Inspection of Car’s Emission Using Infrared Spectrum Technique

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Abstract. A online method to analyze the composing of car’s emission is proposed. In this method, Infrared Spectroscopy theory is used in measure instrument. The emission of car include H2O, CO, CO2, NOx, SOx. None of all the absorption bands can typically sign one of these element. So least square algorithm is used for retrieval of the composing of gas in this paper. The simulations experiment result show that least square algorithm can retrieval the composing of gas in high precision(5%) and Experiment result has shown the feasible.

1. Introduce
The measurement of concentrations of gaseous species is very important in many different areas of modern life, such as environmental monitoring, industrial process control and security issues. Dispersive infrared measuring systems are especially used for the analysis of gaseous pollutants like CO,CO2,NOx, Sox [1]. It is a non-intrusive methods and easy to handle analyzers that do not require sample collection or preparation and provide concentration data with a high temporal resolution are in demand, due to the characteristic spectral gas absorption they are superior to most other sensor principles.

In this paper, the Infrared Spectroscopy theory is used for detect the composing and concentration of car emission. The emission of car include H2O, CO, CO2, NOx, SOx. None of all the absorption bands can typically sign one of these element. So least square algorithm is used for retrieval of the composing of gas.

2. Absorption spectroscopy
Absorption spectroscopy is one of the most commonly used interactions between light and matter. The laser light is directed through the gas under investigation, usually present in an absorption cell, and imaged onto a detector. The intensity of the light reaching the detector depends on the concentration of the absorbing molecules. The attenuation is ruled by the Lambert-beer law [2] and depends exponentially on the product of attenuation coefficient and path length.

\[ \text{Lambert – Beer } \quad T_r = \frac{I}{I_0} = e^{-\alpha cL} \quad (1) \]

The relationship also can be expressed as:

\[ A = \alpha \ cL \quad (2) \]
Where $A = \log(I_0/I)$ is absorbance; $\alpha$ is molar extinction coefficient; $c$ is molar concentration; $L$ is pathlength in cm. By spectrally tuning the laser, profiles of absorption lines can be determined. From their intensity and width, the concentration of the absorbing molecules can be calculated.

Figure 1 shows absorption bands between 1 and 7 um as calculated from the Hitran 2004 database [3] for different important species. From this, we can see that water absorption is present nearly everywhere in the infrared spectral region and nearly all molecular species possess fundamental transitions in that spectral region while in the near-infrared mainly combination and overtone bands occur.

### 3. Least square algorithm

The emission of car include H2O, CO, CO2, NOx, SOx. None of all the bands can typically sign one of these element. So least square algorithm [4] [5] is used for retrieval of the composing of gas in this paper. It is linear relationship between absorption of light and composing of gas volume in vary of wavelength. Light absorption by mixed gas can be described as:

$$A_\lambda = \sum_{j=1}^{p} \alpha_{\lambda j} c_j L$$  

Where $A_\lambda$ is the absorbance when wavelength is $\lambda$; $\alpha_{\lambda j}$ is the molar extinction coefficient when wavelength is $\lambda$ and component of gas is $j$; $c_j$ is molar concentration of $j$ gas. If $k_{\lambda j} = \alpha_{\lambda j} L$ and random error $e_\lambda$ is introduced. The formula (3) is expressed as:

$$A_\lambda = \sum_{j=1}^{p} k_{\lambda j} c_j + e_\lambda$$  

random error $e_\lambda$ is a normal distribution function, the expectation of random error is zero and variance is proportioned with $T^{-2}$, where $T$ is transmissivity ($A = \log(1/T)$). the molar extinction coefficient of mixed gas’s composing is known and $A_\lambda$ is achieved by the sensor. If the baseline is zero. the absorption spectrum formula is:

$$a = KC + E$$  

Where $a$ is a 1Xn vector which is the absorbance in n-$\lambda$; $c$ is a 1Xp vector which include p type of gas’s volume percent; $K$ is a pXn matrix which is the p type of gas’s molar extinction coefficient factor in n-$\lambda$; $E$ is a 1Xn vectors which is random error. Matrix operations is used to estimate the Least square solution of $C$.

$$C = aK'(KK')^{-1}$$  

### 4. Instrument

Figure 2 shows the scheme of instrument. Infrared laser resource and detect (spectrum analysis Instrument) is fixed on the measured piping. The infrared wave from 2um to 5um is emission by infrared laser resource. The infrared laser light through over an absorption piping, the detect (spectrum
analysis Instrument) receive the infrared light and send the spectrum analysis result to computer. The analysis of gas composing is achieved by computer. Furthermore, a solution of systemic error due to pollution of light system window was introduced using a blowing apparatus.

The software of this system include date collection block; laser output control block; gas analyzed block; display block. Laser output control block control the laser circuit to tune the frequency of laser. It provide a variable laser source. Date collection block receive the signal from detect (spectrum analysis Instrument). Gas analyzed block calculate composing of gas by Least square algorithm. display block show the absorption spectrum and analysis.

5. Experiment
The computer simulations use Lambert – Beer theory to calculate the absorption spectrum, where molar extinction coefficient is shown as figure 1; molar concentration is given by table 1 and pathlength L=1m.

| CO   | CO₂  | NO  | NO₂  | H₂O  |
|------|------|------|------|------|
| Input (%) | 1.0 | 2.3  | 0.3  | 0.4  | 3.1 |
| Result (%) | 1.011 | 2.314 | 0.298 | 0.402 | 3.097 |
| Input (%) | 0.9 | 2.1  | 0.2  | 0.8  | 9 |
| Result (%) | 0.902 | 2.11 | 0.191 | 0.808 | 9.031 |

The simulations experiment result is shown in table 1. Comparing the data between input and result we can see that both of experiment have high precision. The max error is below 5%. It shows that least square algorithm can retrieval the composing of gas in high precision. Comparing the two group of experiment, the difference of first experiment data is smaller and the first experiment is more precise. The similar experiment have been done, it approves that the difference of composing will affect the precision of reversion.

Comparing with other algorithm, the computing time of least square is smaller. It provide basic requirement for on-line measurement. but the precision of least square method is lower. Work is continuing with this algorithm.
The car emission is be collect in to a cube vessel. The absorption spectrum is achieved by Infrared spectrum monitoring. Several experiment is be done. Figure 3 shows the absorption spectrum of car emission. The results of reversion show the system’s repeatability. System detect car emission signal on-line by optical fiber.

![吸收光谱图](Figure 3. absorption spectrum of car emission.)

### 6. Conclusion

Infrared spectrum monitoring can meet the requirement of car emission analysis and have broad applicability and high potential because of the possibility of online, in-situ and non-intrusive analysis even in geometries where classical absorption spectroscopy cannot be used. Furthermore, the design of the sensors is not restricted to macroscopic multiple-reflection elements and fiber sensors; structures can be implemented in waveguides, such that miniaturization and multiplexing is easy to achieve. This would reduce the costs because one single laser source can be used for multiple sensor elements which give also information on the spatial distribution of the gases.

### References

1. Li Ye-de, Li Ye-yang and Jia Peng 2002 Micro-computer Infrared Automotive Exhaust Analyzer [J] *Journal of Shandong Institute of Technology* 16 11-13
2. Peter Werle, Franz Slemr and Karl Maurer 2002 Near- and mid-infrared laser-optical sensors for gas analysis [J] *Optics and Lasers in Engineering* 37 101-104
3. Ulrike Willer, Mohammad Saraji and Alireza Khorsandi 2006 Near- and mid infrared laser monitoring of industrial processes environment and security applications [J] *Optics and Lasers in Engineering* 44 699-710
4. Liu Sheng-mei, Xu Chang-jiang and Feng Guang-zeng 2001 The Least Square Constant Modulus Algorithm for Blind Adaptive Multiuser Detection [J] *The Journal of China Universities of Posts and Telecommunications* 8 63-67
5. Fan Youping, Chen Yunping and Sun Wansheng 2005 Multi-classification algorith and its realization based on least suare support vector machine algorithm [J] *Journal of Systems Engineering and Electronics* 16 901-907
6. Gan Zi-qiong, Liu Jun-jun and Tang Sheng-li 2005 Quantitative models for prediction of toxic component concentrations in smoke gases from FTIR spectra [J] *Fire Science and Technology* 24 421-425
7. Ralf Siebert and Jorg Muller 2005 Infrared integrated optical evanescent field sensor for gas analysis [J] *Sensors and Actuators* 119 138-149