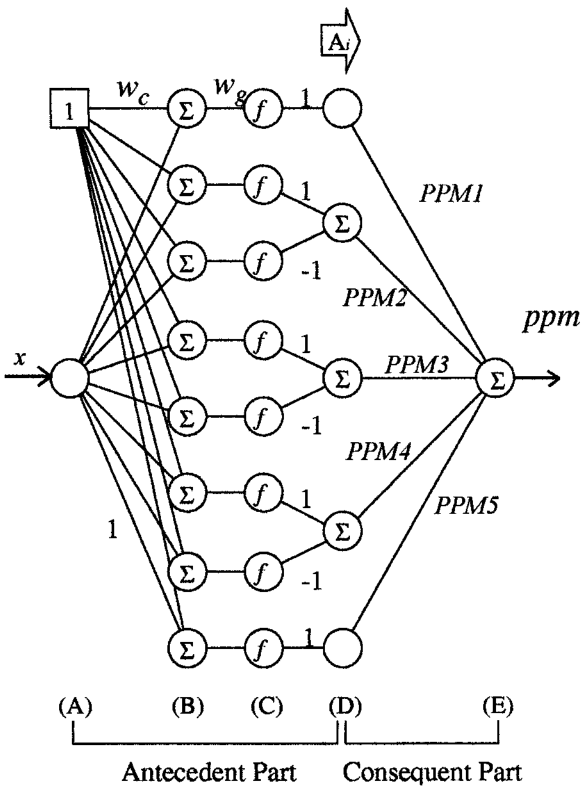

Fig. 6. Structure of a fuzzy-neural network.

Membership functions for the antecedent part are revised by the trained FNN. The trained FNN can perform the following simplified fuzzy inference based on the created membership functions and the aforementioned IF-THEN rules;

$$ppm = \sum_{i=1}^{5} A_i \cdot PPM_i, \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where the numbers from 1 to 5 mean very small or very low , small or low, medium, large or high and very large or very high , respectively. And A_i is the output grades of the trained FNN. Data of membership functions for the antecedent and consequent parts of the if-then rules are obtained easily from the normalized DC components.

4.2 Concentration estimation experimental In Table 2, the results of concentration estimation of hydrogen gas are summarized. In this example, data of very small, small, medium, large and very large for the antecedent part can be extracted from the DC components for 200,400,600,800 and 1000 ppm , that is, PPM1=200, PPM2=400, PPM3=600, PPM4=800 and PPM5=1000 in eq.(2).

Table 2. Results of concentration-estimation.

Concentration(ppm)				
Introduced	Estimated by Fuzzy Neural Network			
200	200	202	201	200
400	404	404	401	400
600	602	611	602	600
800	804	816	803	800
1000	1000	1000	999	997

Figure 7 shows the membership functions of hydrogen for antecedent functions generated by the trained fuzzy neural network. Thin lines denote the initial membership functions and the thick lines are the trained membership functions. The results of concentration-estimation show the value of 5 stages. In the case of hydrogen, these stages are correspond to below 200ppm, nearby 400ppm, nearby 600ppm, nearby 800ppm and above 1000ppm. The estimated concentration results are displayed on LED's. In order to confirm the transient characteristics of the proposed system, the concentration of hydrogen is changed from 200ppm to 1000ppm. It is found that the maximum error of concentration estimation is less than 20ppm and the correct results are shown on LED reflecting the change of induced hydrogen concentration.

5. Conclusion

In this study, we propose the gas discrimination and concentration estimation system for practical use by using DSP and one semiconductor gas sensor. In the proposed system, a high speed DSP is used to realize the system as a stand-alone real-time processing. The extension of memory is done to correspond to neural network and fuzzy neural network. As for software, we developed new algorithm connecting a neural network and a fuzzy neural network. They are applied for the gas discrimination and concentration estimation of the discriminated gas simultaneously. As the result of experiment for gases of 3 species selected as domestic gases, we verified the efficiency of the proposed system

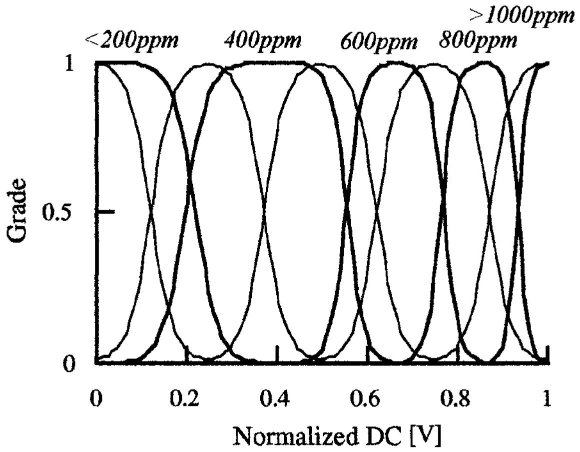

Fig. 7. Membership functions of hydrogen.

as real-time system for gas discrimination and concentration estimation of domestic gases.

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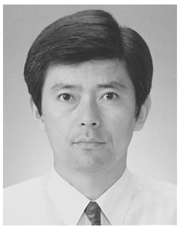
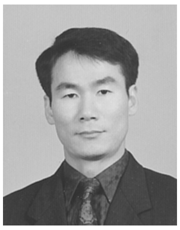


Kazunori Sugahara (Non-member) Kazunori Sugahara received the BE degree from Yamanashi University, Kofu, Japan, in 1979 and the ME degree from Tokyo Institute of Technology, Tokyo, Japan, in 1981. In 1989, he received the Doctor of Engineering degree in Electronic Engineering from Kobe University, Kobe, Japan. From 1981 to 1994, he was on the staff of the Department of Electronic Engineering, Kobe City College of Technology. In 1994, he joined Tottori University, Tottori, Japan, as an associate professor of the Department of Electrical and Electronic Engineering. His current interest lies in the field of one- and multi-dimensional signal processing and their application to the development of recognition systems. Dr. Sugahara is a member of the Institute of Electrical and Electronics Engineers, the Institute of Electronics, Information and Communication Engineers, Japan and the Information Processing Society of Japan.

Ryosuke Konishi (Member) Ryosuke Konishi graduated from the Instrumentation Department, Faculty of Engineering, Kobe University, in 1968, and from the Master's program at the same university in 1970. He also has a Ph.D. from Osaka University. He was appointed to an assistant of Electronic Department at Tottori University in the same year, associate professor in 1977 and professor in 1992. He is engaged in research on development of sensor devices and applications of microcomputers to measurements. Dr. Konishi is a member of the Institute of Electronics, Information and Communication Engineers, Japan, the Institute of Applied Physics, Japan and the Society of Instrument and Control Engineers, Japan. He is a Doctor of Engineering.



Byeongdeok Yea (Member) Byeongdeok Yea was born in the Republic of Korea in 1961. He received the B.E. and M.E. degrees from Korea Maritime University in 1983 and 1985, respectively. He received Doctor of Engineering from the Department of Electrical and Electronic Engineering of Tottori University, Japan in 1999. In 1989, he joined the Division of Maritime Transportation Science of Korea Maritime University and is now an associate professor there. His research interests include the development of high performance thin-film semiconductor sensors and signal processing algorithms from the sensors. He is also interested in neural networks and fuzzy systems.

Tomoyuki Osaki (Non-member) Tomoyuki Osaki graduated from the Electronic Department, Kurayoshi Technical High School, Japan, in 1969, and was appointed as a technician in the Electronic Department at Tottori University in the same year. Since then, he has engaged in research on thin films, surface physics and the application of microcomputers to measurement systems.