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Automobile Exhaust Gas Detection Based on Fuzzy Temperature Compensation System

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Abstract. A temperature compensation scheme of detecting automobile exhaust gas based on fuzzy logic inference is presented in this paper. The principles of the infrared automobile exhaust gas analyzer and the influence of the environmental temperature on analyzer are discussed. A fuzzy inference system is designed to improve the measurement accuracy of the measurement equipment by reducing the measurement errors caused by environmental temperature. The case studies demonstrate the effectiveness of the proposed method. The fuzzy compensation scheme is promising as demonstrated by the simulation results in this paper.

Keywords: Automobile exhaust gas, Fuzzy inference, Temperature compensation.

1 Introduction

There are more and more automobiles in the world, and the annual output of the automobiles has exceeded 50 millions [1]. The automobile exhaust pollution is becoming more and more serious. The accurate measurement and proper treatment of exhaust gas of the automobile are very important. Exhaust gas of automobiles is a main source of pollution, and that pollution is difficult to be treated because analyzing and detecting exhaust gas of the automobile is a complex technology based on many subjects. Many countries invested a lot of man power and financial power to solve the automobile exhaust problems, but there is still no technique that can be accepted by all the users.

Recently, infrared gas analyzer are widely used to detect and measure the components of the gases, but the measurement accuracy are influenced by factors arising from testing conditions, such as environment temperature, which may lead to erroneous gas detection [2], [3].

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Computational intelligence, which is known to be different from the conventional computing, called the soft computing, mainly includes fuzzy logic [4], Genetic algorithms [5], neural networks [6], and the combined method of any formers, such as fuzzy neural networks [7], is being rapidly developed in recent years. Fuzzy logic is a branch of computational intelligence. It is a powerful tool for modeling human thinking and perception. This makes it easier to perform tasks that are already successfully performed by humans. Human experience can be quantized into rules of the fuzzy inference system.

Fuzzy set and fuzzy logic have became one of the emerging areas, which spread across various research fields, including control, pattern recognition, and other engineering problems. It has been applied in traffic control, network planning and fault diagnosis [8], [9], but only a limited number of publications on the application of fuzzy inference on detection of automobile exhaust gas have been reported [10], [11]. Our previous work employed fuzzy inference system into infrared exhaust gas analyzer in order to minimize the effect of the environment temperature and has demonstrated that fuzzy compensation scheme is better than the non- fuzzy method [11]. In this paper our previous works [11] are extended and the more reasonable membership functions and rules are selected to improve the accuracy of the measurements.

The designed fuzzy temperature compensation scheme is shown in Fig. 1.

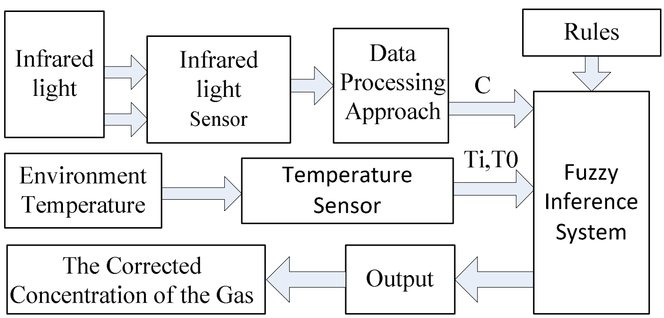

Fig. 1. Fuzzy temperature compensation scheme

There are two inputs and one output in the fuzzy temperature compensation scheme. One of the inputs is the density of the gas, which is obtained by infrared light sensor. The other input is the environment temperature, which is measured by using the temperature sensor. The rules are designed according to expert experience. According the output of the fuzzy inference system, the corrected concentration of the gas can be obtained.

2 Reviewing and Analyzing the Principle of Infrared Automobile Exhaust Gas Analyzer

The selective absorption of gas on infrared ray is used to analyze and process the data obtained from the sensor. The measured data is needed to be compensated because the error is too high when the variation of the temperature is high.

Inert gas does not absorb infrared energy, while the components of automobile exhaust gas are not only composed of inert gases, but also other different atom gases such as, as CO, CH and CO_2, etc. These gases can absorb the infrared energy in certain wavelength because they are not inert gases. 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 these gases, the energy of infrared ray will be reduced when the infrared ray go through the tested gases. The amount of reduced energy depends on gas concentration, the thickness of the gas chamber, and the absorption coefficient. The relationship is shown by Lambert-Beer's law [2], [3], [10], [11]:

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

where

E_0 : the initial infrared energy before going through the gases

E : is exit infrared energy after going through the gases

C: the gas concentration,

L : the thickness of the gas chamber

K: the absorption coefficient.

The absorption coefficient K is a very complicated parameter, which not only depends on the type of the gases, but is also related to the absorbed wavelength, and affected by the environmental temperature, pressure and other factors. Therefore, for the real working environment, in which both the temperature and pressure are varied, *K* directly affects the absorbed energy of infrared ray, ΔE. Huston pointed out that the absorption for the weak-lighted zone and the strong-lighted zone can be represented by the follow equation [10], [11]:

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

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

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. Σ is the wavelength range. P is the general environmental pressure. p is the measured gas pressure.

$$W = (pl/76)\times[273/(273+t)] \tag{4}$$

where t is the environmental temperature; l is the thickness of the measured gas.

Equation (2) and equation (3) are employed for weak-lighted zone and the strong-lighted zone respectively [10], [11].

The above equations show that the environmental temperature is an important factor that influences the measurement accuracy of the sensor. The environmental temperature not only has an effect on the infrared ray absorption, but also directly affects the infrared radiation intensity and infrared detector accuracy.

The aim of this research work is to establish environmental temperature compensation scheme to eliminate the effect of environmental temperature.

When gas chamber is filled with pure nitrogen, the concentration of the testing gas is zero. For the fixed system parameter, gas absorption coefficient and gas chamber length L are fixed. So system parameter K can be obtained [10], [11].

Most of the equipment is operated at room temperature. In this paper, the room temperature 25℃ is selected as the standard temperature. The absolute error of measurement is:

$$e_i = C_{Ti} - C_{25^o C} \tag{5}$$

where C_{Ti} is the gas density measured at the temperature Ti, and $C_{25^o C}$ is the gas density measured at the room temperature 25℃.

It has been demonstrated that higher the degree of the deviation from room temperature 25℃ for the environmental temperature, the higher the measurement errors are [10], [11]. Moreover, the denser the gas concentration is, the higher the measurement errors are. The compensation measurement must be considered because errors are too high to meet the demand of the measurement precision.

3 Temperature Compensation Scheme Based on Fuzzy Inference System

As mentioned in section II, for the different temperature, the sensors have different I/O characteristics. If the characteristic of C_{Ti} is ensured at working temperature T_i, we can get the corresponding output value C. The I/O characteristics can be ensured only under several limited number of temperatures. However, the I/O characteristics under any temperature T_i within the range of the work temperature can be estimated [11].

Fuzzy inference system [8]-[11] is summing up the experiences and quantizing them into a number of rules. After the membership function and rules are designed, the fuzzy inference system can complete the operation simply and rapidly. The outputs of the sensors can be corrected to requested precision by choosing a suitable fuzzy model and establishing appropriate rules.

The inputs and outputs of a fuzzy inference engine are linked by several inference rules, which are converted from expert knowledge in the following format [8]-[11]:

If Input is [(the environment temperature is very low) and (the concentration factor is very low)], then the output is [(The output of sensor is the function of this environment temperature and this concentration of gas))].

Absolute error [11] at different temperatures is used in this paper. The room temperature 25℃ is set to standard zero. The simulation data of the empirical errors at different temperature from -10 ℃ to 60℃ for different density of gas from 1.5% to 19.5% are shown in Table I [11]. The experiment data in Table I show that the error become higher with the gas density increasing.

The fuzzy temperature compensation scheme is shown in Fig. 1. Infrared light is measured by the infrared light sensors. Environment temperature is measured by the temperature sensor. Environment temperature and the density of the gases are inputs of the fuzzy inference system. The corrected concentration of the gases can be obtained by using the output of the fuzzy inference system.

According to the empirical data at different temperature, the two inputs of the fuzzy inference system, temperature and density of CO2 are represented by the fuzzy linguistic variables. The universe of discourse of Temperature from -10 ℃ to 60℃ are divided into six fuzzy sets NB, NS, ZO, PS, PB and PB2 as shown in Fig. 2.

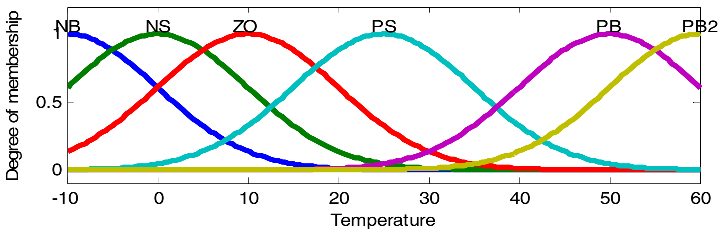

Fig. 2. Membership functions of the input: enviroment temperature

The universe of discourse of the concentration of gas from 0% to 20% are divided into four fuzzy sets S, M, B and VB as shown in Fig. 3. The gauss membership functions are used as shown in Fig. 2 and Fig.3. The universe of discourse of output is quantized into sixteen fuzzy sets and the membership function of the output is shown in Fig. 4.

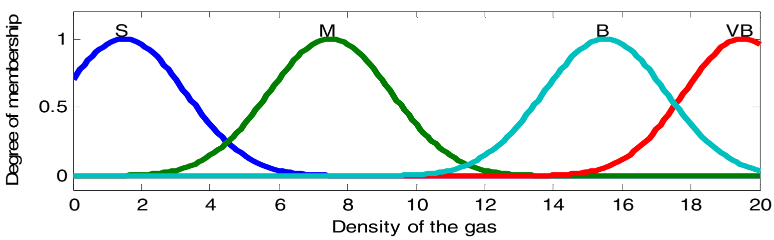

Fig. 3. Membership functions of the input: density of gas

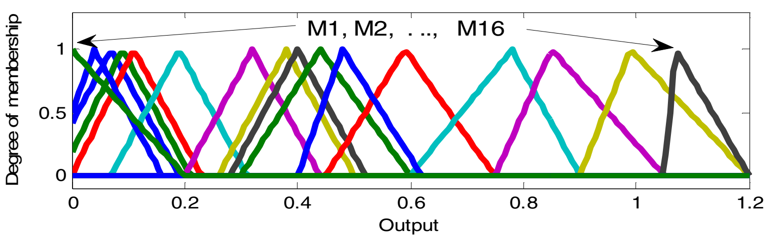

Fig. 4. Membership functions of the Output

The following sixteen rules are used in this fuzzy system:

If (input2 is PS) then (Output1 is M1)
If (input1 is S) and (input2 is NB) then (Output1 is M4)
If (input1 is S) and (input2 is NS) then (Output1 is M3)
If (input1 is S) and (input2 is ZO) then (Output1 is M2)
If (input1 is S) and (input2 is PB) then (Output1 is M5)
If (input1 is M) and (input2 is ZO) then (Output1 is M6)
If (input1 is M) and (input2 is NS) then (Output1 is M7)
If (input1 is M) and (input2 is NB) then (Output1 is M8)
If (input1 is M) and (input2 is PB) then (Output1 is M9)
If (input1 is B) and (input2 is ZO) then (Output1 is M10)
If (input1 is M) and (input2 is PB2) then (Output1 is M11)
If (input1 is B) and (input2 is NS) then (Output1 is M12)
If (input1 is B) and (input2 is NB) then (Output1 is M13)
If (input1 is B) and (input2 is PB) then (Output1 is M14)
If (input1 is VB) and (input2 is PB) then (Output1 is M15)
If (input1 is VB) and (input2 is PB2) then (Output1 is M16)

Fig. 5 shows the whole surface of the fuzzy inference system used in this temperature compensation method. The input 1 represents the temperature and the input 2 represents the gas density of CO2. Simulation experiment results demonstrate that using the limited empirical data in Table I, the errors at any temperature and for any density of the gas can be obtained by the fuzzy compensation system. In the temperature compensation scheme as shown in Fig.1, the function of fuzzy inference system is to estimate the errors causing by the temperatures.

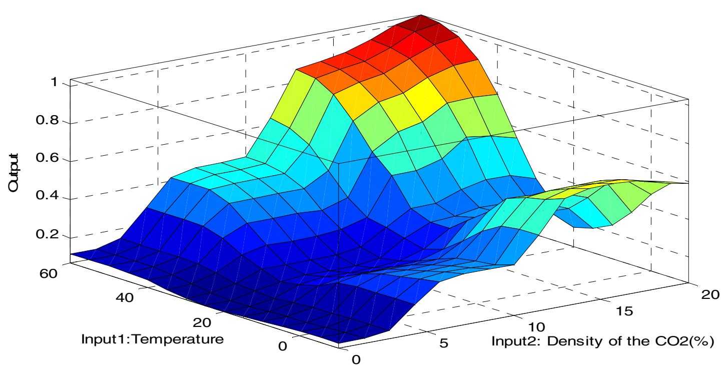

Fig. 5. Output surface of the Fuzzy Temperature Compensation System

According to the above results, the fuzzy temperature compensation scheme shown in Fig. 1 will be a feasible candidate for improving the measurement accuracy. Due to it simplicity, the scheme will be ideal selection for online application.

4 Conclusions

This paper discusses a fuzzy temperature compensation scheme, which can reduce the errors of the infrared automobile exhaust analyzer caused by environment temperature. All other automobile exhaust gas can be detected by this proposed method. Using the density of the CO2 as studying cases, the simulation results demonstrate the efficiency of this method. Using the limited empirical data, fuzzy system can improve the accuracy of the measurement. The universe of discourse should be divided into more fuzzy sets and more empirical data can be used to set up the fuzzy inference system for better result.

According to the Lambert-Beer law, it is obvious that the atmosphere pressure also can affect the measurement accuracy of infrared automobile exhaust analyzers. To consider the atmosphere pressure and to apply fuzzy temperature compensation system to the current automobile exhaust gas analyzer, further research works are needed.

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