Hyperspectral monitoring AOTF-based apparatus

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Abstract. The apparatus for hyperspectral imaging in visible range is described. The rugged and compact design makes it suitable for unmanned aerial vehicles. The system is capable both for recording the entire spectral-spatial data (“hypercube”) and for selective grabbing the spectral images at characteristic wavelengths. This selective mode provides real-time extracting the most valuable information from the monitoring scene and reduces requirements for operation speed and data storage capacity of processing subsystem. The technical characteristics and basic features of the hyperspectral apparatus are presented and discussed.

1. Introduction

Hyperspectral (HS) monitoring becomes more and more attractive technique for various fundamental and practical applications. And, as usual, new scientific and practical tasks require new instruments for their solution. Spectral tunable systems are now widely spread for environment monitoring, soils classification, foliage taxation, security missions and other applications. The HS analysis is based on the relationships between energy structure of the substances and their spectral characteristics. This approach makes possible the identification of composition complex objects and its structure detection. The spectral-spatial “hypercube” \( I(x,y,\lambda) \) is filled with a series of images detected by the HS instruments¹⁻¹¹.

Hyperspectral imaging is helpful in investigations of land and water surfaces, for cartography, for searching deposits of mineral resources, for inspection of humidity status of the soil (extra saltiness, overwetting), status of the biocenoses, etc. A variety of applications require local monitoring of water basins, in particular, lakes and rivers, as well as sea coastal zone: bays, estuaries, offshore aquatories². Another highly important applications concern the agriculture (vegetation index, crop dynamics, pest activity, etc.).

2. UAV platform for HS monitoring

Unmanned aerial vehicles (UAVs) are an extremely promising and widely used mobile platforms for remote sensing. The UAV platforms fill the gap between ground-based instruments, which are usually attached to agriculture technique, and other air vehicles. UAVs provide complex of properties. They are ideally applicable to the monitoring of the Earth's surface at a given point at the specified moment. Their capabilities could not be achieved with even the entire group of satellites. Modern UAVs enable real-time information transferring from on-board equipment to the control center or its continuous recording on internal storage media. Such systems, unlike satellite instruments, are designed for
personal use and for solving a variety of specialized tasks. Therefore, for such systems, the specific characteristics such as flexibility and prompt retuning are particularly important. Disposition at a drone enables HS systems to perform a wide range of new functions. In this configuration, the volume of collected HS data and the particular procedure of their registration can be specified by the user depending on the task.

![Figure 1](image.png)

**Figure 1.** Earth remote sensing levels (from left to right): ground-level mobile platforms (boats, cars); low-flying platforms (UAV, helicopters); high-altitude platforms (airplanes), out-of-atmosphere platforms (satellites, spaceships).

The capabilities for the spectral information analysis significantly depend on the technical specification of the equipment, the recording procedures, the data processing algorithms, the volume of *a priori* information about the inspected objects, and other factors. The development of optimal analysis algorithms is a specific and complex task. With respect to UAV-based instruments, it is complicated by a number of limitations. The on-board radio modules of modern UAVs include a command receiver and a service information transmitter, which permit to control remotely the flight modes and the information collection. Satellite navigation receivers (GPS or GLONASS) are in use to determine the coordinates, speed, flight altitude and other parameters of the UAV movement. The angles of pitch, yaw and roll are determined using on-board gyroscopes and accelerometers. This provides an accurate georeference of the recorded data and facilitates its processing. Further progress in the field of aviation HS equipment is associated with the development of autonomous small-size spectral devices capable to not only collection of spatially-spectral data, but also to on-board real-time analysis of the data.

The main approaches to express-analysis are related to the objects classification and recognition by their spectral characteristics. It requires a variety of operating modes, in particular, the automatic regular calibration "on board", the ability to select the most informative spectral intervals which vary for different tasks. The developed system is capable both for recording the entire spectral-spatial data ("hypercube") and for selective grabbing the spectral images at characteristic wavelengths. This selective mode provides real-time extracting the most valuable information from the monitored scene and reduces the volume of data being recorded, processed and transmitted. Thus, it significantly facilitates development of the HS apparatus and decreases the resources required.

3. Hyperspectral system

The hyperspectral system was assembled in form of the prototype according to the tandem aberration-compensated scheme of AOTF monochromator\(^2\). The arrangement is presented in fig.2,a. Optical path is Z-shaped for compactness. Some elements (single-board computer, high frequency (HF) computer-
controlled driver, including generator and amplifier, power adaptor or alternatively portable electrical accumulator) are exchangeable and depicted schematically.

Figure 2. AOTF-based hyperspectral prototype device: internal view with structural diagram imposed (a) and detected spectral data (b).

The rugged and compact design makes the system suitable for unmanned aerial vehicles. The basic technical characteristics of AOTF are following: bandwidth is 3-9 nm in the spectral range 0.45-0.85 mcm; input pupil is circle with diameter 8 mm and axially symmetrical field-of-view 3°; diffraction coefficient is 60% for control power 5 W, dimension – 100 cm³, weight – 0.5 kg.

The apparatus demonstrates a series of original and useful features: flexible control, capabilities to data selective extraction, quasi-intellectual operation potentials. One of the most distinctive properties is good image quality. It is due to the original double-AOTF-monochromator scheme, in which the second identical AOTF compensates most of aberrations of the first one. Rather good spectral quality makes possible simple stacking of spectral images and extracting in this way the spectral curves for each pixel. It simplifies data processing because all spectral calculations are performed in point. In contrast, single AOTF devices require elaborated procedures for spectral images spatial processing.

Preliminary testing has demonstrated the ability to solve a wide group of scientific tasks: 1) low-aberration imaging at any wavelength of the spectral range; 2) spectrum and spectral characteristics detectability, and 3) complex spectral-spatial identification.

4. Hyperspectral system prototype evaluation using weed plants

One of the important applications of hyperspectral imaging systems is the remote determination of the species composition of plants. The available weed plant species from the Russia middle zone fields were chosen as the test objects. The spectra of three weed plants are shown on the fig.3 and the difference in their spectra is shown on the fig.4.

The shapes of determined plots are quite similar to real spectral dependence of plant objects. This fact is, first of all, due to negligible deformations of spectral images. Also, it is indirectly proves the adequacy of the adjustment, calibration and data processing procedures.

One of the most important steps in hyperspectral data processing is the separation of the object from the background. We used a neural network for the separation and results (fig.5) demonstrate quite sufficient separation quality for the implementation of subsequent steps of data processing.
Figure 3. Weed plants spectra: 1 – Bromus sterilis; 2 – Plantago lanceolata; 3 – Capsella bursa-pastoris.

Figure 4. Weed plants spectra difference: 1 – Bromus sterilis vs Plantago lanceolata; 2 – Bromus sterilis vs Capsella bursa-pastoris; 3 – Plantago lanceolate vs Capsella bursa-pastoris.

Figure 5. Plant leafs separated from the soil (blue coloured).
5. Conclusion

Thus, the described hyperspectrometer based on tandem AOTF aberration-compensated scheme can be efficient tool for UAV platform as it provides flexible control, variability of detection techniques, high quality of images, their integrity (no need to reconstruct images), satisfactory sizes, weight and power consumption.

Such combination of features makes possible implementation of UAV-platform monitoring instrument with HS capabilities and new features. This system can demonstrate adaptive behavior as the next-target choice is dependent on detected spectral information. The described hyperspectral device is capable to optimize the detection procedure using random-spectral-access technique and fragmentary spectral registration approach and also can efficiently form and correct the flight route.

The analysis of the images received using the hyperspectral system shows the possibility of separating some plants in the image according to their spectra. However, two basic improvements are necessary for improving the quality of objects differentiation and recognition: expansion of the dynamic range and advancement of the analytical techniques. The first task can be solved with use of more sensitive camera and algorithms of sensitivity automatic regulation via acoustic wave power control. The second task has a lot of solutions accounting a priori information and spectral-spatial correlations. The key approach is to determine the characteristic spectral features or indices combination, which are more specific than NDVI and others. This will open the way for prompt objects recognition and their condition inspection by means of selective spectral imaging.

6. References

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