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Assembly and evaluation of a spectrometer by using a spectral interferometer

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Abstract

Optical spectrometers require precise optical alignment for reliable performance evaluation. Conventional calibration techniques using emission lamps are limited by discrete spectral lines and low optical power. In this investigation, spectral interferometry is introduced as an optical source for assembling and evaluating an optical spectrometer. The fringe contrast is used for the alignment of optical components, and spectral resolution is determined by the maximum measurable distance of the spectral interferometer. The proposed method provides an efficient tool for both the calibration and performance evaluation of spectrometers.

spectral interferometer, optical spectrometer, alignment tool, performance evaluation

1. Introduction

An optical spectrometer, which typically consists of a slit, a collimating mirror, a diffraction grating, and a focusing mirror, has been essential for material inspection in various fields because of its capability to measure spectral intensity [1]. To achieve the intended spectral range and resolution, most important task is to align and assemble all optical components. Conventional techniques use spectral lines from lamps such as Hg, Ar, and Ne [2], but they provide limited wavelength coverage and low optical power, increasing calibration effort. In this investigation, spectral interferometry is introduced as an alternative light source for spectrometer construction and calibration. Interferometric fringes provide broadband alignment information, and the maximum measurable distance can estimate the spectral resolution of a spectrometer.

2. Method

2.1. Spectral Interferometer

A spectral interferometer uses a broadband light source to generate a spectral interferogram corresponding to the optical path difference (OPD) between a reference arm and a measurement arm. Because the spectral interferogram is generated over a wide spectral range, its contrast can be used for the assembly of a spectrometer. On the other hand, the spectral interferogram becomes denser as the OPD increases and the maximum measurable distance (ΔL_{max}) of the spectral interferometer, which defines the spectral resolution (Δv) as [3]

$$\Delta L_{max} = \frac{c}{4\Delta v} \qquad (1)$$

where c is the speed of light. As known in Eq.(1), the resolution of a spectrometer can be determined by ΔL_{max}.

2.2. Assembly and evaluation of an optical spectrometer

When a spectral interferometer is used as a light source for assembling a spectrometer as shown in Fig. 1, it assists spectrometer assembly in two ways. First, the spectral interferometer generates interference fringes across the full bandwidth of the source, enabling alignment without relying on discrete emission lines. The assembly can be optimized by monitoring fringe contrast, where maximum and uniform contrast indicate proper positioning and tilt of optical elements. Unlike conventional calibration using standard lamps, this alignment can be performed across the entire spectrum.

Second, the spectral resolution of the spectrometer can be estimated from the ΔL_{max}. In this case, a well-calibrated spectrometer with higher resolution is used as a reference. As OPD increases, the interferogram is observed simultaneously in both spectrometers until the fringes disappear in the spectrometer under construction. At that point, the resolution can be derived by using Eq.(1) obtained from the reference spectrometer [4].

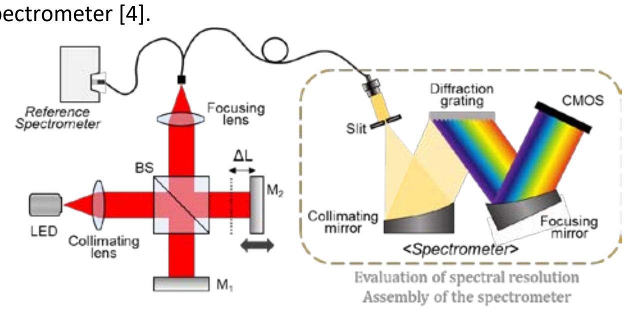

Fig. 1. Assembly and spectral resolution evaluation of the spectrometer using a spectral interferometer.

3. Experimental results

3.1. Alignment of a spectrometer by using a spectral interferometer

Figure 2(a) shows the spectral interferometer configured in this investigation. The light from the LED was delivered by a multi-mode fiber and split by a beam splitter. In the Michelson-type interferometric configuration, one of the mirrors was mounted on a manually translated stage to adjust the OPD. The two reflected beams were recombined, and the spectral interferogram was simultaneously detected by the reference spectrometer and the CMOS camera of the spectrometer under construction. As the reference spectrometer, a commercial high-resolution spectrometer with 0.12 nm resolution in the wavelength range from 350 nm to 800 nm was used, and the spectral interferogram was detected as shown in Fig. 2(b).

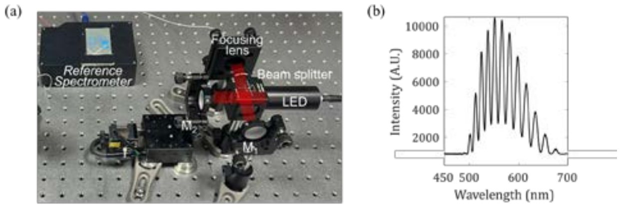

Fig. 2. (a) Photograph of the spectral interferometer setup and (b) its spectral interferogram obtained by the reference spectrometer.

Using the spectral interferogram from the spectral interferometer, the tilt of the CMOS camera of the spectrometer was adjusted using the contrast uniformity of the spectral interferogram. When the CMOS camera was tilted, the spectral interferogram on the camera was changed, and its contrast was also varied. In particular, the contrast uniformity of the spectral interferogram was strongly affected by the angle-deviation from the expected posture. In the experiment, the contrast uniformity of the spectral interferogram was monitored while the CMOS camera was tilted, and the best alignment status was determined as the contrast uniformity of the spectral interferogram was less than 0.07 for the peak-to-valley value as shown in Fig. 3(a).

Then, the position of the CMOS camera was adjusted to detect the spectral interferogram obtained by the reference spectrometer. As shown in Fig. 3(b), the spectral interferogram obtained by the reference spectrometer was clearly observed, and its contrast was approximately 0.6. The contrast of the interferogram obtained by the CMOS camera was varied with detector positions, and the best position was identified as shown in Fig. 3(c) as the contrast was maximum. In this case, the contrast was similar to that of the reference. It is noted that the fringe contrast was calculated from the signal magnitude after removing the upper and the lower envelopes of the spectral interferogram.

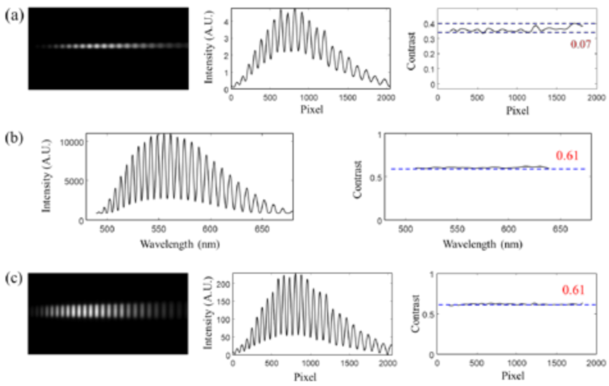

Fig. 3. (a) Spectral interferogram and its contrast with the angle-deviation of 0˚ and (b) Spectral interferogram and its contrast obtained using the reference spectrometer and (c) Spectral interferogram and its contrast with the position deviation of 0 mm.

3.2. Spectral resolution evaluation and wavelength calibration

After the alignment of the spectrometer was completed, its spectral resolution was evaluated using the maximum measurable distance of the spectral interferometer. As the OPD of the spectral interferometer increased, the spectral interferogram became denser in the reference spectrometer as shown in Fig. 4(a), and eventually disappeared in the spectrometer under construction as shown in Fig. 4(b), when the OPD was 52.97 µm. Using Eq.(1), the corresponding spectral width Δv was calculated from the reference spectrometer result and converted into the wavelength.

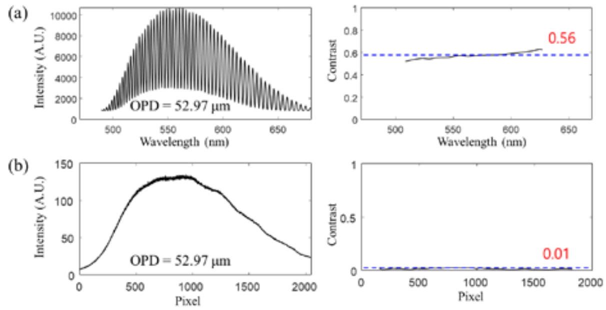

Fig. 4. Spectral interferogram and its contrast obtained by (a) the reference spectrometer and (b) CMOS camera at OPD = 52.97 µm.

The spectral interferometer was also used for the wavelength calibration of the constructed spectrometer. Using the reference spectrometer as a calibration reference, the wavelengths corresponding to the constructive interference peaks in the interferogram were identified. Figures 5(a) and (b) show the spectral interferograms measured by the reference spectrometer and the constructed spectrometer, respectively. Based on the similarity between the two interferograms, peak positions were paired to match pixel indices of the CMOS detector with reference wavelengths. After assigning wavelength values to each constructive interference peak, the full spectrum was calibrated using third-order polynomial curve fitting, as commonly employed in spectrometer calibration. As the result, the fitting residual was 0.3 nm RMSE over the spectral range of 480–650 nm, confirming accurate wavelength reconstruction.

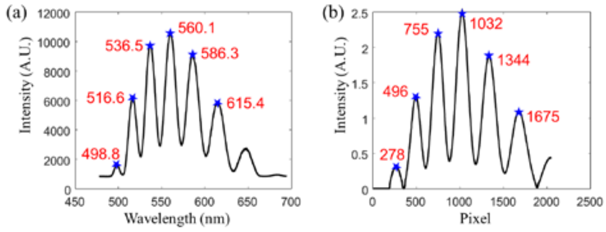

Fig. 5. Spectral interferograms with peak locations obtained by (a) the reference spectrometer and (b) the constructed spectrometer.

4. Conclusion

In this investigation, a spectral interferometer was used as a broadband source to assemble and evaluate an optical spectrometer. Interferometric fringes enabled full-spectrum alignment without standard lamps, while fringe contrast was used to optimize the spectrometer assembly. A spectral interferometry offers a compact and efficient method for spectrometer alignment, calibration, and performance evaluation.

Acknowledgements

It is noted that this conference proceeding is written and modified based on the journal paper [4].

References

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