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Comparison and analysis of wavelength calibration methods for prism – Grating imaging spectrometer

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ABSTRACT

To identify spectral information obtained from the prism - grating imaging spectrometer, it is essential to know the center wavelength for each spectral channel. In this letter, the wavelength calibration principle of push-broom imaging spectrometers is described, and a wavelength calibration device is built. The wavelength calibration of the self-developed prism-grating imaging spectrometer using the peak method and the gravity method is completed, and the center wavelength of each spectral channel is obtained by the two methods respectively. Compared with the peak method, the gravity method can effectively avoid the errors caused by the uneven light spot energy in the process of wavelength calibration, and can more effectively complete wavelength calibration. The two methods can meet the practical application and can be selected according to actual demand.

Introduction

Imaging spectrometers are widely used in the fields including remote sensing, food security and medicine [1–3]. Prism-grating (PG) imaging spectrometer is a push-broom imaging spectrometer with a prism-grating combination as a light-splitting element and an area array detector as a receiving element, and has the advantages of direct vision and portability [4,5].

Wavelength calibration is performed to determine the correspondence relationship between imaging spectrometer probe elements and the central wavelength, and it is a prerequisite for target recognition based on the measured spectrum [6]. In general, the peak method is used for wavelength calibration of push-broom imaging spectrometers, that is, by recording the digital number (DN) values of different wavelengths, and using Gaussian fitting of the wavelengths and the DN values, the pixel center wavelength is then obtained by calculating the wavelength with the highest response [7]. However, many factors can affect measurement of the spectral response function. Different energies are radiated by the light source at different wavelengths, the monochromatic light intensity will not be the same at different wavelengths, the optical system transmittance also varies at different wavelengths, and cameras will respond differently to different wavelengths [8–10]. Because of these factors, the calibration process must adjust the integration time and light source voltage and other measures to ensure that the light spot energy is not too high or too low at each wavelength. In this way, the position at which the light spot energy is adjusted should be recorded during the calibration process to correct the energy at the corresponding position during subsequent calibration data processing, and the correction method is usually to re-measure the position of the energy change [11,12]. Therefore, adjustment of the light spot energies of the peak method causes considerable disturbance during subsequent processing of the calibration data, additionally, during the re-measurement process, there is no guarantee that there will be no fluctuation of the light spot energy, and this reduces the accuracy of the calibration results. However, the gravity method records the position of the light spot on the imaging spectrometer, and the center wavelength of the pixel is obtained by the algorithm fitting of the wavelengths and the positions. It is not sensitive to changes in energy, and thus there is no need to adjust the light spot energy during the measurement process, the wavelength calibration can be achieved faster.

In view of this, in order to wavelength calibration for the prism-grating imaging spectrometer developed by ourselves, we have adopted peak method and gravity method to complete its wavelength calibration. The wavelength calibration results show that both methods can realize the wavelength calibration of the push-broom imaging spectrometer, and it is very versatile. The appropriate calibration method can be selected according to the actual situation.

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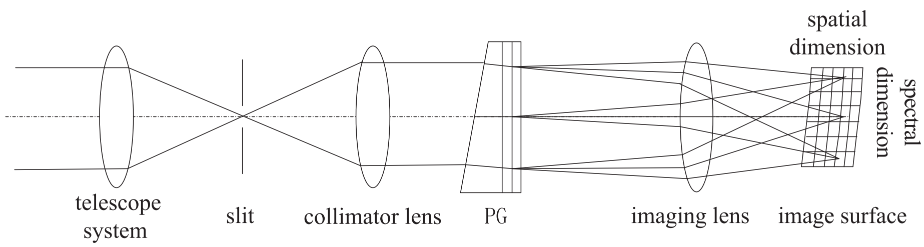

Fig. 1. Schematic diagram of PG imaging spectrometer.

Principle of PG imaging spectrometer

PG imaging spectrometer consists of a telescope system, slit, collimator lens, PG spectroscopic elements, imaging lens and receiving system. The Prism-Grating spectroscopic structure guarantees the light straight in and out, and has the advantages of compact structure and compact portability. The optical structure of PG imaging spectrometer is shown in Fig. 1.

PG imaging spectrometer scans the target in push-broom mode. The imaging spectrometer array detector can obtain three-dimensional information of the target. One dimension is spectral curve (i.e. spectral dimension) and the other dimensions are spatial imaging (i.e. spatial dimension) of the target. The main system parameters of the PG imaging spectrometer to be measured are shown in Table 1.

Wavelength calibration device and method

The wavelength calibration device

The wavelength calibration system for the push-broom consists of a light source, a monochromator, a collimation system, a turntable and a prism-grating imaging spectrometer as shown in Fig. 2. The procedure for wavelength calibration of the prism-grating imaging spectrometer involves the following steps: (1) The light source and monochromator are combined to produce monochromatic light; (2) the monochromatic light changes into parallel light after passing through the collimation system; (3) the detector receives and records the optical signal; (4) the pixel's spatial dimensions are changed by rotating the turntable (this step can be omitted when it is not necessary to finely calibrate); (5) results are calculated using the collected data. The technical specifications of the system are given in Table 2.

The wavelength calibration method

Generally, the center wavelengths of imaging spectrometer are calibrated by recording the DN values of the continuous monochromatic light on the spectral channel, and then performing Gaussian fitting on the recorded data to obtain the center wavelength of the spectral channel. Unfortunately, this method is highly susceptible to the fluctuation of light intensity, which cause inaccurate fitting of the final data. However, the gravity method records the position information of the continuous monochromatic light spot on the spectral channel during calibration process, and then establishing the relationship between the wavelength and the position of light spot. Finally, through the fitting process, the center wavelength of each spectral channel is obtained. The position of the wavelength is obtained by calculating the light spot center of gravity on the detector of the imaging spectrometer using the following formula:

Table 1
Main parameters of PG imaging spectrometer.

index	value
Band range	400–950 nm
Resolution	3 nm
Silt	14.2 mm × 30 μm (L × W)
F#	3.5
Detector	1920 × 1080 (7.4 μm)

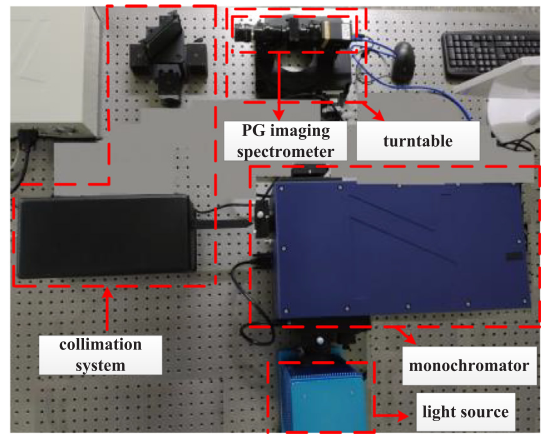

Fig. 2. The picture of calibration system.

Table 2
The technical specifications of calibration system.

index	value
Band range	380–1000 nm
Resolution	0.1 nm
Scanning step	0.2 nm
Repeatability	0.2 nm
Accuracy	0.3 nm

$$C_{gravity} = \sum iS_i/(\sum S_i) \tag{1}$$

Here, Si is the pixel's output signal, and i is the pixel number. A schematic diagram of the fitting curves of the calculation results of the two methods are shown in Fig. 3.

Wavelength calibration results and analysis

In this work, the wavelength calibration system described above was used to calibrate the center wavelengths of the prism-grating imaging spectrometer. Because of the instability of the light spot energy, the signal energy could be either saturated or too low. To prevent this problem, the light source energy was adjusted during the calibration process and the light spot energy adjustment positions were recorded. The light spot position information calculated using the gravity method and the DN value of the light spot were also recorded simultaneously. Localized polynomial fitting of the recorded wavelengths of monochromatic light and light spot positions using the gravity method, that is, the center wavelength of each spectral channel is polynomials fitted by the data of the adjacent two channels, not all the data of the spectral channels are performed by once polynomial fitting. The calibration results are shown in Fig. 4. At the same time, in order to

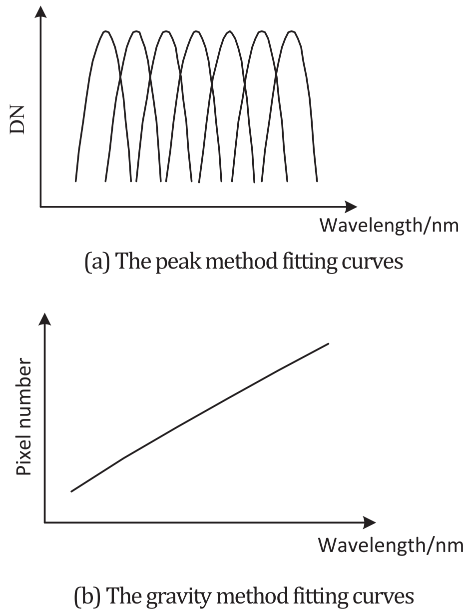

Fig. 3. The A schematic diagram of fitting curves.

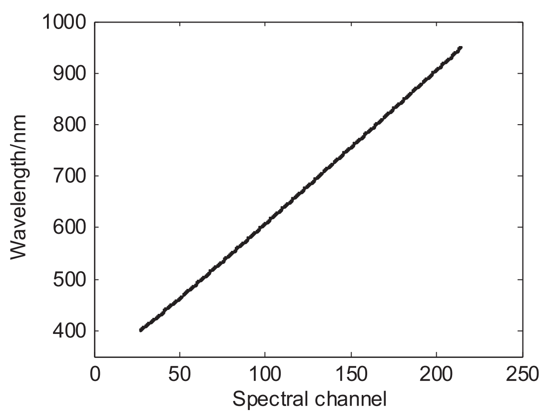

Fig. 4. Wavelength calibration results of the gravity method.

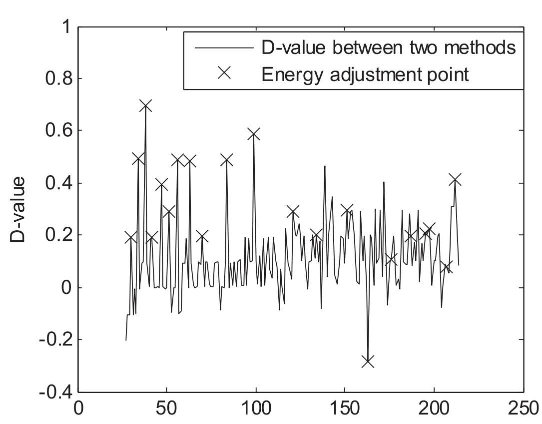

Fig. 5. Comparison of results obtained using two different methods.

compare with the peak method, the recorded wavelengths and DN values are Gaussian fitted, and the center wavelength of each spectral channel is the maximum value of the Gaussian fit curve. The comparison results of the two methods are shown in Fig. 5, among them, D-value means difference value.

As shown in Fig. 5, most of the locations where big differences occur

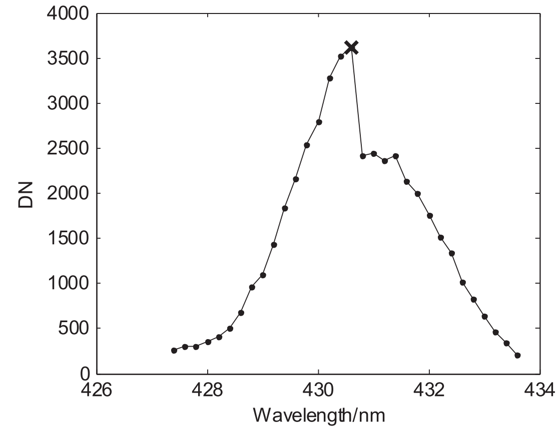

Fig. 6. Original calibration data of the 38th spectral channel from the peak method.

between the calibration results from the two methods are the light spot energy adjustment points, and the part of the spot energy adjustment point of the peak method original data are recalled, as shown in Fig. 6. It can be seen that there is a change in the trend of the curve due to the existence of an energy mutation, resulting in the final data fitting deviating from the actual value. To verify the correctness of the results, the light spot energy adjustment position data were re-measured under the same experimental conditions, and then the re-obtained data were replaced and compared with the normalized calibration results of the gravity method, with results as shown in Fig. 7

As shown in Fig. 7, the difference between the two methods after correction is obviously smaller, but there are still large differences such as those at spectral channels 139, 143, 167 and 172. Analysis of the original data of the channels showed that the existence of an energy fluctuation at these spectral channels, as shown in Fig. 8.

The results above show that the peak method is easily affected by the energy fluctuation of the light spots, and that the light spot energy fluctuation is the fixed existence of the calibration structure, such as the variations in the light source energy, the efficiency of the monochromator for each wavelength, and the uneven response of the imaging spectrometer to each wavelength. The peak method relies on the measured imaging spectrometer output energy of signal to calibrate, it is easy to cause the calibration results deviated, but the wavelength calibration using the gravity method can effectively reduce such problems. By comparison, the calibration results of the two methods differed in the calibration range is less than 0.3 nm, which is one-tenth of the bandwidth of the prism-grating imaging spectrometer. The calibration results of the two methods are all suitable for practical

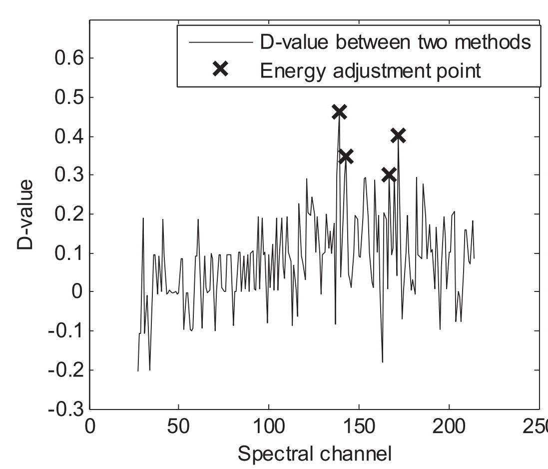

Fig. 7. Comparison of results of the two methods after correction.

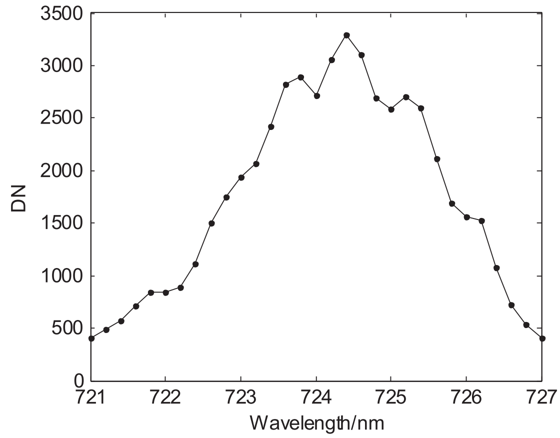

Fig. 8. Original calibration data of the 139th spectral channel from the peak method.

applications.

Conclusions

In this letter, the wavelength calibration of the prism-grating imaging spectrometer was performed using the peak method and the gravity method respectively. And the calibration results obtained by the two methods were compared and analyzed. The main conclusions are as follows. First, the center wavelength of each spectral channel in the center of field of the prism-grating imaging spectrometer was given, which showed a good linear relationship over the entire wavelength range. Second, the results from the gravity method and the peak method were compared, and the differences between the two calibration results were within the scope of 0.3 nm, the gravity method and the peak method can all suitable for practical application to the prism-grating imaging spectrometer. Third, the gravity method in comparison with the peak method has lower sensitivity to sudden changes in the light spot energy, and thus can significantly increase the wavelength calibration efficiency and accuracy to wavelength calibration of PG imaging spectrometer. The two wavelength calibration methods are highly versatile and can be applied to wavelength calibration tasks similar to that of the prism-grating imaging spectrometer.

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References

[1] Li QL, Zhou M, Liu HY. Red blood cell count automation using microscopic hyperspectral imaging technology. Appl Spectrosc 2015;69:1372–80.
[2] Davis CO. Applications of hyperspectral imaging in the coastal ocean. Proc SPIE 2002;4816:32–41.
[3] Qin JW, Chao KL, Kim MS, Lu R, Burks TF. Hyperspectral and multispectral imaging for evaluating food safety and quality. J Food Eng 2013;118:157–71.
[4] Chen HF, Gong Y, Luo C, Peng JT. Design of prism-grating imaging spectrometer with eliminating spectral line curvature. Acta Opt Sin 2014;34. 0922004-1-8.
[5] Yang ZP, Tang YG, Bayanheshig, Pan MZ, Cui JC, Yang J. Optimization design method for optical system of prism-grating ultrasperctral imaging spectrometers. Acta Opt Sin 2014;34. 0911003-1-9.
[6] He ZP, Shu R, Wang JY. Research on method of geometry and spectral calibration of push broom dispersive hyperspectral imager. Proc SPIE 2012;8527. 85270R-1-7.
[7] Zheng YQ. Precise spectral calibration for hyperspectral imager. Opt Precision Eng 2010;18:2347–54.
[8] Li XJ, Ren JW, Liu HX, Wan Z. Spectral response testing and uncertainty evaluation of plane array CCD. Laser Optoelectron Prog 2014;51. 111202-1-8.
[9] Ji H, Jiang HL, Zheng YQ, Ma HT. Spectral calibration of the hyperspectral optical remote sensor. Chin J Lumin 2013;34:235–9.
[10] Zhou Jk, Chen XH, Ji YQ, Chen YH, Shen WM. Spectral calibration for convex grating imaging spectrometer. Proc. SPIE 2013;9045. 90451U-1-9.
[11] Jehle M, Hueni A, Lenhard K, Baumgartner A, Schaepan ME. Detection and correction of radiance variations during spectral calibration in APEX. IEEE 2015;12:1023–7.
[12] Yu XJ, Sun YH, Fang AP, Qi WJ, Liu CJ. Laboratory spectral calibration and radiometric calibration of hyper-spectral imaging spectrometer. IEEE 2014;2:871–5.