Design of a Smart Gas Sensor System for Room Air-Cleaner of Automobile (Thick-Film Metal Oxide Semiconductor Gas Sensor)

Jung-Yoon Kim†, Tae-Zi Shin* and Myung-Kook Yang**

Abstract – It is almost impossible to secure the reproductibility and stability of a commercial Thick-Film Metal Oxide Semiconductor Gas Sensor since it is very difficult to keep the consistency of the manufacturing environment. Thus it is widely known that the general Semiconductor-Oxide Gas Sensors are not appropriate for precise measurement systems. In this paper, the output characteristic analyzer of the various Thick-Film Metal Oxide Semiconductor Gas Sensors that are used to recognize the air quality within an automobile are proposed and examined. The analyzed output characters in a normal air chamber are grouped by sensor ranks and used to fill out the characteristic table of the Thick-Film Metal Oxide Semiconductor Gas Sensors. The characteristic table is used to determine the rank of the sensor that is equipped in the current air cleaner system of an automobile. The proposed air control system can also adapt the on-demand operation that recognizes the history of the passenger's manual-control.

Keywords: Thick-Film Metal Oxide Semiconductor Gas Sensor, Room Air-Cleaner of Automo bile, Characteristic Table, On-Demand Operation

1. Introduction

Precise and stable air quality control systems in vehicles are required to comfortably maintain the passenger space in an automobile. This is because people in a vehicle may be exposed to contaminant air that is undetectable to human senses. In this case, the air-cleaner in a vehicle has to be operated to keep the air in passenger space fresh. Most modern automobiles equip their passenger space air control systems with precise gas measurement systems.

In such measurement systems, a Thick-Film Metal Oxide Semiconductor Gas Sensor is generally used. However, it is almost impossible to secure the reproductibility and stability of a commercial Thick-Film Metal Oxide Semiconductor Gas Sensor since it is very difficult to keep the consistency of the manufacturing environment. [1] That means that each gas sensor would provide a different sensing result under the same measuring environment. Thus it is widely known that the general Semiconductor-Oxide Gas systems are inappropriate for use in precise measurement systems.

Albrecht, Matz, Hunte, and Hildemann [2] developed the intelligent gas sensor system for the identification of hazardous airborne compounds using an array of eight semiconductor gas sensors. However, it requires at least eight semiconductor gas sensors. Thus, it is not suited for an inexpensive system.

In this paper, the output characteristic analyzer of the various Thick-Film Metal Oxide Semiconductor Gas Sensors that are used to recognize the air quality in an automobile are proposed and examined. The analyzed output characteristics in normal air chambers are grouped by sensor ranks and used to fill out the characteristic table of the Thick-Film Metal Oxide Semiconductor Gas Sensors. The characteristic table is used to determine the rank of the sensor that is equipped in the current air cleaner system of an automobile. The proposed air control system can also adapt the on-demand operation that recognizes the history of the passenger's manual-control.

This paper is organized as follows. In Section 2, the description of the Semiconductor Gas Sensors and apparatus are presented. In Section 3, the system configuration of the proposed air control system is shown. In Section 4, the algorithm of the proposed air control system is shown. The last section summarizes the research efforts.

2. Semiconductor Gas Sensors

Many different types of gas sensors are developed and produced from various companies. The semiconductor gas sensor is a general choice for the air-cleaner of an automobile. In this research, we have selected semiconductor gas sensors with different ranks (sensor resistances) from Figaro Eng. Inc., Japan. Fig. 1 shows

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Received 2 November, 2006 ; Accepted 1 February, 2007

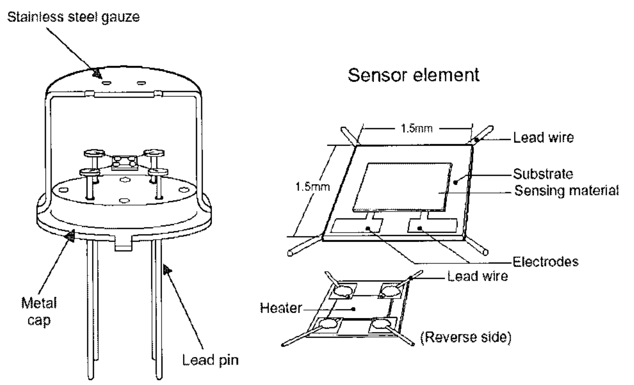


Fig. 1. Structure of a Figaro Gas Sensor

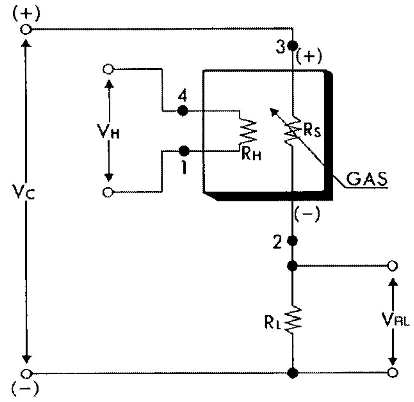


Fig. 2. Basic Measuring Circuit

the structure of the Figaro gas sensor. Using thick film techniques, the sensor material is printed on electrodes (noble metal) that have been printed onto an alumina substrate. The main sensing material of the sensor element is a metal oxide semiconductor. One electrode is connected to pin No. 2 and the other is connected to pin No. 3. A metal oxide heater printed onto the reverse side of the substrate and connected to pins No. 1 and No. 4 heats the sensing material. Lead wires are Pt-W and are connected to sensor pins that are made of Ni-plated Ni-Fe 50%. The sensor base is made of Ni-plated steel. The sensor cap is comprised of stainless steel (SUS304) [3].

The operational mechanism of the gas sensor is simple in principle. Oxygen from the air adsorbs on SnO_2 and removes electrons from the SnO_2 conduction band near the surface. The removal of electrons from the surface of each grain produces an insulating region that dramatically increases the contact resistance between powder grains [1].

Fig. 2 shows the basic measuring circuit. Circuit voltage (V_C) is applied across the sensor element, which has a resistance (R_S) between the sensor's two electrodes and the load resistor (R_L) connected in series. DC voltage is always required for the circuit voltage, and the polarity

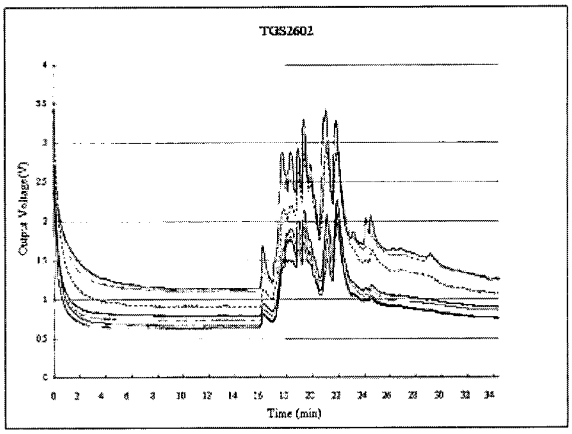


Fig. 3. Output signals of the gas sensor array (Normal, Temperature 24°C)

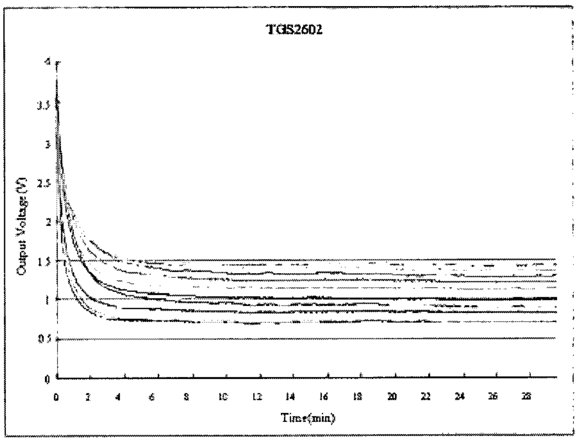


Fig. 4. Output signals of the gas sensor array (The polluted time between 16 and 24 min, Temperature 24°C)

shown in Fig. 2 must be maintained. The sensor signal (V_{RL}) is measured indirectly as a change in voltage across the R_L. The R_S is obtained from the formula shown as

$$R_S = \frac{V_C - V_{out}}{V_{out}} \times R_L \qquad (1)$$

These gas sensors are inexpensive, but the actual characteristics of the sensor vary from sensor to sensor and from production lot to production lot. The only characteristics of the resistances warranted are the range between $10\text{K}\Omega$ and $100\text{K}\Omega$. When they are manufactured, compressed powders aren't noted for their predictability. Slight changes in particular size, intergranular contact area, adsorbed impurities, and which crystal face is dominant, produce changes in the initial relationship between the resistance and the combustible-gas pressure.

Using the basic measuring circuit, the actual characteristics of the gas sensors in a normal environment are shown in Fig. 3. The voltages rise sharply for the first second after energizing, regardless of the presence of

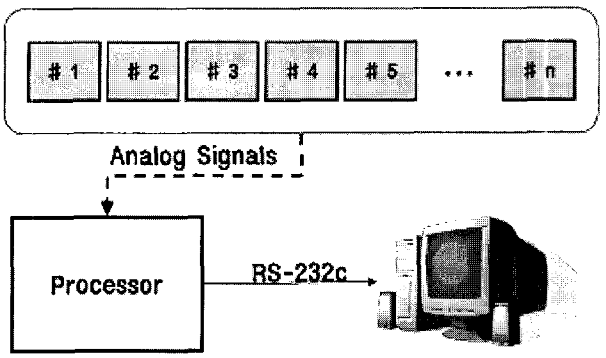
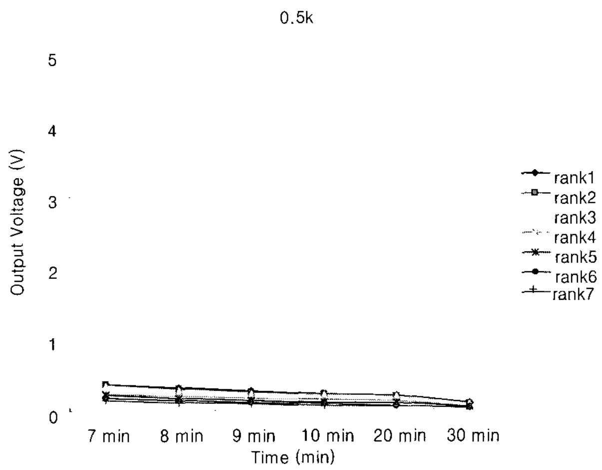
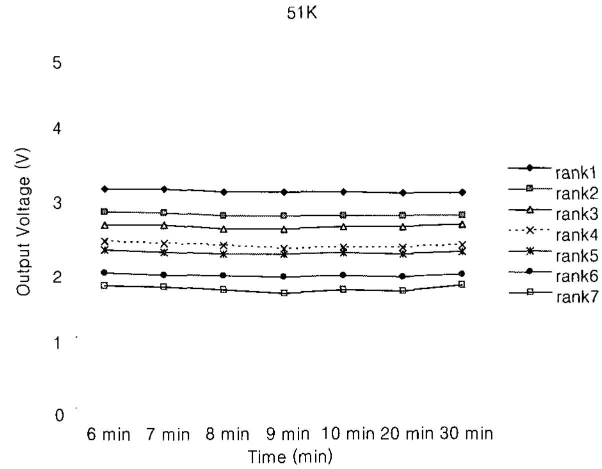


Fig. 5. The system of gathering data for the characteristic table. The seven Thick-Film Metal Oxide Semiconductor Gas Sensors are installed in a common measuring environment and connected via RS-232c interface with a personal computer.

gases, and then reach a stable level according to the ambient atmosphere. Such behavior during the warm-up process is called "Initial Action". The shapes of the sensors' Initial Action are similar, but the levels of the output voltages are totally different. The differences may create some problems such as the interference between the high rank sensors in the normal air and the low rank sensors in the polluted air. Fig. 4 indicates the initial action of the selected seven sensors with the operating air-conditioner in the polluted air. At 16 minutes, although all of the sensors' voltages are changed slightly, the lowest gas sensor's output voltage cannot reach the level of that of the highest gas sensor. Of course, if the degree of pollution is high, they are not interfered with each other. However, the difference of the output voltages is greater than before so that they are still not appropriate for precise measurement systems.



(a) $R_L = 0.5\,K\Omega$



(b) $R_L = 51\,K\Omega$

Fig. 6. Output signals of the seven rank gas sensor array through (a) $R_L = 0.5\ K\Omega$ or (b) $R_L = 51\ K\Omega$ (Normal, Temperature 24°C, Humidity 35)

3. System Configuration

Fig. 6 reveals the output voltages through two different load registers (R_L) from one input. In case of the uncontaminated condition, the output voltages through the load resisters are diverse enough to recognize each rank easily. However, the output voltage value for the contaminated air condition could be retrieved as the output voltage for the normal air condition of a different rank. On the other hand, the output voltages with the 0.5 $K\Omega$ load resistors are concentrated so that there seems to be no problem in the normal air. However, the differences of the output voltages, in the contaminant air, are increasing compared to the previous contamination. Therefore, the characteristic table should contain both of them and be used by the system simultaneously.

Fig. 7 illustrates the precise measurement system using the characteristic table for each rank. A gas sensor sends an analog signal to the Selectable SPDT (Single Pole Double Throw) Switch that is controlled by the processor. The processor chooses one of two different signals through the high or low load resistor. The selected signal is compared with the rank table stored in the serial memory.

The output voltage through the high load resistor ($R_L = 51\ K\Omega$) is used to select the rank of the sensor on the system, because the differences between each rank are big enough to distinguish what the rank is. The low load resistor ($R_L = 0.5\ K\Omega$) is used for detecting contaminant air. The output voltage through the low load resistor is useful to avoid the interference, because all ranks' output voltages are comparatively converged into a single point. Thus, the discrimination of the sensor's rank is up to the high load resistor and the recognition of the contaminant air is up to the low load resistor.

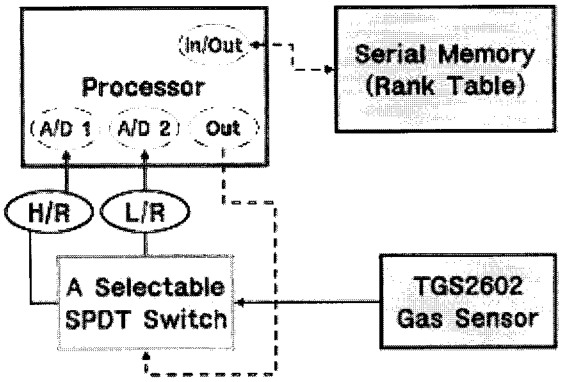


Fig. 7. The system configuration for detecting contaminant air with one Thick-Film Metal Oxide Semiconductor Gas Sensor

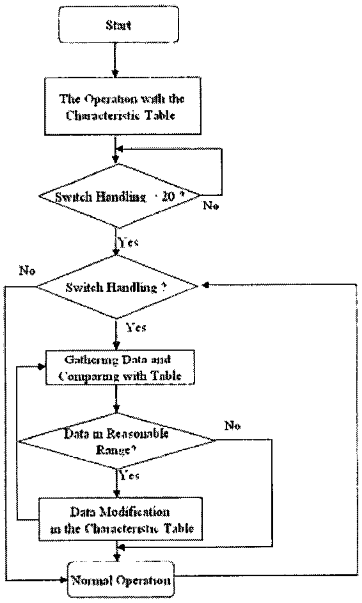


Fig. 8. Flowchart of programming algorithm for the adaptation based on the history of the passenger's manual-control.

4. Algorithm

The flowchart for recognizing the history of the passenger's manual-control is shown in Fig. 8. It begins with the normal operation based on the characteristic table, which contains the various ranks' information. To avoid garbage data such as the new user's handling the on switch without any purpose, an initial operation is proposed. If the switch handling is smaller than 20 or 30, the normal operation is repeated with the characteristic table in the serial memory being the reference. If the switch handling is greater than 20 or 30, the value of the gas sensor at that time is gathered and compared with the previous table. If the difference between the new data and the data stored in the memory is located in the range of the Thick-Film Metal Oxide Semiconductor Gas Sensors' variable characteristics, than the characteristics table is modified. If not, the system maintains normal operation without any change.

5. Conclusion

In this paper, the output characteristic analyzer of the various Thick-Film Metal Oxide Semiconductor Gas Sensors is proposed and examined. The Thick-Film Metal Oxide Semiconductor Gas Sensors are used to recognize the air quality within an automobile. An air control system based on the table from the output characteristic analyzer is also proposed. The system can adapt the on-demand operation that recognizes the history of the passenger's manual-control. The proposed method has been applied to the air cleaning system produced by IL-Kwang Eng. Inc., Korea. It provides better performance than the previous conventional system.

Acknowledgements

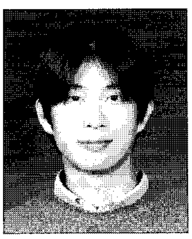
This work has been supported in part by a grant from the Small and Medium Business Consortium of uou (smbc-05010).

References

[1] S. Roy Morrison, "Semiconducting-Oxide Chemical Sensors", IEEE, March 1991 8755-3996/91/0300.

[2] T. Albrecht, G. Matz, T. Hunte and J. Hildemann, "An Intelligent Gas Sensor System For The Identification Of Hazardous Airborne Compounds Using An Array Of Semiconductor Gas Sensors And Kohonen Feature Map Neural Networks", IEE Conf. on Intelligent System Engineering, 5-9 September 1994.

[3] "Technical Information for TGS2602" Figaro Eng. Inc., Japan



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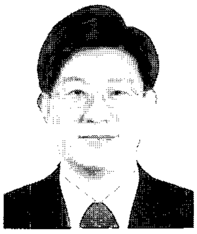

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