Research on Constant Temperature Two-Color Light Sources for Nighttime Visibility Estimation

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Abstract Visibility is the maximum horizontal distance that can be seen. Its observations and forecasts have been widely used in various fields of weather forecasting, environmental pollution analysis, and transportation. The existing visibility estimation methods are mainly divided into scattering type and transmission type. Among them, digital camera method for measuring visibility is the closest to the definition. With the development of digital camera technology, the research and application of digital camera measurement methods have been accelerated. However, in the process of nighttime visibility measurement by using a digital camera, the measurement is inevitably affected by the background light, the gray level of the light source, etc., resulting in unstable visibility measurement, low precision of observation results and small observation range. It is known that the accuracy of visibility measurement can be guaranteed by using the stability of dual light sources. Most studies have used a white light source to solve the measurement visibility instability problem. From the perspective of quasi-monochromatic light sources, the penetration ability of light sources in different frequency bands is different. In the visible range, the characteristics of the penetrating ability are analyzed. Based on the existing dual light sources, a method for nighttime visibility estimation based on constant temperature two-color light sources has been proposed, which realized high-precision and wide-range visibility estimation under different weather conditions. By designing the constant temperature duallight sources, the influence of ambient temperature change on the light intensity is reduced. Constant voltage and the constant current module are used to ensure the consistency of the dual sources light intensity. The integrating sphere is used to ensure the uniformity of the light intensity. According to different penetrating powers of different frequency bands, the two-color light sources are used to achieve high-precision and wide-range visibility. A visibility observation system based on constant temperature two-color light sources has been established. A series of experiments have been carried out. The experimental results show that the consistency of the two light sources reaches 0.99. When the visibility is not good, the light intensity of the blue light reaching the camera is weak, and the measurement result of the red light is close to the true value. When it is sunny, nighttime visibility is good. At this time, the difference in blue transmittance is large, which is beneficial to improve the signal-to-noise ratio. The standard deviation of the blue light source is 36.90, and the measurement result of blue light is close to the true value. When the visibility range is up to 15 000 m, one month of experimental observation is performed. By comparing with real values, the proposed method has great accuracy within the visibility range.

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Introduction

Visibility is the maximum horizontal distance that can be seen[1-2]. Its observations and forecasts[3] have been widely used in various fields of weather forecasting, environmental pollution analysis, and transportation[4]. The existing visibility estimation methods are mainly divided into scattering type and transmission type. Among them, digital camera method for measuring visibility[5-7] is the closest to the definition. With the development of digital camera technology, the research and application of digital camera measurement methods have been accelerated[8-10]. By utilizing densely- deployed video camera facilities distributing along highway roadside, Changli Zhang et al.[11] achieve road visibility monitoring. You Yang et al.[12] have proposed a deep learning approach for directly estimating relative atmospheric visibility from outdoor photos.

However, in the process of nighttime visibility measurement by using a digital camera, the measurement is inevitably affected by the background light, the gray level of the light source, etc., resulting in unstable visibility measurement, low precision of observation results and small observation range[13]. Dai Pangda et al.[14-15] have proposed a night visibility estimation method based on dual light sources. The true relative attenuation of the dual sources with different observation distances are obtained by subtracting each source gray value in the image of the source and the corresponding black body. Then visibility values are inverted. Xiao shourong et al.[16] have proposed using ashielding cylinder to limit the CCD angle. For obtaining the grayscales of the double LED backlights at different distances taken by CCD, the captured image was processed to obtain atmospheric visibility, eliminating background noise. Wang jingli et al.[17] have proposed using the LED array to form a surface source with four illumination reflectors installed around the lighting-source box and one diffuser to improve the illumination uniformity and reduce the fluctuations. According to the relative attenuation of the light source, the above research works rely on the use of the white light source to solve the measurement visibility instability problem, while there is not much research on the quasi-monochromatic light source. Based on the literature [14] and [15], a method for nighttime visibility estimation based on constant temperature two-color light sources has been proposed. By designing the constant temperature dual light sources, the influence of ambient temperature change on the light intensity is reduced. Constant voltage and the constant current module are used to ensure the consistency of the dual sources light intensity. The integrating sphere is used to ensure the uniformity of the light intensity. The two-color light sources are used to achieve high-precision and wide-range visibility. A series of experiments are carried out in the visibility observation system based on constant temperature two-color light sources to verify its effectiveness and applicability.

1 Measurement principle

The nighttime visibility camera principle is based on the transmissive principle. According to Beer-Lambert's law

$$I = I_0 \exp(-\sigma L) \tag{1}$$

where I_0 denote the initial light intensity of the parallel beam, I denotes the transmitted light intensities, and σ is the atmospheric extinction coefficient. By designing the constant temperature dual light sources, the influence of ambient temperature change on the light intensity is reduced. Constant voltage and the constant current module are used to ensure the consistency of the dual sources light intensity. The integrating sphere is used to ensure the uniformity of the light intensity. According to different penetrating powers of different frequency bands, the two-color light sources are used to achieve high-precision and wide-range visibility.

According to Koshmieder's definition, the color temperature is 2 700 K. When the light intensity decays to the human visual threshold $k=0.05$, the atmospheric visibility V and the atmospheric extinction coefficient σ can be expressed as

$$V = \frac{-\ln k}{\sigma} \approx \frac{3}{\sigma} \tag{2}$$

And so

$$V = \frac{-L\ln k}{\ln \dfrac{I_0}{I}} \tag{3}$$

where the initial light intensity I_0 of the light source is unknown, a dual light source visibility measurement method is proposed.

According to the literature [14] and [15], the diagram of the dual light source visibility measurement method is shown in Fig. 1. The light source 1 and 2 are respectively separated from the cameras L_1 and L_2 ($L_1 > L_2$). Then Eqs. (1) changes to

$$\begin{cases} I_1 = I_{01}\exp(-\sigma L_1) \\ I_2 = I_{02}\exp(-\sigma L_2) \end{cases} \tag{4}$$

where I_{01} and I_{02} are the initial light intensity of the parallel beam source 1 and source 2, respectively, I_1 and I_2 are their transmitted light intensities, and σ is the atmospheric extinction coefficient.

Therefore

$$V=\frac{-(L_1-L_2)\ln k}{\ln\left(\frac{I_{01}}{I_{02}}\frac{I_2}{I_1}\right)} \quad (5)$$

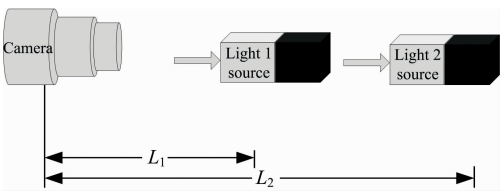

Fig. 1 The diagram of the dual light sources visibility measurement method

The black block is bold

2 A method for nighttime visibility estimation based on constant temperature two-color light sources

Based on the literature [14] and [15], a method for nighttime visibility estimation based on constant temperature two-color light sources has been proposed. The light source 1 and 2 are respectively separated from the cameras L_1 and L_2, and they are two-color light sources. By designing the constant temperature dual light sources, the influence of ambient temperature change on the light intensity is reduced. The constant feedback voltage and the constant current module are used to ensure the consistency of the dual sources light intensity. The integrating sphere is used to ensure the uniformity of the light intensity.

White LED is often used as the source of visibility measurement, but the white LED is susceptible to background light. Under different visibility, when the laser transmission distance is 100 m, the relationship between wavelength and transmittance is shown in Fig. 2.

It is known that the transmittance of red light is high, whereas the transmittance of blue light is low. With a two-color source, the difference in transmittance of blue light in the case where $\Delta L=L_1-L_2$ is a constant becomes

$$\Delta I(\lambda_b)=I_1(\lambda_b)-I_2(\lambda_b) \quad (6)$$

where λ_b is the blue light wavelength.

The difference in transmittance of red light is

$$\Delta I(\lambda_r)=I_1(\lambda_r)-I_2(\lambda_r) \quad (7)$$

where λ_r is the red light wavelength.

As can be seen from Fig. 2, $\Delta I(\lambda_b)>\Delta I(\lambda_r)$ in the range of visible light. Therefore, Red and blue LEDs are used as light sources for visibility measurement.

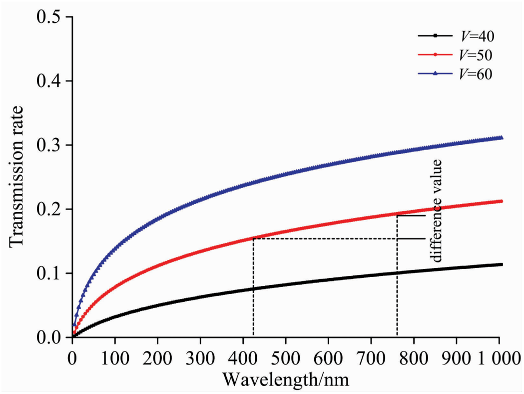

Fig. 2 The relationship between wavelength and transmittance

The visibility is 40, 50, 60

It is known that the initial light intensity of dual light sources is the same at any time. When the light source is red, the Eqs. (4) changes to

$$\begin{cases} I_1(\lambda_r)=I_{01}(\lambda_r)\exp(-\sigma L_1) \\ I_2(\lambda_r)=I_{02}(\lambda_r)\exp(-\sigma L_2) \end{cases} \quad (8)$$

where $I_{01}(\lambda_s)$ and $I_{02}(\lambda_r)$ are the initial light intensity of the parallel beam source 1 and source 2, respectively, $I_1(\lambda_r)$ and $I_2(\lambda_r)$ are their transmitted light intensities, and σ is the atmospheric extinction coefficient.

Therefore

$$V(\lambda_r)=\frac{-(L_1-L_2)\ln k}{\ln\left(\frac{I_{01}(\lambda_r)}{I_{02}(\lambda_r)}\frac{I_2(\lambda_r)}{I_1(\lambda_r)}\right)}=\frac{-(L_1-L_2)\ln k}{\ln\left(\frac{I_2(\lambda_r)}{I_1(\lambda_r)}\right)} \quad (9)$$

When the light source is blue, the Eqs. (4) changes to

$$\begin{cases} I_1(\lambda_b)=I_{01}(\lambda_b)\exp(-\sigma L_1) \\ I_2(\lambda_b)=I_{02}(\lambda_b)\exp(-\sigma L_2) \end{cases} \quad (10)$$

where $I_{01}(\lambda_b)$ aod $I_{02}(\lambda_b)$ are the initial light intensity of the parallel beam source 1 and source 2, respectively, $I_1(\lambda_b)$ and $I_2(\lambda_b)$ are their transmitted light intensities.

Therefore

$$V(\lambda_b)=\frac{-(L_1-L_2)\ln k}{\ln\left(\frac{I_{01}(\lambda_b)}{I_{02}(\lambda_b)}\frac{I_2(\lambda_b)}{I_1(\lambda_b)}\right)}=\frac{-(L_1-L_2)\ln k}{\ln\left(\frac{I_2(\lambda_b)}{I_1(\lambda_b)}\right)} \quad (11)$$

From the Eqs. (4), (9) and (11), it is known that in the same environment, the atmospheric visibility is calculated by using different wavelength sources. In the case of good visibility, the blue LED is used as the light source for visibility measurement. The difference in blue transmittance is large, which is beneficial to improve the signal-to-noise ratio and increase accuracy. When the visibility is poor, the light intensity of the blue light reaching the camera is weak, which causes error interference to the measurement. At this time, the red LED is used for visibility measurement. The accuracy of nighttime visibility measurement is improved by the two-color light source.

3 A visibility observation system based on constant temperature two-color light sources

The structure diagram of the visibility observation system based on the constant temperature two-color light source is shown in Fig. 3. It mainly includes constant voltage and constant current module of dual light sources, the light intensity comparison module, the light source thermostat module, the PID temperature control module, optical structure part, data processing part, etc.

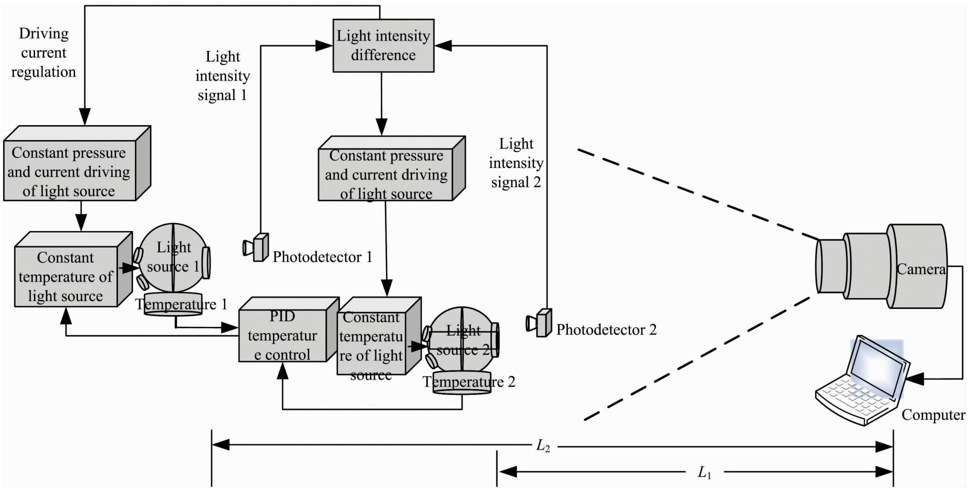

Fig. 3　The structure diagram of the visibility observation system based on the constant temperature two-color light sources

The light source 1 and 2 are respectively separated from the cameras L_1 and L_2 ($L_1 > L_2$)

The volt-ampere characteristic curve of the light source is similar to the diode. A small voltage change causes a large fluctuation of the current. The brightness of the light source is related to the forward current of the pn junction. As the current increases, the number of free electrons and holes injected into the pn junction of the source increases. The probability of radiation recombination increases, and the radiation intensity of the source increases until the recombination of electrons and holes tends to be saturated. At this time, the light intensity reaches a maximum value. Therefore, in order to ensure the stability of the light source intensity, a constant voltage and constant current driving module are used.

In order to ensure the consistency of the dual light sources intensity, the photon detector is used to measure the light intensity. The two light intensity signals are compared and processed. The light intensity of the dual light sources is ensured by adjusting the driving current of the light source 1.

Since the visibility system is installed in the actual environment, the measurement is inevitably affected by the ambient temperature because the temperature has an influence on the light intensity of the light source. In order to ensure the stability of the measurement, the influence of light intensity on temperature fluctuation is reduced by using PID thermostat module. The temperature of the light source is controlled at 50 ℃, higher than the ambient temperature, to eliminate the influence of ambient temperature changes on the light intensity.

The optical structure part is composed of integrating spheres and light sources. The light source drives the module so that the two light sources are simultaneously outputted in two states of blue and red. The integrating sphere ensures the uniformity of the light sources.

Finally, the image is captured by the camera, and then the atmospheric visibility is obtained through computer inversion.

4 Experimental verification

In order to verify the feasibility and versatility of the proposed method, the initial light intensity of dual light sources needs to be the same at any time. Experiments are carried out using the developed visibility observation system. The diameters of the two light sources are all 110 mm, and the MVC1000 camera has an exposure time of 10 ms.

The experimental scene to be tested remains constant during the experiment. The two photodetectors are equally spaced from the two sources. During the experiment, the ambient temperature is about 23 ℃, and the constant temperature module ensures that the temperature of the light source is unchanged at 50 ℃. First, the initial light intensity signals of the light sources are acquired by using two photodetectors. During the measurement process, the photodetector is close to the light source, which can be regarded as no extinction. The measurement results are shown in Fig. 4. The consistency of the two light sources reaches 0.99. The experimental results show that the initial light intensity of the dual light sources is very consistent at any time and the fluctuation is small. The constant temperature dual light sources module is used to eliminate the influence of ambient temperature change on light intensity. The constant voltage and constant current module ensures the uniformity of dual light sources light intensity.

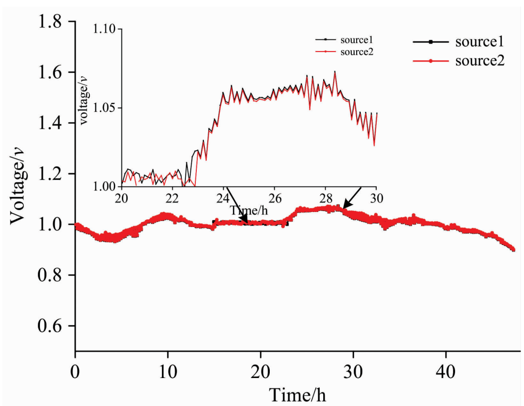

Fig. 4 The light intensity measurement results of dual light sources. The inset: zoom in the partial image

The dual light sources are set to 20 m from the camera L_1 and 50 m from the L_2. The proposed method is compared with the dual light source's method for visibility comparison experiments. Experiments are carried out in the case of a clear night, all of which are compared with real values. A series of experiments are carried out by using the established system. Method 1: Setting the dual light sources to red light and blue light, the camera images are separately acquired for inversion. Method 2: Setting the dual light sources to be white LED, the constant temperature module and the constant voltage and constant current module do not work. Then directly capture the camera image for inversion. The dual light sources observation results of red light and blue light are obtained by method 1, as shown in Figs. 5 and 6, respectively. The second measurement result is shown in Fig. 7. It can be seen from Fig. 5 and Fig. 6 that the penetration ability of the light source in different frequency bands is different. When the dual light sources are red light, the average amplitude of the fluctuation is 6.88%, while the dual light sources are blue light, the average amplitude of the fluctuation is 4.24%. It can be seen from Fig. 7 that the mean value of the fluctuation by method 2 is 9.17%. It is proved that the consistency of the two methods is very good, and the stability of the proposed method is good.

Then, in order to further evaluate the applicability of the proposed method for different weather conditions,

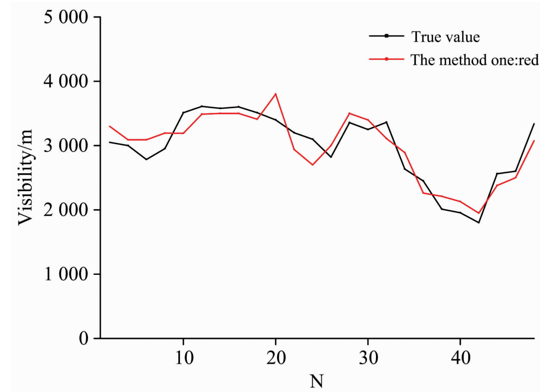

Fig. 5 Visibility measurement results when the dual light sources are red light

L_1 is 20 m, L_2 is 50 m

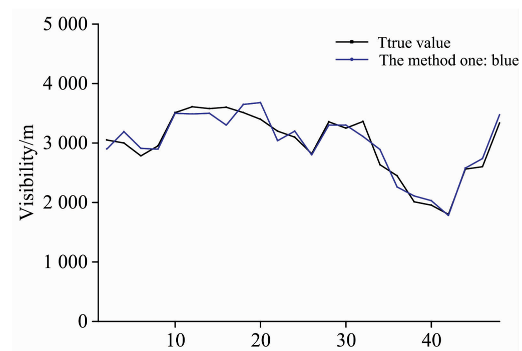

Fig. 6 Visibility measurement results when the dual light sources are blue light

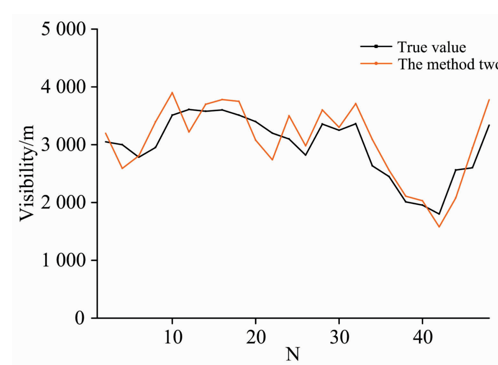

Fig. 7 Visibility measurement results of dual light sources method

experiments under different weather conditions are carried out. The experimental results are shown in Figs. 8, 9, and 10. It can be seen from Fig. 8 that the standard deviation of the dual light sources for red light is 69.217 on a rainy day, and the standard deviation of the dual light sources for blue light is 189.128. At this time, the measurement result of red light is close to the true value. It can be seen from Fig. 9 that the standard deviation of the dual light sources for the red light is 92.21 in the foggy day, and the standard deviation of the blue light is 287.13. At this time, the measurement result of red light is close to the true value. It can be seen from Fig. 10 that the standard deviation of the dual light sources for the red light is 247.75 on a sunny day, and the standard deviation of the blue light is 94.59. At this time, the measurement result of blue light is close to the true value.

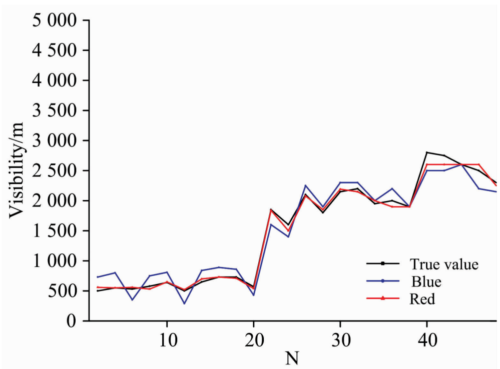

Fig. 8 Visibility measurement results on a rainy day

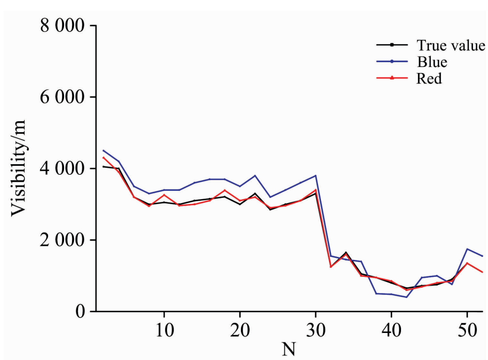

Fig. 9 Visibility measurement results in the foggy day

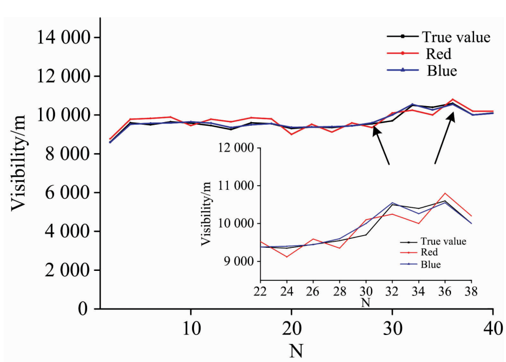

Fig. 10 Visibility measurement results on a sunny day
The inset: zoom in the partial image

When the visibility range is up to 15 000 m, one month of experimental observation is performed. The observations of the two methods are compared with the actual values, and the statistical errors are shown in Table 1. It can be seen from Table 1 that the error of the two methods within visibility range which is up to 15 000 m is less than 11%, and the proposed method can accurately measure within the visibility range.

Table 1 The statistical errors

Visibility/m	Method one: error/%	Method one: error/%
0～5 000	2.16	5.44
5 000～10 000	6.29	10.31
10 000～15 000	4.01	8.64

5 Conclusions

The nighttime visibility measurement is inevitably affected by the background light, the gray level of the light source, etc., resulting in unstable visibility measurement, low precision of observation results and small observation range. Based on the previous research, according to different penetrating powers of different frequency bands, the characteristics of the penetrating ability are analyzed in the visible range. A method for nighttime visibility estimation based on constant temperature two-color light sources has been proposed. A visibility observation system based on constant temperature two-color light sources has been established. A series of experiments have been carried out. The experimental results show that the consistency of the two light sources reaches 0.99. In a rainy and foggy day, the visibility is not good at this time. The light intensity of the blue light reaching the camera is weak and the measurement result of the red light is close to the true value. When it is sunny, nighttime visibility is good. At this time, the difference in blue transmittance is large, which is beneficial to improve the signal-to-noise ratio. The standard deviation of the blue light source is 36.90, and the measurement result of blue light is close to the true value. When the visibility range is up to 15 000 m, the proposed method can accurately measure within the visibility range.

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恒温双色光源夜间能见度观测方法研究

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摘　要　能见度一般为人眼视觉能够观测目标物的最大估计水平距离。能见度的观测和预报已经广泛的应用于气象预报、环境污染分析、交通运输等各个领域。现有的能见度观测方法主要分为散射式与透射式。其中数字摄像式能见度观测方法最贴近能见度定义，随着数字摄像技术的发展，加快了数字图像能见度的测量方法的研究与应用。但在利用数字摄像进行夜间能见度观测量过程中不可避免的受到不同天气背景光、光源灰度等影响从而造成能见度测量不稳定，观测结果精度低、观测范围较小。已知利用双光源的稳定性可以保证能见度的测量精度，大多数研究都是通过使用白光源的角度来解决能见度的测量不稳定问题。本文从准单色光源的角度出发，通过不同频段光源对能见度的穿透能力不同，在可见光范围内对不同频段光源的穿透能力进行特性分析。在已有的双光源基础上，提出了一种改进的恒温双色光源夜间能见度观测方法，实现在不同天气状况下，对能见度的高精度、大范围观测。通过设计恒温双光源，消除了环境温度变化对光强的影响；恒压恒流模块保证双光源光强一致性；利用积分球保证光强的均匀性；根据不同频段光源对能见度的穿透能力不同，选用双色光源实现高精度、大范围能见度的有效测量。在恒温双色光源的能见度观测系统中进行一系列的实验验证，实验结果表明两个光源的一致性达到0.99，能见度不好时，蓝光到达相机的光强弱，红光的测量结果接近真值；晴天时夜间能见度良好，蓝光透射率差值大，有利于提高信噪比，双光源为蓝光的标准差36.90，蓝光的测量结果接近真值。当观测极限为15 000 m时，进行1个月的实验观测，通过与真实值进行比较，所提出的改进恒温双色光源夜间能见度观测方法能够很好的在能见度观测极限范围内进行准确的测量。

关键词　恒温；夜间可见度；两色光源；传输速率；遥感

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