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REQUIREMENTS FOR THE PARAMETERS OF IMAGING SPECTROMETERS ARISING FROM THE USED PREPROCESSING METHODS

Valentin Atanassov, Georgi Jelev, Lubomira Kraleva

Space Research Institute – Bulgarian Academy of Sciences,
e-mail: vatanassov@space.bas.bg, gjelev@space.bas.bg, lkraleva@abv.bg

Key words: *imaging spectrometer, spectral data, preliminary processing, requirements for imaging spectrometer characteristics.*

Abstract: *The paper presents one approach used to determine the requirements for the parameters of imaging spectrometers, obtained as a result of preliminary data processing. It considers the various types of non-uniformities in acquired spectral data, the factors influencing their formation and the respective correction methods used during preliminary processing. The results from preliminary processing depend greatly on the systems' characteristics, too. Using this approach, a number of requirements for the image spectrometric systems imposed by the design and construction process of such type of devices have been determined.*

ИЗИСКВАНИЯ КЪМ ПАРАМЕТРИТЕ НА ВИДЕОСПЕКТРОМЕТРИЧНИ СИСТЕМИ, ПРОИЗТИЧАЩИ ОТ ИЗПОЛЗВАНИТЕ МЕТОДИ НА ПРЕДВАРИТЕЛНА ОБРАБОТКА

Валентин Атанасов, Георги Желев, Любомира Кралева

Институт за космически изследвания – Българска академия на науките
e-mail: vatanassov@space.bas.bg, gjelev@space.bas.bg, lkraleva@abv.bg

Ключови думи: *видеоспектрометри, спектрални данни, предварителна обработка, изисквания към характеристики на видеоспектрометри.*

Резюме: *В работата е представен един подход за определяне на изисквания към параметрите на видеоспектрометричните системи, изведени в процеса на предваритeлна обработка на спектрални данни. Разгледани са различните типове нееднородност в получаваните спектрални данни, факторите които влияят за формирането им и съответните методи за корекция, използвани при предварителната обработка. Резултатите от предварителната обработка са в зависимост до голяма степен и от характеристиките на самите системи. Използвайки този подход са определени редица изисквания към параметрите на видеоспектрометричните системи при разработване и конструиране на тези прибори.*

1. Introduction

Remote sensing of the Earth from Space occupies an exclusively important place in the development of modern science and technologies. The application scope of remotely sensed spectral data and images is expanding continuously to involve new areas, such as ecological monitoring of endangered areas, monitoring of the global changes of natural resources and the environment, climate changes etc. The conclusion may be drawn that spectral images make it possible to map with unprecedented accuracy biophysical and biochemical changes in the Earth's surface and atmosphere status.

Imaging spectrometers are a relatively new remote sensing instrument which, during the recent decades, ranked among the top instruments used in these studies. This high ranking is due to the numerous advantages they offer to remote sensing, the most important of which are: complexity of obtained spectral data, i. e. ability to form spectral data in a great number of continuous spectral channels, fast spectral data acquisition rate, high spectral and spatial resolution etc.

But, alongside with these convincing advantages, the data obtained thereby are subject to numerous non-uniformity effects and noises caused by the instruments' operation and data formation principles, the parameters of data-containing storage, the atmospheric conditions under which the data were acquired, the detector's operation mode (usually, a CCD matrix) and the control electronics, the data conversion and storage systems etc. [1,2]. Each case in which non-uniformity has appeared in acquired data requires the adoption and application of an appropriate strategy for preliminary processing of the acquired spectral data. Therefore, the vast information potential of spectral images may be used in subsequent scientific and practical applications only following an appropriate preliminary processing of the initially acquired spectral data.

2. Preliminary processing methods and requirements for imaging spectrometers

In Imaging spectrometers using the principle of light flow dispersion and pushbroom type of scanning, spectral data for each image line with width of one pixel are obtained simultaneously; thus, the whole image is built line by line to make the entire image (Fig.1). The radiation passing through the input slit and corresponding to one line (with width of one pixel) from the surface of the examined object then falls onto a dispersing element, which decomposes it spectrally. The points along the length of the input slit corresponding to one line of the examined object's image are displayed as spectral lines in the imaging spectrometer's spectral plane (Fig.2). They may be recorded by a matrix detector (usually, a CCD matrix). The whole process is repeated after the platform on which the imaging spectrometer is located moves forward along the carrier's track to a distance equal to one spatial resolution element

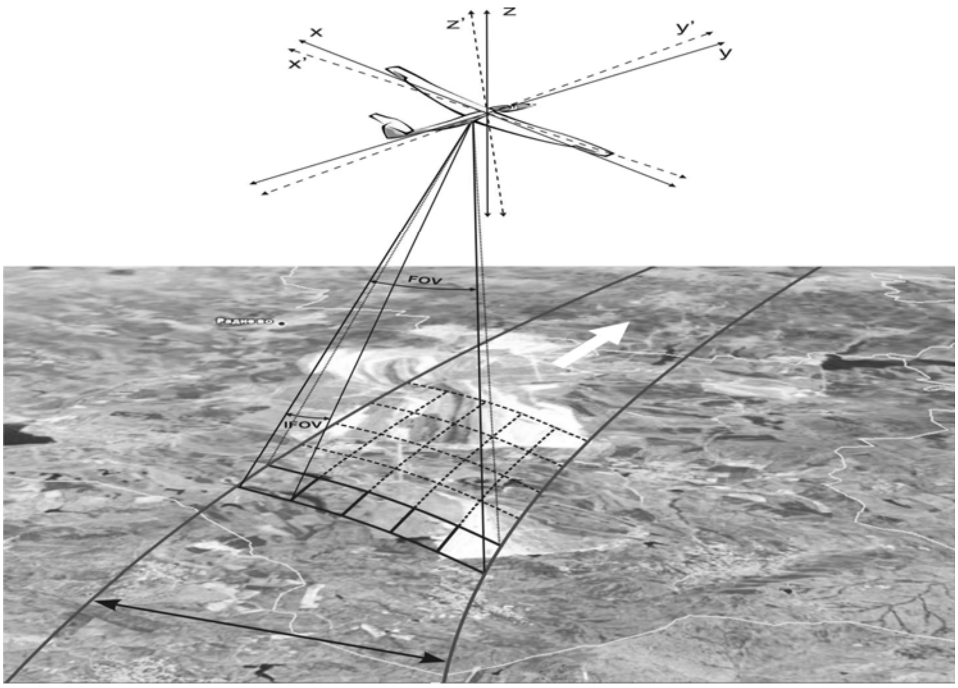

Fig.1. Observation geometry

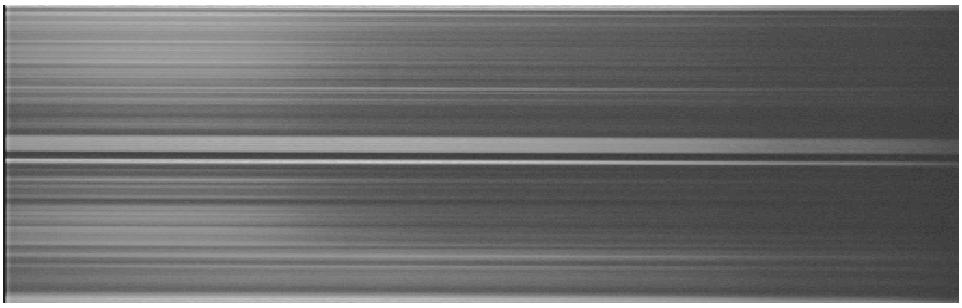

Fig.2. Spectral data for one line of the spectral image

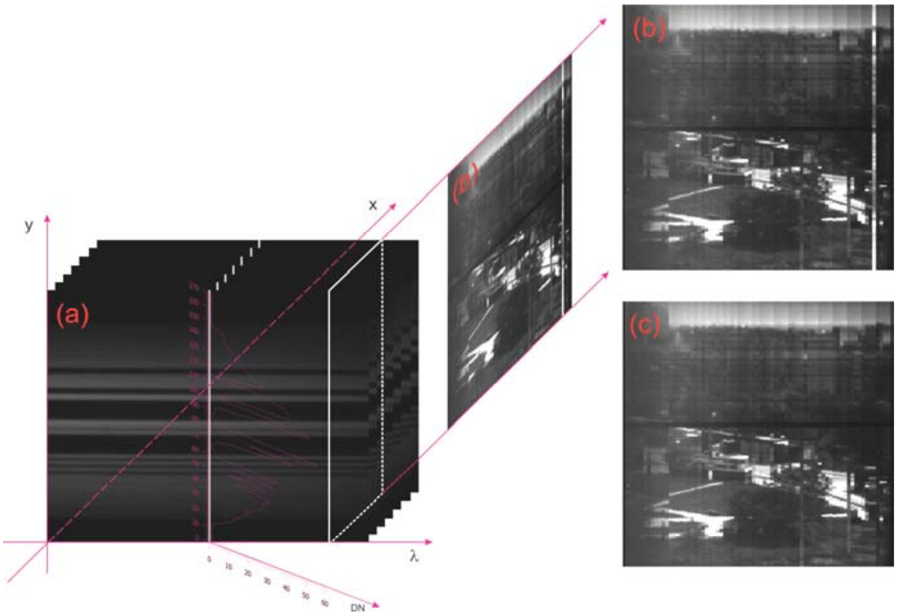

Fig.3. Spectral data forming the so-called "spectral cube" (a), spectral images (b,c).

While conventional images have two coordinate axes, x and y, spectral images also have a third coordinate axis, λ. Thus, the so-called "spectral cube" is formed, in which each plane perpendicular to the spectral axis λ constitutes a spectral image for a definite electromagnetic spectrum wavelength band (Fig.3). Therefore, the spectral image is not built at once, but in series, through a scanning process, as a result of which it is subject to a greater extent to the additional destructive influences of the conditions under which the image is built and which form the image's non-uniformity.

Generally, these non-uniformity effects may be expressed in: missed individual pixels and/or lines in the acquired data resulting from the available bad pixels in the used detector, reading errors, electronics failures, spatial and spectral direction irregularities caused by the generation of the so-called keystone and smile effects induced by the optics etc.

Spectrometric data require correction in the three major aspects – spatial, spectral, and radiometric.

2.1. Spatial non-uniformity

It should be noted that the effects of spatial non-uniformity are manifested to a greater extent by airborne imaging spectrometers, whose platforms are more unstable, so, these instruments are designed to feature greater spatial resolution.

The real imaging spectrometers of the pushbroom type are affected by various effects of spatial non-homogeneity, such as loss of individual pixels, lines or columns, generation of the so-called keystone and smile effects induced by the optics, point spread function non-uniformity etc.

During the correction of spatial non-uniformity, the image within a given pixel must be restored, which is made by choosing an appropriate restoration strategy. The most common image restoration methods are: nearest neighbour resampling, linear interpolation, bilinear interpolation, triangulation method. They have been examined thoroughly and their application for various specific cases is described in literature [3,4].

The chosen restoration method depends on the type of the examined image, as classified by parameters, such as sensor location height, sensor resolution, details of the examined object, whereas the results are nor always unambiguous. Therefore, in studying restoration methods, a somewhat different approach should be applied during the subsequent preprocessing procedures whereas the methods applied on images shall be assessed depending on the correlation links between the elements within the image itself.

Another line along which further studies will proceed is related with the fact that the impact of these methods on the accuracy in the spectral and radiometric aspect has not been paid sufficient attention. Additional studies are needed to assess the impact of spatial restoration methods on the spatial accuracy of spectral images in the spectral and radiometric aspect. For instance, one spatial pixel shift of 0.5 pixels within the image may result in errors of the order of up to 10% in the spectral aspect [5].

To provide for the used restoration methods' effectiveness (least squares mean [LSM] ≤ 2%), the procedures should be performed within a distance of a couple of pixels (≤ 3 pixels), which imposes the following requirements**:**

- to the platforms' stability – deviation between 0.1° and 0.5°;
- to the carrier's velocity – overlapping between 0.1 and 0.3 pixels;
- to the detector's quality – reduction of the number of bad pixels and the size of bad areas, improvement of the uniformity of pixels' response;
- to the control electronics.

2.2. Spectral non-uniformity

The spectral non-uniformity of the instrument's response is determined by the instrument's uniform response over the entire spectral range; usually, it is described by the width (normally, FWHM) (Fig.3) and position (central wavelength λ_n) (Fig.4) of the spectral channels. Therefore, the introduced spectral non-uniformity in the data (axis λ in the spectral cube) is the result of errors in the width and position of the individual channels. It may be caused by the instrument's operation conditions, temperature, pressure, as well as by the stability of the characteristics of the instrument itself.

The instrument's spectral response function is determined in laboratory conditions during the calibration process. The spectral response function is used to describe the instrument's response to input impact – monochrome light [6]. In most cases, the spectral function may be approximated by a Gaussian model or polynomial approximation (Fig.4).

Requirements for reduction of spectral data non-uniformity:

- strict requirements for the instrument's design;
- laboratory calibration;
- envisaging of appropriate procedures for on-board calibration;
- choosing appropriate algorithms for correction of SRF non-uniformities.

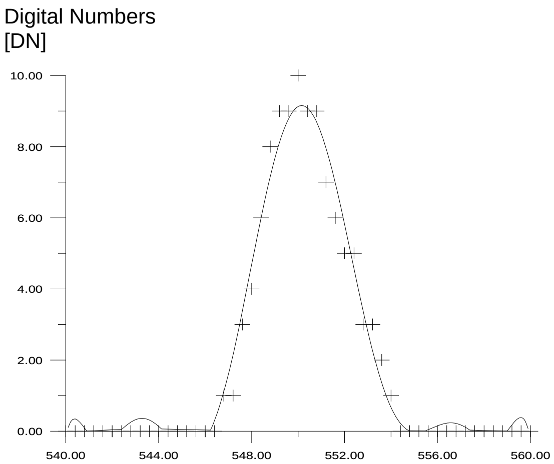

Fig. 3. Spectral response function for the 550nm channel (polynomial approximation) of a videospectrometer ($\Delta\lambda_{in}$1.65nm)

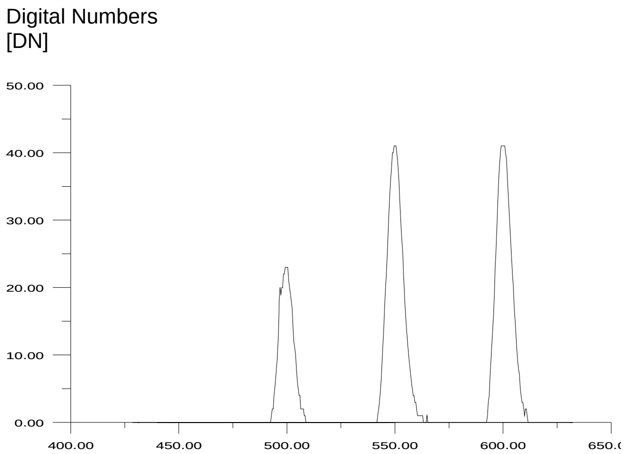

Fig. 4. Determination of the spectral range. Instrument's response to input impacts with central wavelengths λ_0 of 500nm, 550nm and 600nm

It should be noted that the correlation links between the elements along the spectral axis are manifested better.

2.3 Radiometric non-uniformity

Radiometric non-uniformities in these systems are generated by the same above-described **factors**, which determine spatial and spectral non-uniformity:

- the conditions under which the image was acquired: changes in the scene's illumination, atmospheric conditions, observation geometry etc.
- stability of the instrument's response characteristics.

Corrections:

- accounting for the seasonal position of the Sun with respect to the Earth;
- accounting for the distance between the Sun and the Earth.
- accounting for the spectral distribution of solar radiation energy.

Thus, the acquired data are normalized depending on the Sun's illumination conditions.

Another radiometric correction involves transforming the acquired values measured in digital numbers (DN) to represent them in absolute units W/(m^2.sr.nm). This correction is required to make data comparable when reflected radiation has been measured at different times by different instruments.

Requirements:

- detectors: constructed and calibrated in laboratory conductions and featuring linear dependence of the response function on incident spectral radiation;
- stability of the characteristics, so that this linear dependence may be preserved during the experiment's performance;
- envisaged on-board calibration procedures with appropriate hardware;
- The achievement of high spectral and spatial resolution with this type of instruments is also related with the sensors' operation under the conditions of low energy levels of the radiation collected at the sensor's input. The sensors' operation in such modes results in generation of radiometric non-uniformities. Several approaches are available to reduce such radiometric non-uniformities:
- the first of them, naturally, consists in technological improvement of the sensors themselves, improvement of quantum efficiency, reduction of the number of bad pixels, improvement of the pixels' response uniformity;
- another, quite often used approach consists in improvement of sensor integration time, for instance, from x10 μs to x10 ms, whereas the restriction imposed here originates from the instrument's spatial resolution and the carrier's movement velocity, so that the overlaid image be not greater than 0.1 to 0,3 pixels of the examined scene;
- apart from the above restriction, this method also imposes a restriction originating from the dark current levels, which increase with increase of integration time, and the saturation effects in some individual image pixels [7] resulting in the so-called fuzzy image areas whose size should not exceed several pixels;
- the use of TDI instruments, in which sensitivity is increased by summing up several image lines, however, at the expense of resolution.

3. Conclusions

1. The available non-uniformities in acquired spectral data require the application of appropriate preliminary processing of such data. Preliminary processing is a mandatory procedure, if such data will be used for further processing and analysis.

The application of preliminary processing reduces greatly and in certain cases eliminates completely non-uniformity effects on spectral data, which results in increasing the efficiency/cost factor of spectrometric data use.

2. It should be noted that preliminary processing cannot compensate the omissions or inaccuracies made during the instrument's construction. Therefore, based on the performed analysis during preliminary processing, requirements for the specific parameters of spectrometric systems under construction are formulated which should be satisfied.

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