A Moving Mirror Driving System of FT-IR Spectrometer for Atmospheric Analysis

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Abstract. A moving mirror driving system of FT-IR spectrometer for atmospheric analysis was developed. It uses a tilt-compensated interferometer, a He-Ne laser reference interference system, and a driving system based on microcontroller with the control mechanism of adaptive adjustment Fuzzy-PI. The structure is simple and easy alignment. The controller is robust and high precision. It can be used in many applications of atmospheric analysis, such as open path or solar occultation flux FT-IR methods.

Keywords: FT-IR; moving mirror; driving; control, atmospheric; analysis, Fuzzy-PI.

1 Introduction

Optics remote sensing technology has developed very fast those years, of which FT-IR spectrometry is the dominant technique with substantial advantages in SNR, resolution, speed and detection limits over other ones. Methods include measurements over open paths in situ, sampling and measurement in closed cells, remote sensing using the sun, sky or natural hot objects as an IR radiation source [1]. Usually, the field conditions are more complicated and instability over laboratory, especially in the situations of vehicle, ball-borne, airborne, space born applications [2], [3]. They need the spectrometer be more stable, reliable and anti-interference which traditional ones can't stratify.

Mirror driving is the most important part in a FT-IR spectrometer. To get the correct spectrum, the moving mirror must be driven with high precision. But it is easily affected by the factors such as vibration and temperature. For FT-IR spectrometer used in the atmospheric, the moving mirror driving system should be carefully designed in order to fulfill the requirements of measurements.

With the need of FT-IR spectrum for the application of atmospheric analysis, we developed a moving mirror driving system. The system contains a tilt-compensated interferometer, a He-Ne laser reference interference system, and a driving system based on microcontroller with the control mechanism of adaptive adjustment Fuzzy-PI. Its structure is simple and easy alignment and the controller is robust and high precision. It has been used in some applications based on the open-path and solar occultation methods.

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2 Principles of FT-IR Spectrometry

The structure of a typical FT-IR spectrometer is show in figure 1. It is consist of Michelson interferometer, infrared source, He-Ne laser interference system, detector, data acquirement and process systems.

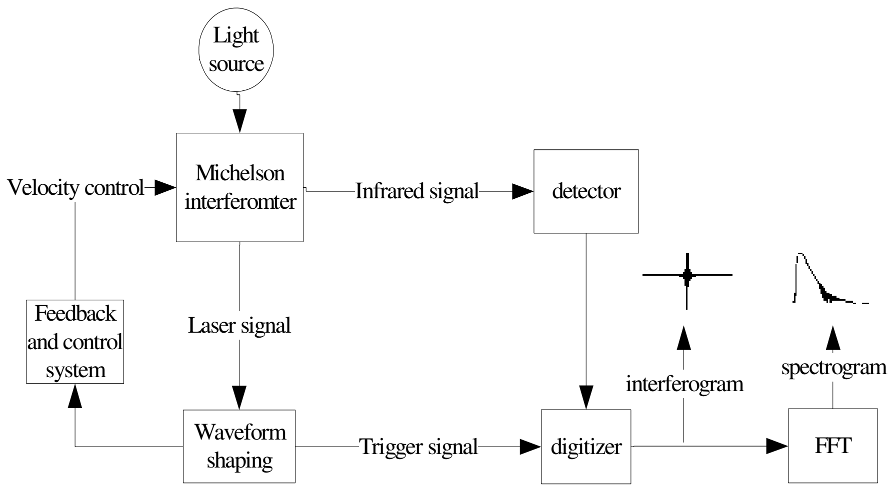

Fig. 1. Fourier transform infrared spectrometer system

The principle is based on the interference characteristic of light and this process is completed by Michelson interferometer [4]. Let suppose a beam with wavenumber $\tilde{\nu}_0$, and the intensity is $I(\tilde{\nu}_0)$, the intensity at the detector is expressed below.

$$I'(\delta) = 0.5I(\tilde{\nu}_0)(1 + \cos 2\pi\tilde{\nu}_0\delta) \tag{1}$$

δ is the optical path difference (OPD). After detection and amplification, a wavenumber-dependent correction factor is added to Eq. (1).

$$I(\delta) = 0.5H(\tilde{\nu}_0)I(\nu)\cos 2\pi\tilde{\nu}_0\delta = B(\tilde{\nu}_0)\cos 2\pi\tilde{\nu}_0\delta \tag{2}$$

When the source is a continuum, the interferogram can be represented by the integral.

$$I(\delta) = \int_{-\infty}^{+\infty} B(\tilde{\nu})\cos 2\pi\tilde{\nu}\delta d\tilde{\nu} \tag{3}$$

And the spectrum can be gotten by the cosine fourier transform.

$$B(\tilde{\nu}) = \int_{-\infty}^{+\infty} I(\delta)\cos 2\pi\tilde{\nu}\delta d\delta \tag{4}$$

Eq. (3) and (4) are the basic integrals of FT-IR spectrometry. From which we can see that to get the correct spectrum, the interferogram must be measured at the distance of equally OPD which is controlled by the moving mirror. In the whole scan process, the moving mirror must be well aligned.

3 Interferometer Structure

There are many kinds of interferometer structure. The simplest type consists of a fixed and a moving plane mirror with a beamsplitter held at an angle bisecting the planes of these two mirrors [5]. The plane of the moving mirror must not tilt by an amount that will cause the OPD for the ray that is reflected from one edge of the moving mirror to differ from the OPD for the ray reflected from the diametrically opposite edge by more than about $\lambda_{min}/10$. This level of precision is very hard to achieve.

To eliminate the effect of tilt, cube-corner retroreflector can be used to replace the flat mirror. It is the three-dimensional equivalent of the roof and compensated for tilt in any direction. But the use of it has the disadvantage of requiring quite delicate initial alignment and introducing some polarization effects.

The FT-IR spectrometer for atmospheric analysis need a simple and easy alignment design. To meet this requirement, we use a tilt-compensated interferometers design with four mirrors as shown in figure 2.

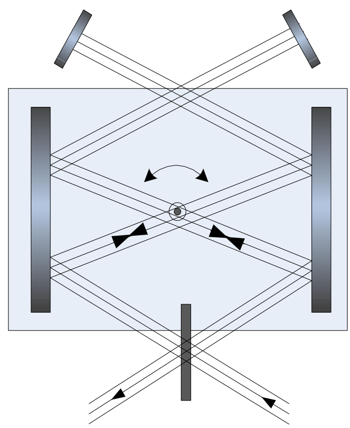

Fig. 2. Tilt-compensated interferometer with four mirrors

In the interferometer, two mirrors are mounted on a common base plate which is rotated to give rise to the path difference in two arms of the interferometer. Any misalignment of the tilt table will cause each beam to be affected in the same way, so the effect of the tilt of the mirrors on the tilt table is compensated. With these characteristics, it is very stable and anti-interference.

4 Driving and Control System

The moving mirror driving and control system diagram is shown in figure 3. It consists of He-Ne laser detection and process circuit, digital signal process circuit, microcontroller system and motor driving circuit.

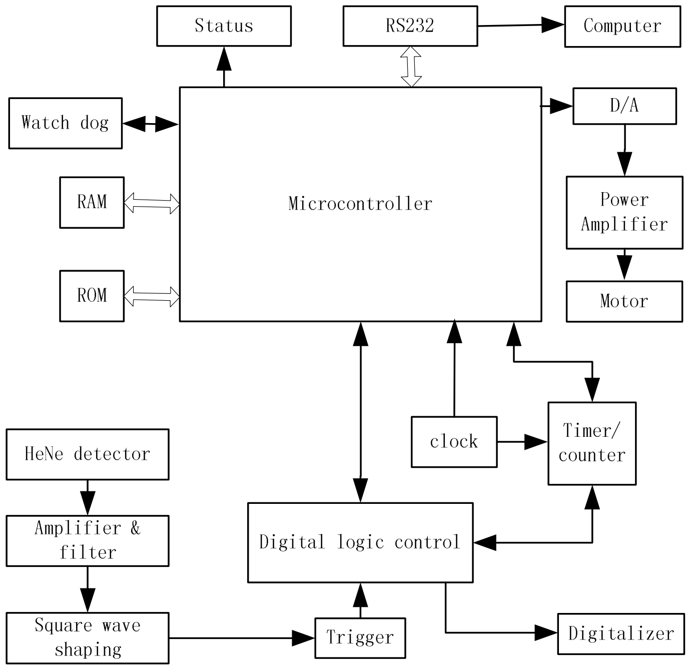

Fig. 3. Moving mirror driving and control system diagram

In the system, He-Ne laser which wavenumber is 632.8nm is used to achieve detection of scan velocity and as trigger of equal OPD sampling. The laser interferogram after the Michelson interferometer is detected by a photodiode detector. The signal is then be amplified and filtered to produce a sinusoidal wave. It is then reshaped to become square wave after passing a shaping circuit and inputs to the microcontroller system.

In the digital signal process circuit, the He-Ne square signal is used to produce zero cross pulse signal which has twice the frequency over the original signal. This signal has three usages. First, the digital logical control unit put it into the digitizer's trigger source. Second, the pulse signal inputs to a timer/counter (C/T) which uses the system clock as reference source. The C/T counts the clock number during one signal cycle time. The microcontroller reads this number and used gets current velocity after calculated. Third, the microcontroller counts the pulse signal and used it to calculate the scan distance.

The control algorithm runs on the microcontroller that uses the calculated velocity as reference input. It produces a control value. After a D/A converter, this value becomes analogous signal which then is amplified and used to drive the motor. This will complete a close loop moving control.

The microcontroller has a 64KB ROM and RAM with system extension. Its status is monitored by an auxiliary circuit whose has the function of watchdog. It also accepts the control parameters from the computer through a RS232 interface. So the computer can control the maximum OPD and scan velocity of moving mirror.

5 Control Method

Mirror driving with high precision is significant for the system, and the control method must be carefully designed. In the control theory, classical PID controller as a linear controller can form the control value by the difference between the reference value and output value with composing the proportion (P), integration (I), and differentiation (D) in a linear way. But in the moving mirror driving system, there exist some non-linear characteristics because of the precision of components and some uncertain factors such as change of load and outside interference [6]. Thus, the simple PID will not suitable for this application.

Fuzzy control as an intelligent control method is suitable for the control model that has non-linear and uncertain characteristics. By combining the fuzzy and PID control method, we get the Fuzzy-PI controller which can improve dynamic response and control precision. But because the control parameters are fixed, they don't have the ability of adaptive adjustment. To do this, an adaptive adjustment Fuzzy-PI controller is realized base on the Fuzzy-PI controller. The control diagram is shown in figure 4.

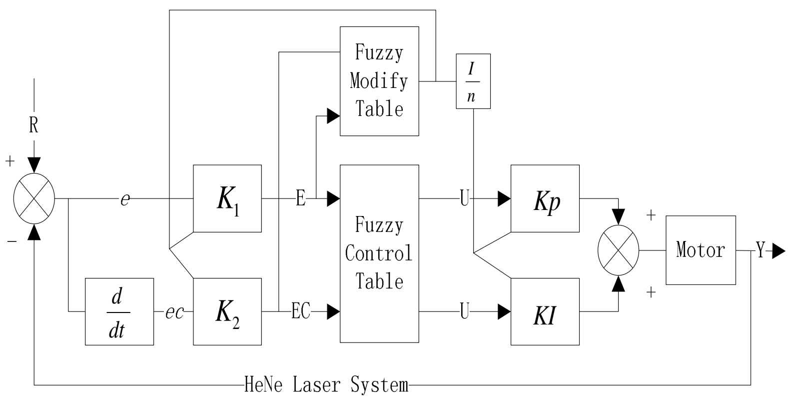

Fig. 4. Adaptive adjustment Fuzzy-PI control diagram

In the controller, Kp , KI , K_1, K_2 can be modified based on the change of E and EC, so they has the adaptive ability and can change with the different e and ec. Let the language variable N of n has the fuzzy subset N= {AB, AM, AS, OK, CS, CM, CB}. The universe of N is N= (1/8， 1/4， 1/2， 1， 2， 4， 8). Design the assigned table of degree of membership of N. The assigned table of degree of membership and fuzzy subsets of E and EC are the same as the fuzzy controller. The method of parameter adjustment is expressed by the modify rule. The fuzzy modify table of parameters adaptive adjustment can be calculated by the compound algorithm as simple fuzzy controller and manual amendment.

6 Experiment and Application

The response curve of control system is shown in figure 5. It shows that the adaptive adjustment Fuzzy-PI controller has a faster response speed, and stable response curve

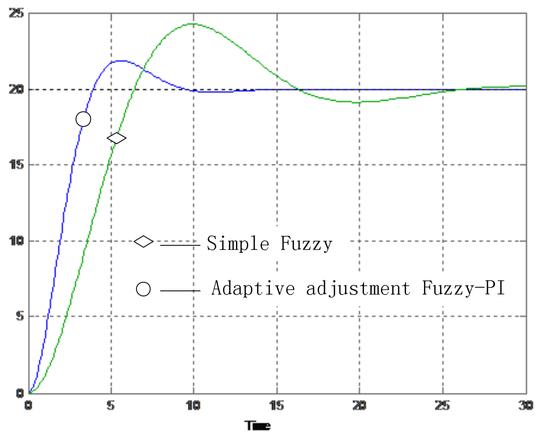

Fig. 5. Response of two kinds of control methods

compare to simple fuzzy controller. The performance of control precision and anti-interference is also butter.

A FT-IR spectrometer system is developed based on the mirror control system whose spectrum resolution is 1cm-1. The frequency of He-Ne laser interferogram is 6 KHz. By the method of double side scan, 16384 data point of infrared interferogram is sampled and shown in figure 6.

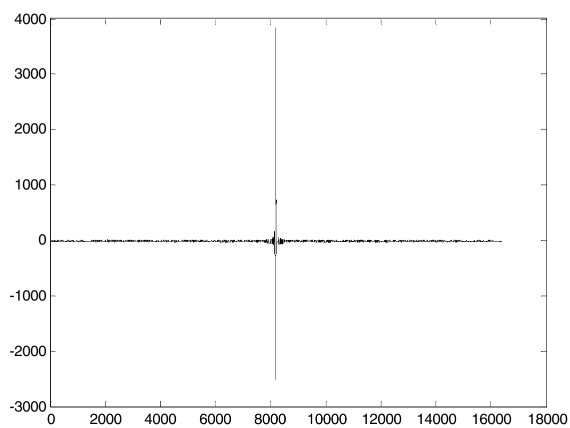

Fig. 6. Interferogram of developed FT-IR spectrometer

Atmospheric monitoring systems include open-path and solar occultation flux methods were also developed with the FT-IR spectrometer above. These systems were used in the World Exposition in ShangHai and Asian Games in Guangzhou in 2010. The results show that the systems are reliable and stable and are suitable for these kinds of applications.

7 Conclusion

With the need of FT-IR spectrum for the application of atmospheric analysis, a moving mirror driving system was developed. It contains a tilt-compensated interferometer, a He-Ne laser reference interference system, and a driving system based on microcontroller. The paper describes the designs of interferometer structure, driving and control system and control method. In the end, some experiments and applications are given. The results show that this system is simple and easy alignment. The controller is robust and high precision. It is suitable for the applications in the field environment.

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