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HYPER SPECTROMETER BASED ON AN ACOUSTO-OPTIC TUNABLE FILTERS FOR UAVS

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ABSTRACT

The problem of creating a hyper spectral opto-electronic system for observing natural and artificial objects by means of unmanned aerial vehicles (UAV) is considered. The structure and composition of the system that solves this problem are described. It is based on acousto-optic filters. The results of laboratory testing of the hyper spectrometer are presented.

Keywords: hyper spectral imaging, tuneable acousto-optic filters, remote sensing

Hyper spectral systems (HS), providing synchronous registration of spectral data and its spatial distribution, have a high potential for application in the field of earth surface monitoring, natural resources and economic activity [1–2]. Systems and methods that can provide optical information from a particular location at a particular time are now becoming increasingly valuable. The location of the recording system on the aircraft is most effective for regular and operational monitoring of land plots. The use of compact UAVs for hyper spectrometer basing increases the mobility of the system and allows obtaining data more quickly [3–4].

To date, a variety of schemes and designs of hyper spectral imaging systems have been developed. According to the principle of spectral selection they can be divided into two large classes:

- Systems with spatial decomposition of the spectrum;
- Systems that have an optical filter (monochromator) that is tuneable by wavelength.

However, the developed systems don't yet adequately meet all the requirements for UAV devices. These requirements can be conditionally divided into several groups, such as physical (image registration in a wide spectral range with a large number of spatially solvable elements in the frame at two coordinates with a minimum level of aberrations), structural (sufficiently small overall dimensions and energy consumption, resistance to external influences), and methodical (the possibility of obtaining information about the objects under study in real time).

The approach based on the spatial decomposition of the spectrum is difficult to realize on the UAV platform, since it requires uniform rectilinear motion. Therefore, for such devices a tuneable monochromator is preferable capable of registering spectrally contrasting images of objects. Methods of rapid analysis of incoming optical information are necessary for the operational decision on the further actions of the system, in particular, on the trajectory of the UAV. Selective spectral data recording tools can be particularly effective. They can be implemented on the basis of tuneable acousto-optic (AO) filters [5], providing fast and arbitrary spectral access, which allow flexible selection of the spectrum of the recorded information.

The composition and structure of a HS, the features and characteristics of its key element (AO filter), the principles of its operation and the results of laboratory testing are described below.

SYSTEM STRUCTURE

A double compact AO monochromator is used in the developed hyper spectrometer as a spectral element [6]. It consists of two identical AO cells, deployed by 180°, which provides compensation for the majority of spatial-spectral distortions [7]. In each of these cells the incoming luminous flux is polarized by reflecting it from one of the faces of the anisotropic TeO_2 crystal. This scheme without a polarizer makes the design of the monochromator simpler and allows reducing light losses during the passage of polarizer.

The optical scheme of the developed AO hyper spectrometer is presented in Fig. 1. The radiation from the object under study 1 is directed by means of the telephoto lens 2 to the input of the AO monochromator. The beam splitter 3, which remove 10 % of the radiation to the colour video camera 5, is installed in front of it. The monochromator consists of two identical non-collinear rotated 180° cells 6 and 8 and the polarizer 7 located between them. On the oblique face of cell 6 the input stream is divided by polarization. Further, the optical radiation, whose wavelength corresponds with the exact fulfilment of synchronism conditions, diffracts on the lattice created by the acoustic wave. As a result, the polarization of the radiation changes the orientation. The radiation of other wavelengths passes through the AO cell without changes and is cut off by the polarizer 7. Similarly, in the AO cell 8 the light diffraction repeats with the polarization change, which provides additional radiation filtration. The selection of the filtered radiation takes place on the oblique face of the cell 8. Then it is focused by the lens 10 on the sensor of the monochrome video camera 11. It is possible to reconstruct the diffraction gratings period and to obtain an image of the object at an arbitrarily given wavelength by changing the frequency of acoustic waves using a high-frequency generator located in the control unit 9. The signal from the video camera 11 enters the computer, where it is processed with the help of specialized software and archived for further analysis by other methods.

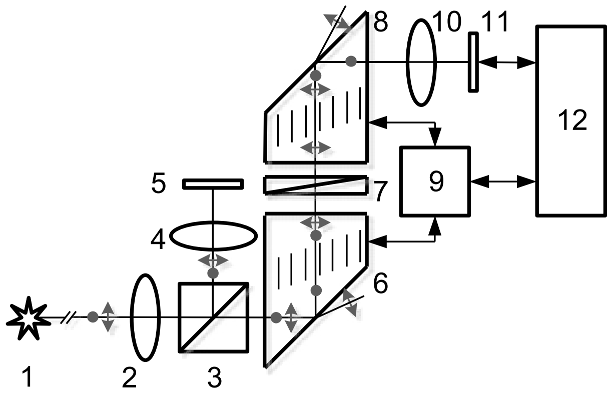


Fig. 1. Block diagram of the AO hyper spectrometer:
1– object under study; 2 – input lens; 3 – light splitter; 4, 10 – lenses;
5 – colour video camera; 6, 8 – AO cells; 7 – polarizer;
9 – control unit (generator); 11 – monochrome video camera; 12 – computer;
light polarization is indicated on the rays, and ultrasonic diffraction gratings are depicted in AO cells

The main elements of the hyper spectral system are shown in Fig. 2. They have the following characteristics: the spectral range is (450–850) nm; the bandwidth is Dl = 5 nm at the wavelength l = 633 nm, which corresponds to the transmission window at optical frequencies 100 cm^{-1} and approximately 100 wavelength-resolvable channels; the transmittance is 60 % (at the wavelength 633 nm); the entrance pupil is 8 mm; the field of view is 3°×3°; the spatial resolution is 600×500 elements; the power consumption is not more than 5 W; the weight of the system operating part (with optics but without the

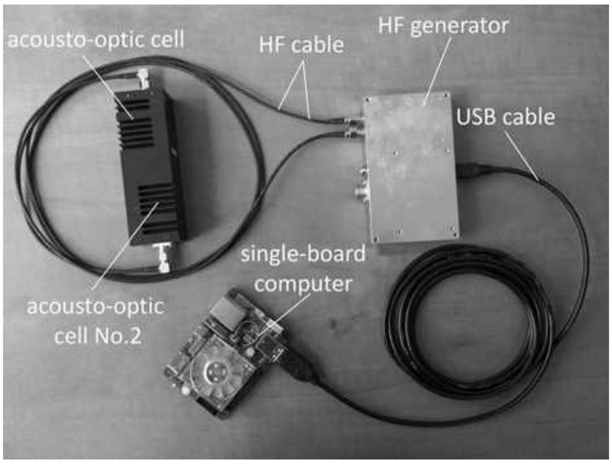
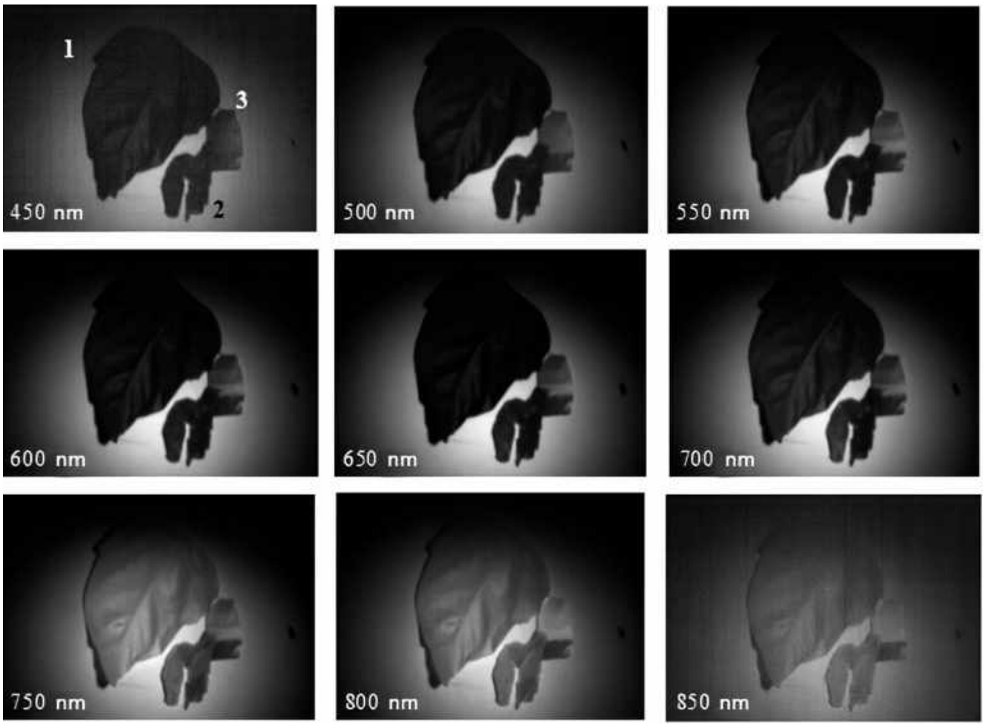
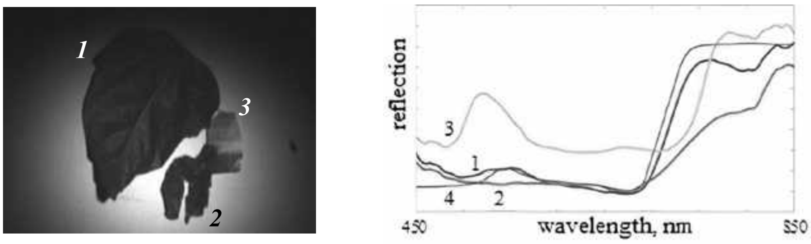


Fig. 2. Basic elements of the hyper spectrometer model



a)



a) *c)*

Fig. 3. Registered images of objects: green geranium leaf (1), kelp (2), green cardboard (3): spectral (a) and black-and-white (b) images, as well as reflection spectra (b) determined from spectral images in comparison with poplar leaf (4), [16]

computer) is 1.2 kg; the length is 20 cm; the control is performed by USB2.0.

The characteristics of the system are generally not worse than those of other systems of a similar purpose based on the diffraction grating [8–9], including using prisms [10], based on a Fabry-Perot interferometer [11], based on a Fourier-transform spectrometer [12] and on a multispectral ("multi--aperture") matrix detector [13]. Such systems have the following characteristics: the spectral range is l_{max}/l_{min}=1.5–2.5; the number of spectral channels is from several tens to several hundreds and the number of solvable elements by angle (space) is 100–1000. At the same time, their mass and power consumption are not lower than those of the AO system: (1–10) kg and (10–20) W. Some systems have a wide operating range, for example, HYDICE and AVIRIS have (0.4–2.5) μm, and substantially include a set of devices having a total mass more than 300 kg and power consumption more than 100 W [14, 15]. Thus, the hyper spectrometer based on the AO filter is one of the most effective technical solutions suitable for UAVs.

TESTING

Two plant objects (fresh leaf of tree and dried kelp) and one artificial (a piece of painted cardboard) were chosen for comparison. The things had a close colour shade – green. Registration of spectral images of these objects and determination of their spectral characteristics were made to illustrate the performance of the hyper spectrometer model. Fig. 3 shows the spectral images of these objects in the wavelength range from 450 nm to 850 nm in 50 nm steps with a halogen lamp illumination.

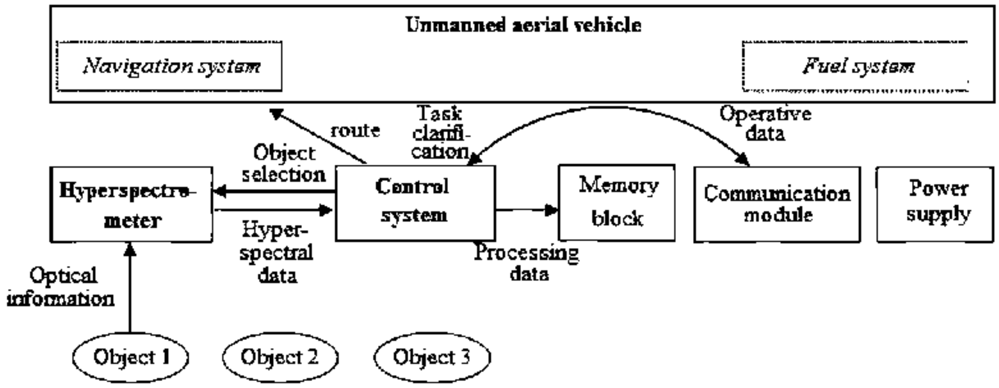


Fig. 4. Control scheme for a UAV with a hyper spectrometer

The mutual contrast of the object elements at different wavelengths varies significantly. For comparison, Fig. 3, b shows the image obtained by the same monochrome camera without the AO filter (wideband image). The obtained hyper spectral data made it possible to identify reflection spectra (Fig. 3c), the general form of which is consistent with the reference data [16–17].

SYSTEM OPERATION PRINCIPLES

The main task of the system is the implementation of personalized hyper spectral monitoring. This means that the object under study and the type of task are determined directly by the user of the system and can be changed considerably from case to case. To do this, it is necessary to provide the possibility of clarifying or even changing the task directly during the flight. Accordingly, all elements of the system must be manageable and customizable. Such a system can contain the following three main modules: 1) a platform that provides its movement and positioning in space; 2) a hyper spectrometer that collects optical information; 3) the control device that forms the task execution algorithm in accordance with the given goal, and also taking into account the received information and the current situation. In addition, the system can have additional modules, for example, a communication module, an information storage unit and other devices that perform specialized functions. However, when the system is based on the UAV, neither the amount of available memory and computing resources, nor the bandwidth of the communication channel allow to completely process the flow of spectral information that the hyper spectrometer can provide, and therefore it is necessary to ensure the effective selection of useful information for obtaining real-time monitoring results.

The main principles on which the described system should be built, designed to solve various tasks based on the hyper spectral imaging, are the following: flexibility, manageability, the ability to quickly perform the analysis of recorded data, the ability to work in an autonomous mode and quickly reorient to other tasks. In the future, the system can be made adaptive, that is, quickly and independently reacting to the situation change.

To realize this concept, the carrier must be compact and easily manageable and allow various types of motion. The hyper spectrometer and control device must consume a minimum amount of resources.

This corresponds to a technical solution in the form of a compact multicopter and an image spectrometer based on controlled AO filters.

The multicopter is able to provide movement at various (even sufficiently low) speed, as well as modes of hovering and controlling the height of observation. The hyper spectrometer based on AO filters allows to implement an arbitrary spectral imaging algorithm: with any step in the spectrum, any sequence of wavelengths, varying exposure and varying spatial resolution, determined by observation height, angular field of view and the number of solvable positions.

The main tasks that the hyper spectrometer should solve: objects detection, their selection, identification, state control. For this purpose, however, effective methods of spectral-spatial distribution analysis should be developed and implemented in the form of software modules. One of the key approaches is the reduction of the full array of hyperspectral data, which requires both a long recording time and large computing powers, to a minimally necessary set of data, namely, a set of spectral images obtained at the most informative wavelengths from the point of view of the problem being solved. Such an approach realizes the method of fragmentary spectral registration, formulated and substantiated earlier for problems of this type [18].

The control device can be implemented on the basis of a compact computer that performs several hierarchically ordered functions: from controlling the AO monochromator and processing of hyperspectral data to analyzing the situation and making decisions, including those relating to the trajectory and flight mode. Control commands must be transferred to all elements of the system, including a separate independent flight management tool. The entire task must be divided by the control device into stages, each of which contains a description of the movement type, the measurement (observation) mode, the task of analysis and possible reactions of the system. When going to the next stage, all information received at the current moment should be taken into account, and therefore the task can be executed in different scenarios (branching algorithm).

The scheme of data exchange between the main components of the developed HS is shown in Fig. 4.

CONCLUSION

The developed hyper spectral device has physical and technical properties that make it possible to use it effectively on UAVs: compact size, low power consumption, the possibility of simultaneously obtaining spectral and colour images in a wide enough range of wavelengths (450–850) nm with high spectral (~5 nm) and spatial (600–500 elements) resolution, as well as compensation of chromatic aberrations. It enables recognition of images, both in spectrum and in the form of elements in the mode of their spectral contrast. In the future, it is planned to test it on site and implement real-time object recognition algorithms.

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