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LI. Shujin

Ming BAI

Quan WANG

Bo CHEN

Xiaobing ZHAO

See next page for additional authors

Author
LI. Shujin, Ming BAI, Quan WANG, Bo CHEN, Xiaobing ZHAO, Ting YANG, and Zhaoxia WANG

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Detecting Automotive Exhaust Gas Based on Fuzzy Inference system

Li Shu-jin[a], Bai Ming[a], Wang Quan[a], Chen bo[a], Zhao Xiao-bing[a], Yang Ting[b], Wang Zhao-xia[a,c]*
a, School of Electronics Information Engineering, Tianjin Key Laboratory of Film Electronic and Communication Device, Tianjin University of Technology, Tianjin 300191, China.
b, School of Electrical Engineering and Automation, Tianjin University, Tianjin 300072, China
c, Department of Electrical and Computer Engineering, National University of Singapore, Singapore 119260
*E-mail: zhxwangmay@163.com

Abstract—**This paper proposes a method of detecting automotive exhaust gas based on fuzzy logic inference after analyzing the principle of the infrared automobile exhaust gas analyzer and the influence of the environmental temperature on analyzer. This paper analyses the measurement error caused by environmental temperature, and then makes a non-linear error correction of temperature for the infrared sensor using fuzzy inference. The results of simulation have clearly demonstrated that the proposed fuzzy compensation scheme is better than the non-fuzzy method.**

Keywords-infrared analyzer; automotive exhaust gas; fuzzy inference; temperature compensation

I. INTRODUCTION

Analyzing and detecting automotive exhaust gas is a complex technology based on many subjects. At present, there are more than 500 million automobiles in the world, and the annual output has exceeded 50 millions [1]. With the automotive exhaust pollution becoming more and more serious, the accurate measurement and proper treatment of exhaust gases of the automobile are becoming more and more important. Automotive exhaust is one of the main sources of pollution, which is a moving source, and those sources of pollution are difficult to be treated. Many countries use a lot of human and financial power to carry out the studies but no technique can be accepted by all the users.

Known different from the conventional computing, computational intelligence, which is called the soft computing, mainly includes fuzzy logic [2], Genetic algorithms [3], neural networks [4], and the combined method of any formers, such as fuzzy neural networks [5], is being rapidly developed in recent years. Computational intelligence research does not reject statistical methods, but often gives a complementary view. Fuzzy logic is a branch of computational intelligence. It is a powerful tool for modeling human thinking and perception. Human experience can be used in the design of the fuzzy controller. This makes it easier to perform tasks that are already successfully performed by humans.

In order to improve the accuracy of the measurements, the compensation mechanism of some parameters, such as environmental temperature, had been employed by some researchers [6-7].

Fuzzy sets and fuzzy logic have become one of the emerging areas, which spread across various research fields, from control, pattern recognition, and artificial life. It has been applied in traffic control, network planning and fault diagnosis [8]. However, there are few literatures that had studied on the application of fuzzy logic to deal with automotive exhaust gas. The motivation of this paper is to employ fuzzy logic to detect the automotive exhaust gas.

II. INSTRUMENT MEASUREMENT PRINCIPLE OF THE INFRARED AUTOMOTIVE EXHAUST GAS ANALYZER

The Bill law and the selective absorption of gases on infrared ray are used to analyze and process the data of sensor. The measured data is needed to be compensated.

Inert gas does not absorb infrared energy, while the automotive exhaust gas which is composed of different atom gases such as CO, CO_2, and hydrocarbon (HC) etc, can absorb the infrared energy in certain wavelength. The wavelength of the infrared energy, which can be absorbed, is called characteristic wavelength or feature wavelength. The absorption intensity is reflected by absorption coefficient. Due to the absorption of those gases, the energy of infrared ray will be reduced when the infrared ray go through the gases. The reduced energy ΔE has relationship with the gas concentration, the thickness of the gas chamber L, and the absorption coefficient. The relationship follows the Lambert-Beer's law [9],

$$\Delta E = E_0 - E = E_0(1 - C^{KL}) \tag{1}$$

where E_0 is the initial infrared energy before going through the gases, E is exit infrared energy after going through the gases. The absorption coefficient K is a very complicated parameter, which is not only dependent on the type of the gases, but is also related to the absorbed wavelength and affected by the environmental temperature, pressure and some other factors. Therefore, for the real working environment, in which both the temperature and pressure are varied, K is a variable. Since it directly affects the absorption energy of infrared ray, ΔE, Huston pointed out that the absorption for the weak-lighted zone should be the following equation [9],

$$E=\int_{\Sigma} A(\lambda)d\lambda = cW^{1/2}(P+p)^q \quad (2)$$

The absorption for the strong-lighted zone should be [9]:

$$E=\int_{\Sigma} A(\lambda)d\lambda = C + D\log W + Q\log(P+p)^q \quad (3)$$

where c 、 C 、 D 、 Q 、 q are constants determined by experiments. $A(\lambda)$ is the absorption function for certain wavelength. $d\lambda$ is infinitesimal increment of the wavelength. $\Sigma=\lambda-\lambda_0$ is the wavelength range. P is the general environmental pressure. p is the measured gas pressure. $W=(pl/76)\times[273/(273+t)]$. $t(^oC)$ is the environmental temperature. l is the thickness of the measured gas.

It is clearly shown that the environmental temperature is a important factor that influences the measurement accuracy of the sensor. The environmental temperature not only effects on the infrared ray absorption, but also directly affects the infrared radiation intensity and infrared detector accuracy. That is the reason why the application of temperature experiment method in the analysis of infrared gas is an effective way to establish environmental temperature compensation models.

III. THE MEASUREMENT FOR THE EXHAUST GAS UNDER DIFFERENT TEMPERATURE

In fact, the environment affects the accuracy of the measurement greatly. The error of the sensor can be ignored. For the same system, the light intensities received by two sensors at the same time are similar. We can get the following equation [6],

$$U_1/U_2=(K_1/K_2)e^{-KCL} \quad (4)$$

Assuming system parameters $K_0=K_1/K_2$, when gas chamber is filled with pure nitrogen, the concentration of CO_2 is zero, so we can determine system parameters [6],

$$K_0=U_1/U_2 \quad (5)$$

From the above transformation, we can get the gas concentration [6],

$$C=(-1/KL)(\ln U_1-\ln K_0-\ln U_2) \quad (6)$$

i.e. $C=K^{'}X$, where $K^{'}=(-1/KL)$, $X=(\ln U_1-\ln K_0-\ln U_2)$. For the fixed system, parameter, gas absorption coefficient and gas chamber length L are fixed. Moreover, we can work out $U1$ and $U2$ by measurement. So we can take the above formula as the theory basis of CO_2 concentration measurement.

In this paper, the room temperature 25℃ is selected as the standard temperature because the instrument calibration for data measuring is carried out at this temperature, and most of the equipments are operated at this temperature. The absolute error of measurement is:

$$e_i=C_{Ti}-C_{25^oC} \quad (7)$$

Where C_{Ti} is the gas density measured at the temperature Ti, and C_{25^oC} is the result measured at the room temperature 25℃.

The four different concentrations of the gas used in literatures [6-8] follow the prescriptive components of the new national standard in 2008. The four concentration levels of the gas CO_2 are 3.5%, 6.0%, 7.2% and 12.1% respectively. It is demonstrated that the higher the degree of the deviation from room temperature 25 ℃ to the environmental temperature, the higher the measurement errors are. Moreover, the denser the gas concentration is, the higher the measurement errors are. Some compensation measurement should be considered because errors are too high to meet the demand of the measurement precision [6-8, 10].

IV. COMPENSATION METHOD BASED ON FUZZY INFERENCE SYSTEM

For different temperatures, the sensors have different I/O characteristics. When the working temperature is T_i , if the characteristic of C_{Ti} is ensured, we can get the corresponding output value C. The I/O characteristics can only be ensured under several limited number of temperatures. However, we can work out the I/O characteristics under any temperature T_i within the range of the work temperature by the principle of approach or errors correction, and then the value C can be ensured. The principle of error correction method is constructing positive functions to make the outputs of the sensors only having a linear relationship with the measured signal, and having no relationship with the temperature signal. The choice of the constructor function directly affects the size of the error correction.

The principle of fuzzy inference method [8] is summing up the experiences and quantizing them into a number of rules, and reasoning by the rules, which can complete the operation simply and rapidly. Through choosing a suitable fuzzy model and establishing appropriate rules, the outputs of the sensors can be corrected to requested precision.

The room temperature 25℃ is selected as the reference temperature. The fuzzy rules were set up according to the experience and experimental data.

The correction model [10] is shown in Fig. 1, behind the sensors, there is a fuzzy inference controller, which takes the temperature detected by a temperature sensor as another input signal, and then gives the corrected value through fuzzy inference. The fuzzy controller is generally composed of fuzzy module, rule base, fuzzy inference engine and de-fuzzy module.

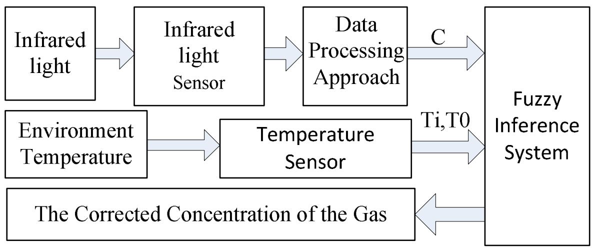

Figure 1. Temperature compensation model of infrared light sensor.

Fuzzy inference can be based on the Mamdani model or T-S model [8]. The fuzzy system has been designed as zero-order T-S model in this paper. The output memberships of the model are fuzzy single-point set.

The universe of discourse of temperature from -10 to 60 ℃ was divided into five fuzzy sets, which are NB, NS, ZO, PS and PB, while the universe of discourse of the other input concentration of gas from 0% to 20% was divided into four fuzzy sets S, M, B and VB. The Gauss membership functions are used and shown in Fig. 2.

Empirical values of the errors at different temperatures from -10 ℃ to 60℃ for different gas density from 1.5% to 19.5% are listed in table 1. The data shows that the errors become higher as the gas density increases, and the test errors at the room temperature 25℃, which are selected as ideal situation in this paper, are the lowest for certain density of the gas.

In the fuzzy inference system, the uncertainty of the input for density of the gas are quantized into 4 linguistic variables, namely, S, M, B and VB, as shown in Fig. 2 (a). The classes of the temperature (NB, NS, ZO, PS and PB) as five linguistic variables are presented by five membership functions shown in Fig. 2 (b).

Comparing with non-fuzzy method, fuzzy temperature compensation experiment results at the temperature 40℃ for different density of the gas are shown in table 2. The simulation results demonstrate that fuzzy compensation method can decrease the absolute error significantly and it can reach the basic purpose of temperature compensation.

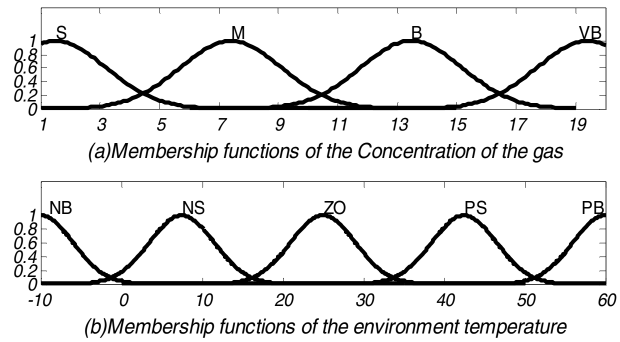

Figure 2. Membership functions of the input of fuzzy inference system.

TABLE I. EMPIRICAL VALUE OF THE ERRORS AT DIFFERENT TEMPERATURE FOR DIFFERENT DENSITY OF GAS CO_2

Temperature (□)	Density of CO_2 (%)					
	1.5	5.5	7.5	11.5	15.5	19.5
-10	0.09	0.30	0.38	0.57	0.78	0.99
0	0.07	0.24	0.32	0.42	0.59	0.72
10	0.04	0.17	0.19	0.31	0.44	0.56
25	0.00	0.00	0.00	0.00	0.00	0.00
50	0.11	0.32	0.40	0.66	0.85	0.99
60	0.12	0.40	0.48	0.67	0.89	1.07

TABLE II. THE MEASURED ERRORS AT SAME TEMPERATURE 40℃ FOR DIFFERENT DENSITY OF GAS CO_2

Absolute error	Density of CO_2 (%)					
	1.5	5.5	7.5	11.5	15.5	19.5
Non-fuzzy method	0.05	0.18	0.21	0.33	0.46	0.54
Fuzzy compensation method	0.01	0.03	0.08	0.13	0.16	0.21

V. CONCLUSIONS

This paper proposes a scheme that corrects an infrared automotive exhaust analyzer using fuzzy inference system. The simulation results demonstrate the efficiency of this method. The universe of discourse should be divided into more fuzzy sets for better result. According to the Lambert-Beer law and rule of the absorption of gases on high-light zone and low-light zone, the variety of atmosphere pressure can also affect the error of infrared automotive exhaust analyzers.

The further research works will be focusing on the effects of atmosphere pressure and employing this method in the real automotive exhaust gas analyzer.

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