EXPERIMENTAL STUDY OF THE OPTICAL TRANSFER FUNCTION (OTF) AND SPECTRAL ACCURACY OF THE IMAGING HYPERSPECTROMETER BASED ON THE OFFNER SCHEME

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Abstract. We deal with the imaging spectrometer based on the Offner scheme. We define the optical transfer function of the imaging spectrometer based on the Offner scheme. We define the spectrum reconstruction error for red LED.

Keywords: diffraction gratings, imaging hyperspectrometer, spectral image, Offner scheme.

Citation: Blank VA, Skidanov RV. Experimental study of the optical transfer function (OTF) and spectral accuracy of the imaging hyperspectrometer based on the Offner scheme. CEUR Workshop Proceedings, 2016; 1638: 8-15. DOI: 10.18287/1613-0073-2016-1638-8-15

Introduction

Imaging spectrometers have become a powerful technique to solve many problems, such as a precise imaging of the wide areas, object identification, recognition, target detection, environmental diagnostic and control [1-3]. The spectrometers application fields are the researches, remote sensing, medicine, ecology, production, agriculture, security and many others.

Imaging spectrometers are the optical instruments, which combine a common imaging with spectroscopy to record the spectrum of each point on the area [4-6]. The gratings or prisms are often used to separate the light spectral components. The use of gratings provides more density of the spectrometers. The Dyson and Offner schemes are distinguished among these spectrometers. The Dyson scheme is the most simple [4, 7]. It consists of lens, a silica glass and a concave grating, the slit is perpendicular to the level of the Fig. [8].

Also, the trials have been made in recent years with the use of the grating optical elements or the structured filters to simplify the design of the imaging hyperspectrometers.[9, 10, 11]

It is preferably to use the Offner spectrometers to get high quality hyperspectral Fig., because they have better quality of the Fig. and spectral resolution than other types of imaging spectrometers for the long length of the slit diaphragm and a relatively small focus distance. The classical Offner scheme consists of a spherical dish and aspherical convex gratings [3, 12, 13]. The level of the geometrical aberrations of this system is low, due to the fact that the optical beam is reflected twice by the main dish of the spectrometer and the basic aberrational distortions is compensated due to the different signs for the different reflections [13]. The articles [3, 14, 15] describe the hyperspectrometer design based on the Offner schemes, in [14] there was realized the research, where the authors experimentally measured point spread function (PSF), showing that this function corresponds to the modeling results [15]. However, there is no research in [14] to determine the optical transfer function (OTF) of the spectrometer and its spectral resolution. In this article, we research the hyperspectrometer OTF and its spectral characteristics using black-and-white graphic table lighted by the illuminant with a nominal spectral distribution.

The OTF determination and spectrum restore functions

The OTF of the hyperspectometer and the spectrum reconstruction error were defined in this research. The optical setup consisting of the spectrometer based on the Offner scheme was constructed for this purpose (Fig.1).

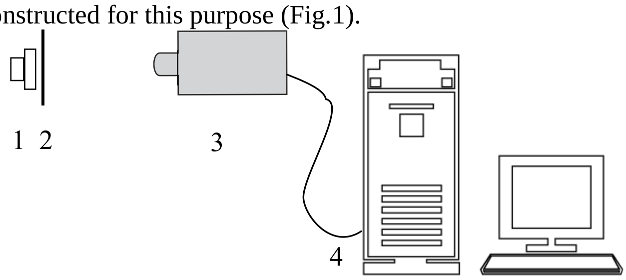


Fig. 1. The scheme of the setup, where 1 – spotlight, 2 – graphic table, 3 – spectrometer based on the Offner scheme, 4 – computer

The LED spotlight was used as a light of the graphic table – 2, that allows using of different types of LED to change the spectral distribution in the beamed optical path – 1, 3 – operable spectrometer (hyperspectral camera) closed by the opaque cover.

The model of the spectrometer based on the Offner scheme is shown in Fig. 2. The telephotographic lens "Jupiter-21M", the spectrometer slit width 15 μm, TOUPCAM UCMOS03100KPA camera with a maximum resolution of 2048 x 1536 pixels, the size of the sensible area - 6,55 × 4,92 mm, the pixel size - 3.2 microns. The grating with a spatial frequency 30mm^{-1} marked on a convex reflector was used in the hyperspectrometer.

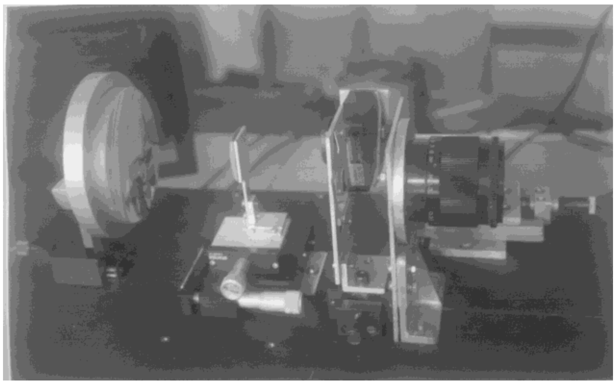


Fig. 2. The model of the spectrometer based on the Offner scheme

We analyze the possibility to restore the images, made by the spectrometer based on Offner scheme. The multiple types of images were used for this experiment, such as: lighting scales (Fig. 3), black and white graphic table for quality control of the depicting lens (Fig. 4).

Lighting scale is displayed on a white screen using a computer projector, and the image was scanned by a software change of the scale position on the screen.

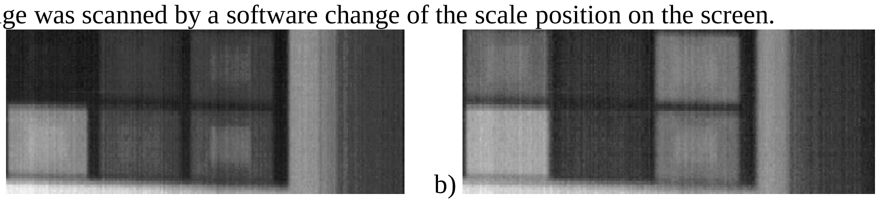
a)  b)

Fig. 3. The images formed by the imaging spectrometer based on the Offner scheme

As can be seen in Fig. 3, the images of the lighting scales in the hyperspectrometer are equally sharp for all colors at any wavelength in spite of the different spectral distribution corresponding to each color.

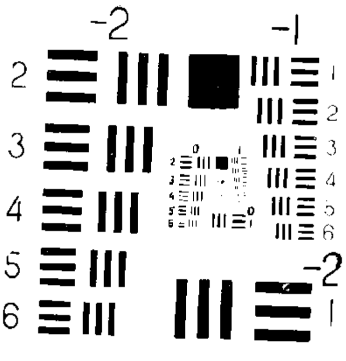


Fig. 4. The graphic table for the OTF determination

The standard black and white graphic table (Fig. 4) was used to determine the hyperspectrometer OTF. To determine the OTF the graphic table was placed at a distance of 0.8 m from the spectrometer and lighted the other way around by the LED spotlight with the current mode of white light.
The scheme of the used LED spotlight is shown in the Fig. 5.

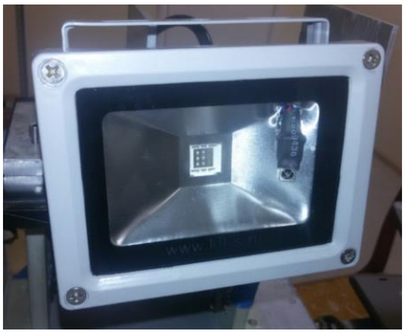


Fig. 5. LED spotlight

We got the spectral distribution for each position of the slit diaphragm during the graphic table scanning.
The example of the spectral image of the graphic table section is shown in Fig. 6. The scanning was realized by the image shifting at intervals of 2 mm.

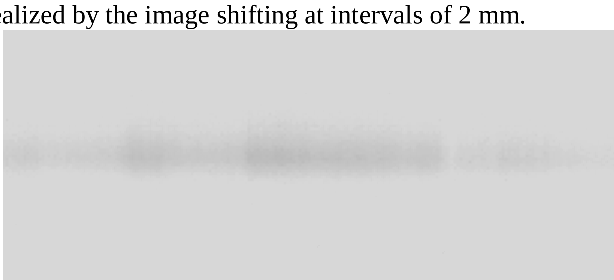


Fig. 6. The spectral image of the graphic table section, illuminated with white light

To form the hyperspectral cube [16], the sequence of spectrometer images should be processed. The hyperspectral image of the illuminated with white light graphic table was restored after the processing of the resulting images. The Fig. 7 shows the hyperspectral image components for the wavelengths 550 nm, 570 nm, 620 nm and 640 nm.
The contrast of the periodically striped images on the graphic table was determined according to the Fig. 7a. The contrast of the amplitude grating image was defined by the formula

$$k = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}, \qquad (1)$$

where I_{max} - the intensity of the image of the graphic table amplitude grating at the maximum, where I_{min} is the intensity of the image of the graphic table amplitude grating at the minimum.

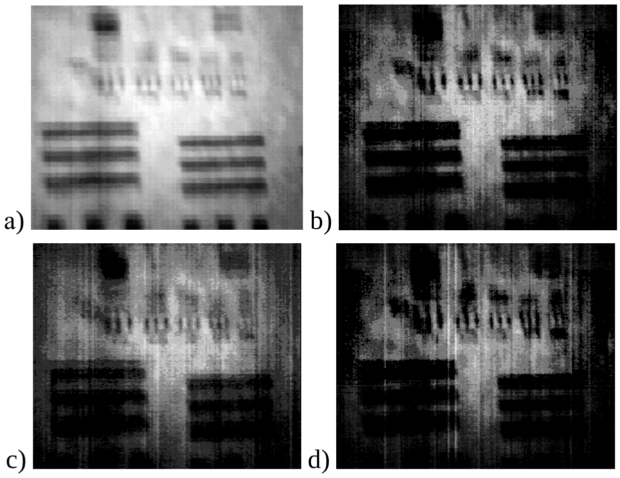


Fig. 7. The graphic table image by the hyperspectrometer at a wavelength of: a) 620 nm; b) 550 nm; c) 640 nm; d) 570 nm

The section view (Fig. 8) was formed for the periodically striped image shown in the Fig. 7. The I_{max}, I_{min} for the image contrast determination was formed on the basis of this section view.

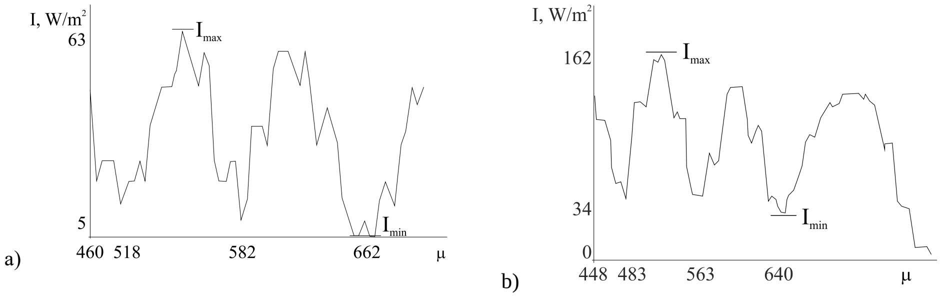


Fig. 8. The section view was formed for the periodically striped image shown in the Fig. 7: a) 24 mm^{-1}; b) 28 mm^{-1}

The average contrast value was determined by the formula

$$\bar{k} = \frac{\sum_{i=1}^{n} k_i}{n}$$

Then, the standard deviation (SD) was determined using the formula (2)

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{k}_i - \bar{k})^2}\ , \tag{2}$$

where n – is the measurements number, $\bar{k}$ - is the average contrast amount.
The OTF chart (Fig. 9) was plotted on the basis of the obtained results, the full line and chain-dotted line in Fig. 9 shows the OTF of the spectrometer obtained by the calculation in the Zemax software bundle [17].

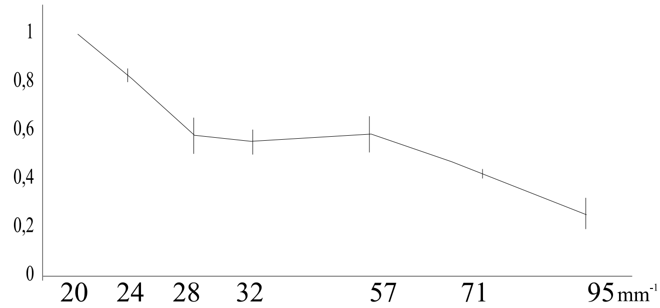


Fig. 9. The OTF of the imaging spectrometer with wavelength of 620 nm

There is generally close agreement between the calculated and experimental results. As for the high the percentage error for the experimental and calculated data is not more than 10%. In the range of the medium frequencies it is not more than 20%.
The red LED spotlight was used to determine the spectrum reconstruction error. The rays of the LED spotlight were projected on a white sheet of paper and then scanned by the spectrometer.
The spectrum of this light source, measured by the MS7501 spectrometer was used as the measurement standard. The Fig. 10 shows the spectrum of the spectrometer based on the Offner scheme (dash line) in comparison with a reference spectrum of the MS7501 spectrometer (solid line).

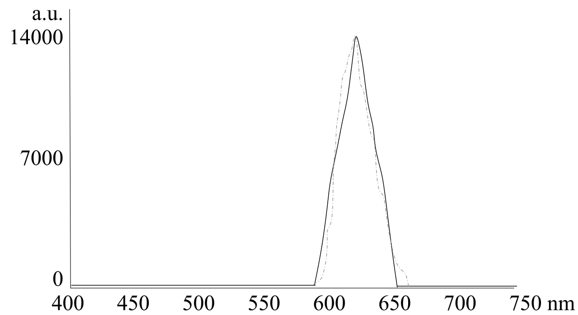


Fig. 10. The spectrum of the MS7501 spectrometer and the spectrum of the imaging hyperspectrometer with wavelength of 620 nm

The measurement error value (standard deviation) of the spectrometer based on the Offner scheme was obtained on the basis of the obtained spectral distribution and its comparison with the reference distribution. For the red LED spectrum this error accounted for 18%. The large amount of this error is associated with a relatively slow response of the array used in this spectral range, as well as with the fact that the light source with a narrow spectral range was used there.

Conclusion

In this research the spectral images were made by the imaging hyperspectrometer based on the Offner scheme. On its basis the accuracy of the red LED spectral function formation, which is compared with a reference, measured by the specific MS7501 spectrometer was checked. The standard error was 18%. Also we experimentally determined the OTF of the imaging spectrometer based on the Offner scheme. The close agreement between the experimentally obtained OTF and the calculated data was shown in this research.

Acknowledgment

The work was funded RSF grant 14-19-00114.

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