Experimental study and calibration of the imaging hyperspectrometer based on the Offner scheme

V V Podlipnov¹,², V A Blank¹,² and R V Skidanov¹,²

¹ Image Processing Systems Institute - Branch of the Federal Scientific Research Centre
“Crystallography and Photonics” of Russian Academy of Sciences, Molodogvardeyskaya str.
151, Samara, Russia, 443001
² Samara National Research University, Moskovskoe Shosse 34, Samara, Russia, 443086

e-mail: podlipnovvv@ya.ru, veronica_b@smr.ru, romans@smr.ru

Abstract. In this paper, a hyperspectrometer based on the Offner scheme is described. Experimental testing of the hyperspectrometer model was carried out. The spectral characteristics of the imaging hyperspectrometer are investigated. With the help of a tunable laser, calibration data of the experimental design of the hyperspectrometer were obtained, which allowed each channel of the hyperspectral image to correspond to a specific wavelength. The spectral sensitivity of the imaging hyperspectrometer was experimentally obtained. The software for obtaining hypercubes is presented. Using the example of calculating the NDVI and WBI indices, the technical capabilities of the prototype is showed.

1. Introduction

The hyperspectrometer described in this paper is built on the basis of the Offner scheme. This scheme is described in detail in [1-3]. In [4], primary studies of the prototype of a hyperspectrometer based on the Offner scheme were carried out. The hyperspectrometer described in this work was built on a common duralumin base, on which elements of the optical circuit were placed using optomechanics. Optomechanical fasteners provided the necessary displacement for the alignment, which in turn significantly increased the mass-dimensional characteristics of the imaging hyperspectrometer. In this regard, in this paper we proposed a design that significantly reduced the mass-dimensional characteristics of the layout. This solution significantly increased the mobility of the device.

For further use and obtaining results, there is inevitably a need for an accurate calibration of the instrument. To solve this problem, various researchers resort to such methods as modeling [5-6] analysis of the signal transfer function for different wavelengths [7], taking into account the characteristics of the optical elements of the circuit and the detector [8], cross-calibration based on the results of experimental surveys [9]. These methods are rather inaccurate for various reasons. In this paper, it is proposed to use a two-stage calibration, the first of which allows one to determine the correspondence of the hypercube channels to wavelengths, the second one allows to adjust the brightness of various channels in such a way that they correspond to the standard spectrum as much as possible.

2. Design of a prototype of a hyperspectrometer

Appearance of the hyperspectrometer is shown in Figure 1. This hyper-spectrometer uses lightweight fasteners made of aluminum alloys, and the casing is made of plastic, which allows to achieve weight reduction of up to 2.64 kg. Overall dimensions were 370 × 130 × 136 mm.
3. Calibration of the hyperspectrometer

To establish the correspondence of the channels of the hyperspectral image to the wavelengths, the software was calibrated. The image was taken from a screen on which a beam of laser light with tunable wavelength EKSPLA NT242 was directed. As a result of the calibration, a calibration table was obtained, which establishes the correspondence of the channels to the wavelengths (Table 1).

| Laser wavelength, nm | Band number | Band width, nm |
|----------------------|-------------|----------------|
| 420                  | 7           | -              |
| 440                  | 25          | 1.11           |
| 460                  | 43          | 1.11           |
| 480                  | 61          | 1.11           |
| 500                  | 79          | 1.11           |
| 520                  | 96          | 1.18           |
| 532                  | 110         | 1.17           |
| 543                  | 118         | 1.38           |
| 550                  | 124         | 1.17           |
| 560                  | 132         | 1.25           |
| 580                  | 150         | 1.11           |
| 600                  | 168         | 1.11           |
| 650                  | 213         | 1.11           |
| 750                  | 304         | 1.1            |
| 800                  | 352         | 1.04           |
| 843                  | 383         | 1.04           |

At the same time, according to the survey results, it was found that the spectral resolution, with a channel width of 1.11 nm, is not worse than 4.44 nm. Also, a good agreement between the experimental results and modeling results was obtained in [3], where it was predicted that overlapping of second-order spectra of short wavelengths with first-order spectra of the long-wavelength part of the visible range of light was predicted. In the course of the experimental study, the spectral sensitivity of the matrix to various wavelengths was also obtained.

The matrix used in this device design has a complex sensitivity characteristic for different wavelengths of light. According to the manufacturer [10], its effectiveness has the form shown in Figure 2.

In addition, the diffraction grating of the hyperspectrometer also has an inhomogeneous performance characteristic. Thus, a source of white light in the form of a xenon lamp used in projectors was used to calibrate the level of the spectral channels. White light was projected onto a white screen, after which its image was taken with a hyperspectrometer and then processed. As a result, a spectrum of white light having the widest spectral range was obtained. The obtained spectrum was compared with the spectrum obtained by the MS7504i reference spectrometer.
This procedure is described in detail in our early work [11].

![Figure 2. Spectral sensitivity of the CMV 4000 matrix.](image)

4. Experimental study of a prototype of a hyperspectrometer

The used hyperspectrometer layout and image processing obtained by it using the obtained calibration data allow calculating vegetative indices, such as, for example, NDVI, Water Band Index (WBI). These indices are important for assessing growth, maturation, plant stress and forecasting yields in agriculture.

For the field experiments, the hyperspectrometer was mounted on a tripod, which could be adjusted in height and tilt, as well as allowing the camera to be rotated at a required angular speed.

After the images were shot using specially developed software, spatial correction was performed, obtaining layers and further hypercubes.

The appearance of the program is shown in Figure 3.

![Figure 3. Screenshot of the program for obtaining hypercubes.](image)

To configure the hypercubes, you need to specify the zone of interest, angular adjustments and other parameters.

Figure 4 shows a hypercube RGB image of potatoes, onions, beets.
Using the dedicated software, a hyperspectral image of a locality was assembled (via constructing hypercubes). To perform the assembly, pre-calibration of the area of interest in the images. Various types of crops can be detected. Figure 5 depicts spectra of three different crops.

![Figure 5. Spectra obtained using hyperspectral imagery. Crops from top to bottom: beets, onions, potatoes.](image)

Subsequent processing of the derived hyperspectral data was implemented using the ENVI software [12]. The ENVI algorithms were utilized to calculate and map the crop moisture indices. Figure 5 shows the results of processing the hypercubes of potatoes.

![Figure 6. RGB image of the spatial distribution of green mass of potato plantations (a), calculated vegetative indices: NDVI (b), WBI (c).](image)

The value of the WBI index is presented in the form of a histogram in Figure 7.
The maximum of the distribution corresponds to a value of 1.34. The minimum value of the water band index correspond to 0.85 and a maximum of 1.83. For this crop (potatoes) and the state of irrigation. After irrigation, the maximum distribution corresponds to the value of 1.43. The minimum value of the index correspond to 0.86 maximum of 2.00.

![Figure 7](image)

**Figure 7.** The histogram of WBI potatoes.

The maximum of the distribution of dried vegetation corresponds to a value of 1.20. The minimum value of the index correspond to 1.00 and a maximum of 1.39.

As can be seen from Fig. 6, the calculation of vegetative indices is made only in areas occupied by greenery. Where the vegetation is absent or almost completely dried, the WBI index is not determined (Figure 8) and does not participate in determining the average WBI in the histogram.

Also, the WBI index was evaluated in other crops before and after irrigation. The results of the evaluation are presented in Table 2.

![Figure 8](image)

**Figure 8.** RGB image of the spatial distribution of dried vegetation (a), calculated vegetative indices: NDVI (b), WBI (c).

| agricultural crop | WBI Before irrigation (min/max) | WBI After irrigation (min/max) |
|-------------------|---------------------------------|--------------------------------|
| potatoes          | 1.34 (0.85/1.83)                | 1.43 (0.86/2.0)                |
| onion             | 1.38 (0.92/1.85)                | 1.43 (0.94/1.93)               |
| Beet              | 1.25 (0.91/1.6)                 |                                |

Soil moisture before irrigation 25,4 % (80 % HB in the layer 0,4 m), after irrigation soil moisture 31,8 %, или 100 % HB in the layer 0,4 m.

5. Conclusion
The paper presents the results of a study of the prototype of a hyperspectrometer based on the Offner scheme. The results of the study, using the example of calculation of the NDVI and WBI indices, showed its high technical characteristics. The possibility of indirect determination of the moisture
content in the plant mass can be useful for agriculture, the definition of arid and flammable areas remotely. The prototype presented is sufficiently mobile, easy to use.

6. References
[1] Karpeev S, Khonina S, Murdagulov A and Petrov M 2016 *Vestnik of Samara University* 15 197
[2] Rastorguev A, Kharitonov S and Kazanskiy N 2017 *Computer Optics* 41(3) 399 DOI: 10.18287/2412-6179-2017-41-3-399-405
[3] Kazanskiy N, Kharitonov S, Doskolovich L and Pavelyev A 2015 *Computer Optics* 39(1) 70
[4] Skidanov R and Blank V 2016 *Computer Optics* 40(6) 968 DOI: 10.18287/2412-6179-2016-40-6-968-971
[5] Kazanskiy N, Kharitonov S, Karsakov A and Khonina S 2014 *Computer Optics* 38(2) 271
[6] Prieto-Blanco X, González-Nuñez H and de la Fuente R 2011 Off-plane anastigmatic imaging in Offner spectrometers *JOSA A* 28 2332
[7] Karpeev S, Khonina S and de la Fuente R 2011 *Computer Optics* 39(2) 211
[8] Skidanov R and Blank V 2016 *Computer Optics* 40(6) 968 DOI: 10.18287/2412-6179-2016-40-6-968-971
[9] Siliuk O and Katkovskii L 2016 *Sovremennye Problemy Distantionnogo Zondirovaniya Zemli iz Kosmosa* 13 261
[10] CMV4000 (Access mode: http://www.cmosis.com/products/product_detail/cmv4000)
[11] Podlipnov V and Skidanov R 2017 *Computer Optics* 41(6) 869 DOI: 10.18287/2412-6179-2017-41-6-869-874
[12] Kokaly R and Bahr T 2014 *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS)* 807755 1

Acknowledgments
This work was supported by the Federal Agency for Scientific Organizations under agreement No. 007-GZ/Ch3363/26 (experiment) and by Russian Federation Ministry of Education and Science grant number 3.3025.2017/8.9 (technology) and by leading scientific school NSh-6307.2018.8 (element calculation).