A NEW METHOD OF LOCALIZING GAS SOURCE POSITIONS FOR A MOBILE ROBOT WITH GAS SENSORS

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ABSTRACT

A remotely locate a gas source using a mobile robot with new type gas sensors is proposed. We proposed a new method of discrimination and quantification of gases by a single semiconductor gas sensor, based on the information embedded in a nonlinear dynamic response. We applied the method of gas sensor to a mobile robot, which locate a gas source; it is possible to reply in the time order of several seconds. We also discuss challenge problems of the "chemotaxis" robot.

Keywords: Nonlinear response, Tin oxide gas sensor, Robot navigation

INTRODUCTION

Rescue robots operated in disaster-stricken areas need gas sensors to detect the positions of gas leak. However the performance of existing gas sensors is not satisfactory for this kind of usage, because mainly of slow response and lack of discrimination ability. In efforts to give discrimination ability to gas sensors, many researchers have adopted methods using a multi sensor array of gas sensors with different properties, but these methods suffer problems of insufficient information content, low accuracy, and lack of robustness.

On the hypothesis that the biotic senses, especially taste and smell, are actively using dynamic and nonlinear properties of response (Fig. 1.), we proposed an idea that intelligent sensor systems could be built by using nonlinear dynamic response to an externally applied oscillation of a sensor parameter in an ordinary sensor device [1,2]. Because the properties in dynamic response of gas sensor outputs depend on the kind and the quantity of gas, we can discriminate and quantify gas from output of only a single sensor.

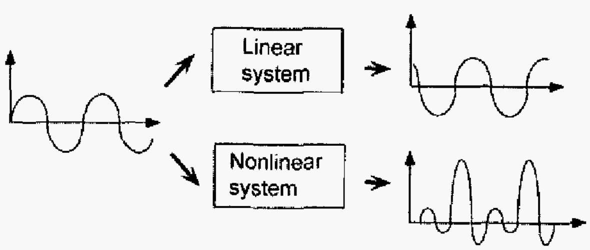

Fig. 1. Schematic figure of dynamic responses of linear and nonlinear systems.

In order to use gas sensors in practical applications, we have developed a small intelligent gas sensor system for discrimination and quantification in real-time using a *single semiconductor* gas sensor [3-5]. This system is based on the above method using information embedded in nonlinear dynamic response. By applying sinusoidal wave voltage to the heater attached to the sensing material, a characteristic time-dependent trace of the sensor resistance depending on the environmental gas is obtained. In order to analyze the response in a quantitative manner, the Fast Fourier Transform (FFT) is first applied. Higher harmonics obtained from the FFT are then processed using discrimination analysis and multiple regression algorithms. The system operates at 1Hz, which is fast enough for gas sensing.

Then we have proposed a new method of localizing gas source positions by combining some of the above gas sensor systems placed in separate positions. The gas sensors operate simultaneously and, from their outputs, the concentration gradient of a specific gas can be obtained. In the past, some reports are appeared [6], however we applied the new method to a mobile robot which can localize a gas source position. The robot can detect the direction of a specific gas source in few seconds. This behavior of the robot is inspired by the chemotaxis of biological organisms. The chemotaxis is one of the most important features in rather simple organisms. We developed a mobile robot that is controlled with the chemotaxis model, and the effectiveness of the biomimetic control is confirmed through a set of experiments.

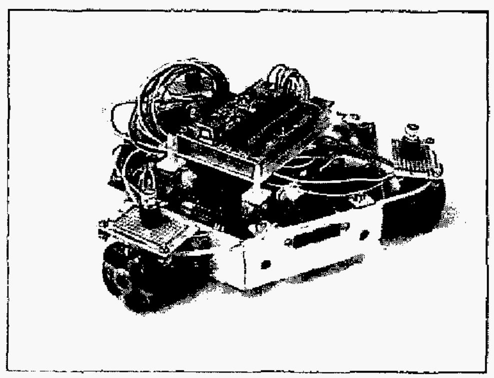

Fig. 2. The mobile robot with the nonlinear dynamic gas sensor systems.

EXPERIMENT

Fig. 2 shows the outward appearance of the prototype mobile robot that three semiconductor gas sensors (TGS-2400 manufactured by Figaro Engineering Inc.). The sensors are attached the upper side of the wheel respectively and connect the sensor control unit that attached center place of the upper side of the robot. As a result, the sensors are situated the each convex of the triangle robot body, and the distance became 17cm each other. The sensors are manufactured using the thick film printing technique and are marketed for the aerial quality monitor.

To obtain high performance in terms of time accuracy and reliable data acquisition, we used a high-performance micro-controller (PIC18F452 manufactured by Microchip Inc.) as the main control unit. The time sequence of an applied voltage and measurement of sensor resistance is completely determined by the micro-controller, and the time accuracy of the sequence is very high. In order to achieve a wide range of sensor resistance (varying 5-digit scale), the value was translated to the logarithmic one and stored in the micro-controller. By using the Pulse Width Modulation (PWM) technique, VH can have any value between 0 and 5 volts as the short time average value, while it can have only two values (0 or 5 volts) at anyone time point. Because the period of PWM is short enough (51.2 μs) in comparison with the period of VH, we can assume that the VH value was slickly changing.

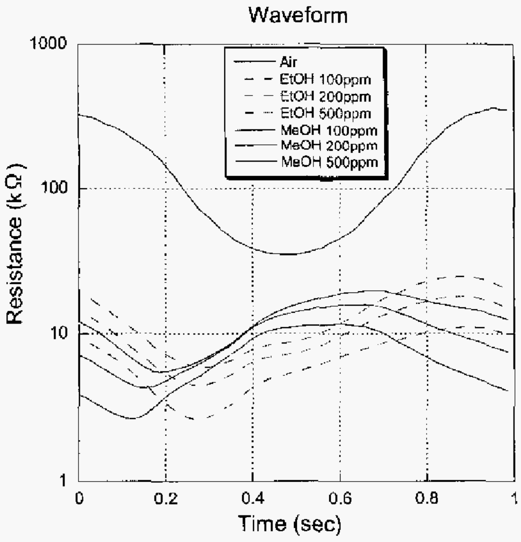

Fig. 3. Sensor resistance change in air, ethanol and methanol vapor 100, 200 and 500ppm.

The main body of the mobile robot is PPRK BrainStem Robot (Acromate Inc.). The body has the mechanism, which advances to the direction with the freedom of 360 degrees by the three omni-directional roller wheels. A programmable controller named "BrainStem" controls the movement of the body. The connections between the sensor unit and the "BrainStem" controller are three channels of digital line that indicate the direction to move on.

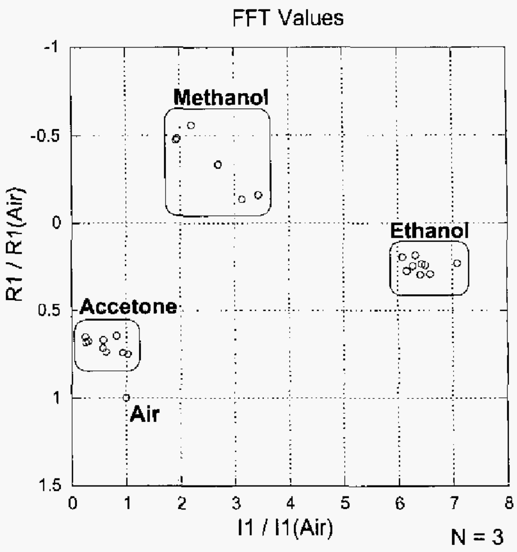

Fig. 4. Scatter plot between two FFT components in air, ethanol, methanol and acetone.

RESULT AND DISCUSSION

Figure.3 shows typical experimental traces of the surface temperature of the SnO_2 sensing layer and the resistance in control air and in the presence of ethanol and methanol gas. It shows the waveform data, which were acquired by the module in air and ethanol, methanol vapors at concentrations of 100, 200 and 500ppm. It is obvious that the waveform changes due to the species of ambient gas rather than its concentration.

Figure.4 shows a scatter plot between two FFT components. R_1 and I_1 represent the real and imaginary components of 1st harmonic of the waveform. Each coordinate is normalized by the value of R_1 and I_1 in air. The points indicate the measurement values of air and ethanol, methanol and acetone vapors with concentrations of 100, 200 and 500ppm and the squares indicate the molecular species. It is clear that we can distinguish the species from these component values. In addition, the response was markedly improved and converged within 10 seconds.

It is known that the waveforms of the sensor response are more stable for long term than absolute values, thus we think that estimated concentrations obtained by multiple regression of FFT are more stable and reliable than estimations by other methods.

Fig. 5 shows the response of the estimated concentrations under the condition which ethanol gas propagates by diffusion process. The vertical axis showed the estimated gas concentration, which was calculated from the coefficient obtained beforehand by the multi regression analysis. We prepared the ethanol liquid with the quantity that became 100 ppm concentration to the chamber into the sponge and set to diffuse little by little. Also we set a distance between the sponge and the sensors to approximately 10 cm. It seems that the local concentration of the sensor neighborhood initially became more than 100 ppm, because it takes quite long time to become that the whole chamber get into a uniform concentration.

The upper lines in Fig. 5 indicate the concentration which was calculated by the coefficient obtained respectively from three FFT components that are constant, 1st real and 1st imaginary. The two lines of the underside indicate the concentration which was calculated only from constant component. Because the constant component is same as the integration value of the sensor response waveform, it is approximately equivalent to static response value that is measured by the conventional way. The calculated concentrations response from three components show the obviously quick and sensitive response than the concentration calculated form constant components. The reason why the calculated concentrations that is obtained by three FFT components exhibit high sensitivity is under investigation. However the reason must be related that these estimated concentrations are utilizing the feature of waveforms of a nonlinear response.

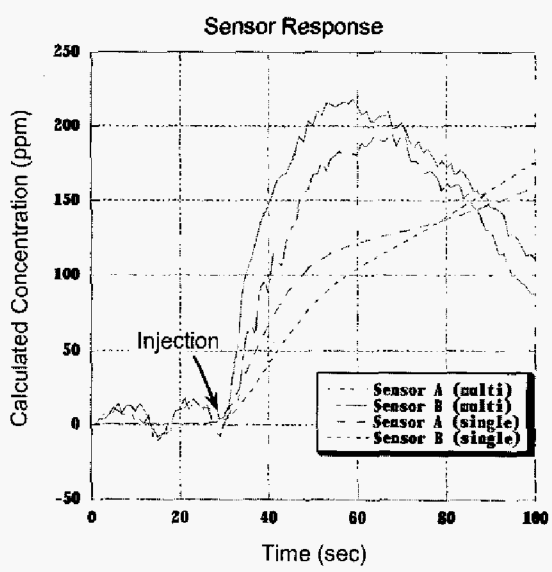

Fig. 5. Response of the estimated concentrations under the condition that ethanol gas is diffusing.

Fig. 6 shows the schematically overview of the algorithm that controls this robot. Three heaters in three gas sensors are applied the sinusoidal wave voltage by the same period and the sensor unit acquires the responses independently. After the waveforms are operated a logarithm translation, these are taken apart by the frequency component by the FFT. After that, we calculated the each concentration by multiplying a multiple regression coefficient at each component. Each set of multiple regression coefficients are calculated by the multi regression analysis from the data that was obtained by a prior measurement.

By the algorithm, the robot decided an actual movement direction to advance is the direction indicated by the sensor that exhibits the highest concentration, when the calculated concentration exceeds a threshold. This algorithm has an advantage that the direction is decided easily and automatically, however we thinks that the algorithm must be verified whether it is possible to reach a gas leakage position with the surely when the gas concentration has any distribution.

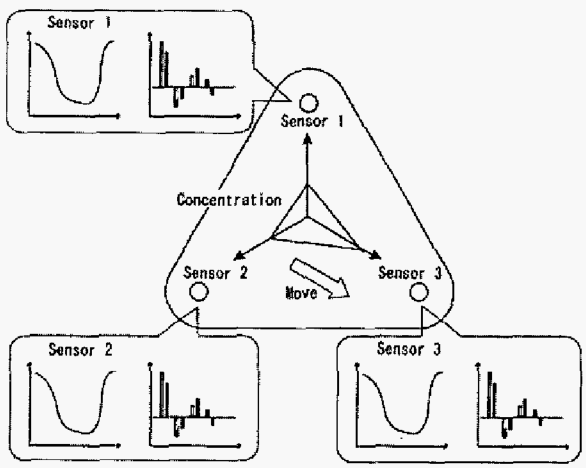

Fig. 6. Basic algorithm of determining the direction of gas source position using three nonlinear dynamic gas sensors.

CONCLUSION

We proposed the mobile robot to have incorporated chemotaxis algorithm into using the gas sensor system which used the dynamic nonlinear response in real-time. As the future problem, we will investigate the more realistic gas leakage source detection algorithm and the system, which changes a threshold with type of gas. To develop the system that changes a threshold with the type of gas, we believe that this method is fundamental because it is impossible to process the information of gas species and its concentration in real-time by former gas sensor systems.

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