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Improve extinction coefficient accuracy with optical compensation

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ABSTRACT

Extinction coefficient is the base parameter of visibility measurement, its measurement error determines the accuracy of the visibility meter. In the paper, the error sources are analyzed, and a new optical structure is proposed by adding the optical compensator. For the new structure, the measurement model based on boundary constraints is provided to reduce measure errors. Based on the new model, use an improved algorithm to solve the error convergence problem. The new algorithm use exponent arctangent function as base function, three parameters i, j and k control the contour of the function. With simulation tool, the optimization values are obtained. The experimental results show that the extinction coefficient relative error is reduced by 18% in the entire measurement region, the fluctuations of the relative error is reduced to 7.3%.

1. Introduction

With the air pollution is serious increasingly, the environmental problem is brought into sharp focus more and more. The measurement of atmospheric visibility, an important parameter to measure air quality, is put forward higher requirements. Koschmieder [1] law build the relation between atmospheric visibility V and extinction coefficient β. Extinction coefficient becomes the important parameter of measuring visibility. Extinction coefficient measured by visibility meter is the sum of atmospheric aerosol particles scattering coefficient and absorption coefficient [2–7]. There are two main measurement methods [8–10], transmissive method and scattering method. Finland Vaisala's FD12P and PWD20 visibility meters use scattering measurement method, which basic foundation is Lamber-Beer [8] law. US Novalynx 8330 transmissometer uses transmissive method, which basic foundation is Mie scattering theory in 1908 proposed by Mie [11]. Extinction coefficient defined by the World Meteorological Organization shows that the coefficient is a parallel beam's loss light quantity ratio [12], the beam propagates the unit distance in the atmosphere and color temperature is 2700 K incandescent light emitted. So the transmission method is near to the define and its accuracy is higher. In the measurement of transmission method, the relation between extinction coefficient and transmittance is logarithmic. This makes the higher absolute error in higher transmittance region, and the higher relatively error in lower transmittance region. Due to the uncertainty of time and space changes in the atmosphere, extinction coefficient measured are also random and fluctuant [13,14]. References [15,16] improved measurement light path, and the result was improved. However, when the transmittance is less than 5% and higher than 80%, extinction coefficient error is larger and the visibility meter accuracy is affected under the conditions of large dynamic range, for the nonlinear of low light and the circuit saturation of high light.

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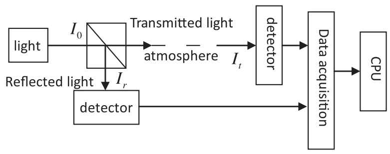

Fig. 1. Extinction coefficient measurement schematic.

To solve this problem, we proposed an improved method. The neutral density filters with different transmission were used as compensator. The light transmittance in the all measurement channel would be adjusted in ideal area of response system. By establishing transmission automatic tracking equations, the small signal and the signal near saturation zone had achieved adaptive gain compensation. Thus, measurement error reduced. In compensation algorithm, we presented the exponent arctangent type variable step size LMS algorithm. The algorithm avoided the defects of the existing algorithm [17–20], achieved rapid convergence in parameter measurement process, reduced the steady-state error, and made the accuracy of visibility increase.

2. Measurement principle and improved model

2.1. Measurement principle and error

Extinction coefficient measurement principle with transmissive method is shown in Fig. 1. High-power light source emits pulse light. Pulse width is τ, period is T.

$$I_0(t) = I_0\,[u(t\text{-}nT) - u(t - nT - \tau)] \tag{1}$$

$$u(t) = \begin{cases} 0 & (t < 0) \\ 1 & (t > 0) \end{cases}, n = 0, 1, 2, 3.......$$

The light source is divided into two beams by the beam splitter. Beam splitter's transmission coefficient is k_t and reflection coefficient is k_r. The transmitted beam reaches the detector through the atmosphere, which distance is L. The reflected beam gets into the detector directly.

$$I_t = k_t I_0\,[u(t - nT) - u(t - nT - \tau)] \times e^{-\beta L} \tag{2}$$

$$I_r = k_r I_0\,[u(t - nT) - u(t - nT - \tau)] \tag{3}$$

Data acquisition unit acquires two optical signals synchronously. In the transmitted channel, I_t is changed into u_t,

$$u_t(t) = k_t k R I_0 [u(t - nT) - u(t - nT - \tau)] \times e^{-\beta L} \tag{4}$$

where k is the receiving factor of the detector, R is feedback resistor.

The pulse signal is not easy to calculate directly. In SCM, with Fourier transformation, $u_t(t)$ is changed,

$$u_t(t) = \frac{k_t k R I_0 \tau}{T} e^{-\beta L} + \frac{k_t k R I_0 \tau\omega}{\pi} \sum_{n=1}^{\infty} Sa(\frac{n\omega\tau}{2}) \cos(n\omega t) \times e^{-\beta L} \tag{5}$$

After filtering, the center frequency is ω, the gain is A,the output signal is

$$u_t(t) = \frac{k_t k R I_0 A \tau\omega}{\pi} Sa(\frac{\omega\tau}{2}) \cos(\omega t) \times e^{-\beta L} \tag{6}$$

By RMS, the signal is converted into a DC voltage signal. It is

$$U_t = \sqrt{\frac{1}{T}\int_0^T u_t(t)dt} = \frac{1}{\sqrt{2}} \frac{k_t k R I_0 A \tau\omega}{\pi} Sa(\frac{\omega\tau}{2}) \times e^{-\beta L} \tag{7}$$

In the reflected channel, the DC voltage signal is

$$U_r = \sqrt{\frac{1}{T}\int_0^T u_r(t)dt} = \frac{1}{\sqrt{2}} \frac{k_r k R I_0 A \tau\omega}{\pi} Sa(\frac{\omega\tau}{2}) \tag{8}$$

According to Eq. (7) and (8), it can be obtained that

$$\beta = \frac{1}{L} \ln \frac{U_r k_t}{U_t k_r} \tag{9}$$