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Preliminary testing of acousto-optical hyperspectrometer for UAV

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Abstract. We presented basic results of the preliminary testing of acousto-optical hyperspectrometer for unmanned aerial vehicle. The image quality is rather high, so the reliable spectra for each spatial element can be reconstructed. The stability of sensing characteristics is studied. It is shown that warming-up of the photodetector as well as of the acousto-optic crystal results in variations of the output signal due to temperature drift. This study places additional requirements upon the system behaviour in changing environment. We discussed results of green leaves testing.

1. Introduction
Hyperspectral surveying from flying vehicle is an effective technology for studying and monitoring the Earth surface [1,2]. Hyperspectral devices, located on the unmanned aerial vehicle (UAV), open new opportunities for monitoring the underlying scenes. In particular, they make it possible to realize the concept of remote monitoring by means of a personal device according to individual assignment. It can be suitable for such important tasks as prompt identification of the shoots of agriculture plants [3] and fallow lands [4].

Hyperspectral devices based on tunable optical filters are best suited to this concept. They are capable of optimization of the monitoring procedure for specific tasks by means of quick change of the algorithm according to the information received. In addition, such systems are suitable for prompt extraction of useful information - just on board in real time.

We designed and implemented such a device based on acousto-optical tunable filters (AOTF) [5].

We earlier demonstrated that for small-size UAVs, the approach based on diffraction gratings [6] is difficult to implement, and therefore an appropriate hyperspectrometer require tools for selective detection of spectral data and methods for their rapid analysis. Such HS device can be implemented with use of acousto-optical tunable filters (AOTF) [7,8], which provide fast and random spectral access. These active optical elements are capable to a flexible choice of the spectral information [9]. Below, the concept of the AOTF-based UAV-mounted HS system is presented, the structure of the HS system is considered, the characteristics of the AOTF monochromator are described, and also the technical problems to be solved are discussed.
The next stage of the work was the analysis of the quality of images detected as this property influences directly on the analysis reliability and can complicates it.

The following characteristics were tested in the work:
- data reproducibility, short-term and long-term stability, the uniformity of the signal over the field of view;
- image quality;
- validity of spectral reconstruction from the series of spectral images.

Below, we describe the hyperspectral device, consider the draft concept of its operation and present the results of the preliminary testing in laboratory conditions. Then some conclusions and suggestions are formulated.

2. Device structure and characteristics

The developed hyperspectral system is based on original design [10] and use the compact double AOTF monochromator [11]. In addition to the hyperspectral survey channel, it implements an ordinary, color channel for recording RGB images (figure 1).

![Figure 1. Structural diagram of the AO hyperspectrometer: 1- object; 2, 5, 7 - input and output lenses; 3 - beam splitter; 4 - AO monochromator; 6 - monochrome video camera; 8 – RGB video camera; 9 - AOTF control module; 10 - computer; 11 - hyperspectral images; 12 - color image.](image)

The wavelength $\lambda$ of the radiation selected by the AO filter is driven by the program operating at the personal computer. The radiation from the object under investigation is collected by the input optical system and after the spectral filtration it is focused on the photodetector array. Images from cameras are displayed on the monitor separately or in the superimposed mode and saved for further processing.

The monochromator used in the AO system provides double filtration in the distortion compensated mode [5]. It provides the following characteristics:

| Technical characteristics | Value |
|---------------------------|-------|
| Optical scheme            | Two non-collinear AOTFs |
| Spectral range            | 450 ÷ 850 nm |
| Spectral resolution       | 5 nm at 633 nm |
| Transmission coefficient  | 60% at 633 nm |
| Diameter of entrance pupil| 8 mm |
| Angle aperture            | $3\degree$ |
| Number of resolvable lines| $320 \times 250$ pairs |
| Power consumption         | < 5 W |
| Dimensions                | $12 \times 4 \times 3$ cm$^3$ |
| Weight                    | < 500 g |

For sampling spectral images, there were used a monochrome camera Allied Vision Manta G419-NIR with following characteristics:
sensor size – 1”;
pixel size – 5.5×5.5 mcm;
pixel number – 2048×2048.
We use just central region (1000×1000) to avoid vignetting.

3. Testing
As was stated above, the testing was performed in three stages focusing on (1) consistency with general image detection requirements, (2) image quality and (3) spectral reproduction. All experiments were conducted in the same configuration (figure 2).

![Figure 2](image)

**Figure 2.** The testing configuration. 1 – hyperspectrometer, 2 – object, 3 – optical source. Working distance $L = 1.5$ m.

First testing stage includes series of experiments of estimation following properties: data reproducibility, short-term and long-term stability, the uniformity of the signal over the field of view. For checking the uniformity of the brightness of the image, the image was divided into classes and the false-colour picture (figure 3, a) clearly demonstrates the circular symmetry of the image that is caused by vignetting effect.

![Figure 3](image)

**Figure 3.** The broken into classes image of three freshly cut geranium sheets: a – unprocessed spectral image; b – brightness-equalized (normalized) image.

After normalization, the image became more homogeneous (figure 3, b). Therefore, the preliminary calibration was adequate.

Analysis of noise characteristics of monochrome camera photodetector reveals that signal-to-noise ratio is inhomogeneous across the field of view and in fact, the entire field of the photodetector breaks up into 4 rectangular zones with different sensitivity characteristics.

The conducted researches have shown that there are a number of factors, which can negatively influence the analysis of hyperspectral information.

They are associated with the optical system (vignetting, pollution), the video camera (heterogeneity of the matrix), and the AOTF (spectral calibration).
Thus, to effectively use the hyperspectral system in monitoring tasks, it is necessary to eliminate these problems in hardware or to develop methods for correcting the effect of these factors.

The carried out researches have shown: the repeatability of the received data is satisfactory, temperature distortions must be corrected, the optical system should be optimized, satisfactory for the tasks in view.

The second series of experiments was aimed at image quality testing. It based both optical test patterns and real objects like leaves.

![Figure 4. Spectral images of test patterns of two types in red region.](image)

According to the test patterns images (figure 4) the number of resolvable elements is approximately 700×700. There are a little (1%) discrepancy of scaling factors along horizontal and vertical directions in grid at figure 4, a. However, the scaling factors ration in grid at figure 4, b equals to 1 with accuracy not more than 0,5%. Probably it is due to lateral location of the first grid and indicates the presence of high-order (non-linear) distortions. (Dark marks in picture caused by unavoidable impurities at the detection sensor of the camera.)

![Figure 5. Spectral images of fresh picked leaves in red spectral region: a – green leave (1) and yellowed leave (2) of the same plant (hibiscus) at wavelength 716 nm, b – Lime (3) and Chestnut (4) leaves at wavelength 724 nm, c – spectra of leaves in the spectral region 500-800 nm.](image)
As can be seen from the spectral images of vegetation (figure 5), the hyperspectrometer differentiates certainly fresh and faded leaves, whereas healthy leaves of different sorts of trees looks quite similar according to it coloration. As well, their spectra being different also have many similarities. This fact is suitable for quick estimation of the projective cover factor as all the green vegetation produce the same spectral effect.

Next pair of experiments concern on spectral properties of the hyperspectrometer. We use specific objects of different structure as an example of rubbish as well as spectral test patterns.

Using a series of spectral images (figure 6), we reconstructed the spectrum of each element in the spectral region 500-800 nm. The analysis reveals the fact that many materials having green hue exhibit rather similar spectral curves. Probably, it is due to the same colouring agent used.

The spectra (figure 7) are in good correspondence with the colour of each element.

4. Conclusion
The developed HS system can be used to monitor local areas from th bard UAV coast and can be launched from the shore as well as from the ship or boat.

There is still a number of problems to be solved: to stabilize the optical system of the hyperspectrometer (by mechanical, electronic, optic, software and other tools); to develop methods for spectral optimization and adaptation of the monitoring procedure; to improve and adapt methods of detection and identification of objects by their spectral characteristics, which are now actively developed [12]; to develop the structure of the management and decision-making system, including
communications with the user; to solve the issues of equipment protection from the environmental influence. The suggestions to resolved these problems were formulated.

Nevertheless, in general, tests demonstrated applicability of AO hyperspectrometer to monitoring environment. The device is ready to the next phase of testing, which is out-of-door experiments.

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