Application of airborne video-spectral complex for estimating the damages of forest territories

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Abstract – The technique of spectra and images acquisition using VSC-2 from the board of helicopter and the results of data processing with the allocation of the areas of various tree species, drying out fir-groves, glades and burnt areas are described. The device records 4-6 spectra per one spectrozone image of a scene. On the basis of the statistical analysis the technique of obtaining a spectrum in any point of spectrozone image is developed using reference points for which the spectra are known. The technique of construction of image mosaic and spectra to image registration were also developed.

Keywords: aerial shooting, spectrozone image, spectral signature, mosaic, color contrast, supervised classification, dried fir groves.

1. INTRODUCTION

The airborne videospectral complex VSC-2 is intended for operative control of forests from the board of aircrafts and helicopters (Belyaev et al. 2001a, b). Most of the research works on the remote sensing of vegetation populations usually take the data recorded from space. Some researchers use data acquired with devices placed on airplanes (Vanderbilt et al. 1998, Puumalainen and Susila 1999, Gougeon 1997). Airborne data acquisitions come over satellite based missions (Cetin 2004) because the user has influence on the mission in terms of time schedules, flight line arrangements, calibration measurements, spectral/spatial resolutions, and acceptable weather conditions. The highest accuracy in terms of classification of individual species was obtained using the airborne devices, such as AVIRIS.

At the same time there are practically no research data acquired with the help of helicopter-based devices. Such research has both doubtless advantages, and some disadvantages. Despite the more non-stability of helicopter axes in comparing with airplane the helicopter can fly with less velocity, can provide better selectivity of a scene, more mobility, less height, better spatial resolutions, can fly under the clouds. You have also the opportunity to change spectral filters for spectrozone image acquisition even during the flight. However it has some drawbacks if the gyro-stabilization platform is not used (as it is the case with VSC-2), the main is instability of device optical axis direction. This complicates the construction of area mosaics of images. In some cases the intra-track and especially inter-track gaps can take place.

Compact Airborne Spectrographic Imager CASI-2 (ITRES 2002) is the most similar to VSC-2 system as to its functional purpose, although it is a push-broom type scanner of object plane. It makes it possible to acquire images in many spectral channels simultaneously. While the VSC-2 is a scanner of image plane and includes four TV CCD cameras. In addition the VSC-2 can acquire the polarization images (for the first three Stockes parameters) in any chosen spectral channel. So, VSC-2 is capable to acquire only three spectrozone (or polarization) images simultaneously. However, this disadvantage has been eliminated by developing the technique (Katkovsky et al. 2004), applying of which results in the data obtained by VSC-2 become practically equivalent in its information content to the data of video-spectrometer with dozens of channels. At the same time very often three spectral zones are enough to get a good identification of vegetation species (Thenkabail et al. 2000, Gong et al. 2003). But in contrast to automatic digital classification, based on the images recorded with hyper-spectral digital camera, in this case some manual processing is required with regard to size, location, texture, context, etc. of the images to ensure a more accurate classification (Ellis et al. 2001). Though many new algorithms have been lately developed for hyper-spectral data classification, traditional pixel-based classification algorithms are also often used (Lumme 2004) as they yield results not worse, than more complex and advanced methods.
Remote measurements using VSC-2 from a Mi-2 helicopter have been carried out. Processing techniques allow for diagnostics of forests pathology, identification and mapping of the forest areas affected by vermin, illnesses, fires, wind falls, clearings, etc.

2. THE VIDEO-SPECTRAL COMPLEX VSC-2 AND DATA ACQUISITION

VSC-2 includes the external block of optical detector modules and onboard managing computer. The external block of optical modules is intended for installation on an external bracket of a helicopter. The external block includes high resolution spectropolarimeter of visible and near IR spectral ranges MS-09, the block of spectrozone-polarization shooting BSPS-01, the surveying color television camera ("Sony" OS-75D) and the device of exact geographical positioning GARMIN GPS-35LPH (the interval of updating the navigation data is 1 s).

Spectropolarimeter MS-09 records the spectra of reflected radiation with the spectral resolution of ~2 nm in visible and near IR spectral ranges (1024 channels in the region of 350-1150 nm). Spectropolarimeter includes also polarization filter block. The device records 4-6 spectra per one spectrozone image of a scene. These spectra originate from the areas with the size of near 2 x 2 pixels located along the axis of current image in the direction of flight with time gaps of 2-3 s.

The BSPS-01 is intended for simultaneous acquisition of digitized spectrozone images (in TV format) within three various narrow (30 – 60 nm) spectral channels (chosen from

12 possible ones) in a range of 350-1150 nm with fixing of various planes of linear polarization in each spectral channel.

For the case study we chose three sites: forests of Stoubtsy (Stolbtsy), Maladzechna (Molodechno) and Navahradak's (Novogrudok) regions in Western Belarus. The choice was dictated by a number of reasons. First, each of the sites has different tree species. Second, areas with drying fir groves, infested by beetles (*Ips typographus*), trees affected by root moulds and sponges, and also traces of fires have been found within the sites by ground inspections. Acquisition has been carried out from various altitudes from 200 up to 1000 meters. The spatial resolution, determined by both TV camera and the digitizing device (the resolution of digitizing board is less than that of a CCD camera), varied from 0.38 m up to 1.9 m depending on altitudes. The velocity of a helicopter was maintained near 90 km/h. The best results in terms of recognizing and contrasting of vegetation were obtained using optical filters with the pass band centres of 560, 655, 820 nm. The choice of these bands is based on the results of information importance research of spectral channels during laboratory experiments (Belyaev et al. 2001c).

3. DATA PROCESSING

3.1 Preliminary processing.

Both the digitized video-images acquired by the surveying TV camera, and spectrozone images have been processed. The TV images are used as auxiliary ones in order to simplify the frame to frame registration of the spectrozone images, and to the borders grid of quarters and apportionments of Belarus GIS 'Forest resources'. This is made possible by a wider field of view of the surveying television camera and by the natural colors of surveying images. The surveying standard (R,G,B) images can also be used for thematic processing and classification of forest objects as spectrozone ones.

The geographical coordinates, which are given out by GPS, could facilitate the registration of images to GIS or maps. However, GIS 'Forest resources' is not registered with geographical coordinates, and has only local relative coordinates in the framework of each forest area (timber enterprise). This complicates creation of large area mosaics.

The various levels of light illumination of the Earth surface on the different frames and lines of shooting is a specific problem of almost all remote measurements in which the absolute values of spectral brightness are measured. Recording illuminating spectra is necessary for getting the images of spectral reflectance coefficients. However various sites of the Earth surface (even within one frame) can be shaded by the clouds of various optical thicknesses creating different illuminations of the sites that is hard to take into account. Many image processing software packages have functions for aligning the images brightness (for example, by adjustment of brightness histograms). However such smoothing can result in distortion of true relative brightness values of various objects that is not always desirable for thematic processing. One of the solutions for the problem is using classification methods whose results do not depend on the level of illumination (only the form of a spectral curve is analyzed, for example, Spectral Angle Mapper classifier). We offer the next simple way of setting equal illumination in the chain of the images overlapped in pairs. The program searches for the same set of pixels in the two overlapping images. These pixels brightness values are equalized with multiplication of the second image by the average brightness relation of those pixels in the first and second images. Then this operation is repeated for the following pair where the first image is the second one of the previous pair, etc. Such procedure does not change relative brightness values of one frame in contrast to histogram's adjustment and equalizes irradiances in all frames.

After preliminary processing the forest images the area mosaics, which were registered with the corresponding vector maps of GIS 'Forest resources' with borders of quarters and apportionments were obtained. For not overlapped (or overlapped in the separate frames) lines the registration of each flight line to the border grid of GIS 'Forest resources' was carried out at first, and then the area mosaic was constructed using the images of separate lines.

3.2. Thematic processing.

The initial data for classification are either the area geo-referenced mosaics of images acquired with the surveying television camera, or the area mosaics of spectrozone images. In some cases the classification on color attributes (this is a visual classification of pseudo-color images) may be applied as initial approach. It should be mentioned that different tree species and tree conditions are sharply allocated by color on synthesized images. For example, apportionment, where the fir-trees occupy all 100% of the area, looks definitely darker (green), than apportionment, where these trees occupy 90% of the area. Also, if composite image of channels 560, 820, 655 nm has reddish-lilac hue spots, it testifies, as it is known from our experience, that these spots contain the trees which are damaged or are drying out. This was confirmed by subsequent ground inspections. Color characteristics of various classes, which correspond to the color image synthesized through R, G, B from spectrozone images in channels 560, 820, 655 nm, were received and described. The afforestation inspection data were taken from the database of GIS 'Forest resources'.

The visual classification is carried out, as a rule, at the first stage of analysis and it allows for a preliminary determination of an approximate number of classes and their spatial placement. This information can be used for defining the regions of interest (training samples). What visual classification does not do is to determine spatial borders of classes, their areas and statistical parameters with necessary accuracy. A more accurate thematic classification is provided by a computer pixel-based supervised classification. Good results have been obtained with the method of the maximum likelihood classification. As an example the results of the thematic supervised classification using the method of the maximum likelihood are shown on Fig. 1 for fragment of forest site of Stoubtsy (Stolbtsy) images. Training samples were defined inside small areas of relatively homogeneous apportionments using the database of GIS 'Forest resources'. There practically were not unclassified pixels on classification fragments of the images. Taking into account that a high enough threshold probability (0.98) of referencing the pixel to any class has been set, one could say that the number of classes and their training samples have been determined quite adequately and accurately.

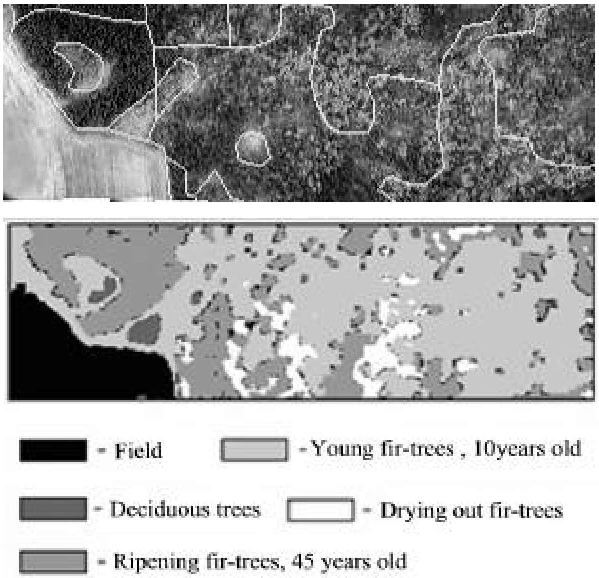

Figure 1. Initial image fragment and the result of his thematic classification on 5 classes.

Mapping the burned forest areas and assessing forest fire consequences is not less important than detecting active fires. Estimating the damages caused by the loss of the forest stands using images acquired from airborne shootings, is more authentic and inexpensive way than any estimations done by using space images or ground inspections. Site near Navahradak (Novogrudok) was selected as it had been recently damaged by forest fire. The study has helped solve the problem of allocation and mapping of forest fire areas and develop a procedure for estimating the degree of damage caused by forest fires. The same channels 560, 820, 655 nm were used to clearly distinguish the burned areas from other natural objects, such as sparse growths of trees, peatbogs, glades and bogs. The analysis of accompanying spectra (the examples of the spectra corresponding to various types of the objects are given on figure 2) consists also in rejecting the unnecessary classes of objects obtained at the first stage of

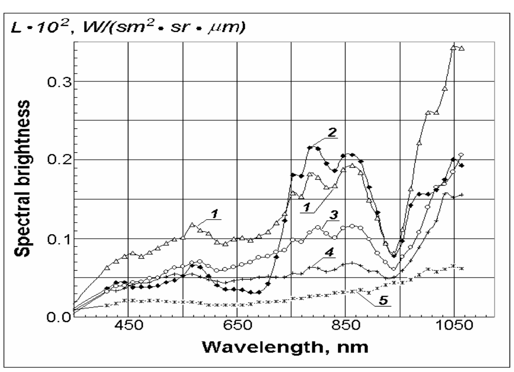

Figure 2. Brightness spectra received by spectroradiometer ? S-09 for various types of surfaces: *1*–field vegetation; *2*–healthy fir-tree forest; *3, 4*–fir-tree forest with the different degrees of trees burning-out; *5*–completely burned-out forest.

classification (unsupervised), and in choosing the most reliably established small sites of burnings as training area samples for the subsequent supervised classification. After determining the absolute image pixel size projection on the ground the burned forest area was calculated.

3.3. Spectral and spatial data interpolation

For obtaining the spectrozone images in any given number of narrow spectral channels using shootings with 3-channel spectrozone camera coupled with spectroradiometer which measures several spectra on a frame the technique of spectral-spatial interpolation was developed. The technique is based on existing high pair linear correlations of reflected spectral radiation on various wavelengths for soil-vegetation objects (Katkovsky et al. 2004). It means that spectral brightness in many spectral regions might me expressed through some independent reference wavelengths, namely: 560, 655 and 820 nm, which are used in VSC-2. Using these three channels the spectrum in arbitrary spatial point can be completely reproduced. To achieve this purpose it was necessary to solve additionally the following two problems: to carry out an absolute energy calibration of BSPS-01 for recalculating the image brightness from DN into absolute brightness units for joint processing with spectra; to develop the procedure and algorithm of spatial registration of spectra to corresponding points of images using the geographical and time coordinates from GPS for automatic constructing a mosaic template.

Linear relation is statistically valid for two brightness's in two spectral channels with high pair linear correlation: λ (designated a narrow spectral channel of the spectroradiometer, near 1 nm in width) and ? λ' (designated a broadband spectral channel corresponding to BSPS-01 and equal to 30-40 nm in width centered at λ'):

$$S_\lambda(x,y) = k(\lambda,\Delta\lambda')S_{\Delta\lambda'}(x,y) + b(\lambda,\Delta\lambda') \qquad (1)$$

were $S_\lambda(x,y)$ – value of brightness in spatial point (x,y) (corresponding to spectroradiometer field of view) of the image, $S_{\Delta\lambda'}$ - brightness value measured by spectroradiometer and integrated through the channel ? λ', $k(\lambda,\Delta\lambda')$, $b(\lambda,\Delta\lambda')$ – unknown coefficients which are supposed do not depend on spatial coordinates (averaged on coordinates). Coefficients $k(\lambda,\Delta\lambda')$, $b(\lambda,\Delta\lambda')$ for any pair of narrow and broadband channels $(\lambda,\Delta\lambda')$ with high correlation can be calculated using representative enough sampling of spectra, acquired along flight tracks and having the value of NDVI vegetation index close enough (in a range given in advance) to NDVI value (calculated with BSPS data) in the point, for which spectrum will be calculated. Using the basic idea, expressed by formula (1), we get the estimation of a spectrum $S_\lambda(x,y)$ in arbitrary point of image through the measured spectra $S_\lambda(x_i,y_i)$ in some points close to (*x*, *y*) on NDVI criterion, and brightness's $B_{\Delta\lambda'}$ measured in channel ? λ' of BSPS:

$$S_\lambda(x,y) = \frac{1}{N}\sum_{i=1}^{N}\left\{S_\lambda(x_i,y_i) + k(\lambda,\Delta\lambda')\left[B_{\Delta\lambda'}(x,y) - B_{\Delta\lambda'}(x_i,y_i)\right]\right\}$$

Here *N* – the number of measured spectra, used for calculations and satisfied the condition on NDVI, the absolute values of brightness $B_{\Delta\lambda'}$ are averaged over the angular field of view corresponding to spectroradiometer one, and $k(\lambda,\Delta\lambda')$ is calculated applying least-squares method for mentioned group of measured spectra ($(x_i, y_i) \equiv (i)$):

$$k(\lambda,\Delta\lambda') = \frac{N\sum_{i=1}^{N} S_{\lambda}(i) S_{\Delta\lambda'}(i) - \sum_{i=1}^{N} S_{\lambda}(i) \sum_{i=1}^{N} S_{\Delta\lambda'}(i)}{N\sum_{i=1}^{N} S_{\Delta\lambda'}^{2}(i) - \left(\sum_{i=1}^{N} S_{\Delta\lambda'}(i)\right)^{2}}$$

The version of technique with using non-calibrating DN spectra and spectrozone images is also designed. On fig. 3 an interpolated spectrum is presented composed of the parts of different dotted curves in comparing with spectrum (continuous curve) measured by spectroradiometer at the same point. Different dotted parts show what channel of BSPS was used to retrieve this part of the spectrum. It means the largest correlation of used channel and marked part of the curve.

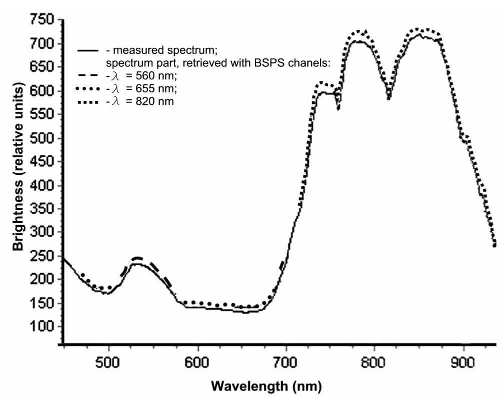

Figure 3. Comparing interpolated and measured spectrum

4. CONCLUSION

The images synthesized from spectrozone ones (acquired with spectral filters at 560, 820, 655 nm) allows for preliminary thematic classification of the forest sites images on species content, phytopathology condition, damages caused by fires. The results of computer classification were compared with some afforestation inspection descriptions in database GIS 'Forest resources' (by percentage content of various species). Correlation of results of classification and descriptions in GIS is quite high (about 75-95%) in all cases.

Because of high spatial resolution, VSC-2 could be used for the purposes of validation of classification results for images of spaceborne systems. Especially this concerns the quantitative determining the size and borders of some types of damages such as glades and consequences of forest fires.

Video-spectral device VSC-2 is a convenient and effective tool for carrying out the monitoring of not very large forest territories from a helicopter. The authors intend to further improve the device parameters (namely, the spectral range should be expanded up to 300-2500 nm). To improve the image quality the gyro-stabilization platform should be used.

5. REFERENCES

1. B. I. Belyaev, L. V. Katkovsky and V. A. Sosenko, 2001a, "Aerospace researches of natural formations in an optical range of wavelengths". Belarusian State Univ. Proc., v. 4 'Physics' (Minsk: BSU), pp. 103-125.

2. B. I. Belyaev, J. V. Belyaev, V. V. Veller, V. M. Zalyotny, L. V. Katkovsky, E. I. Nesterovich, V. A. Sosenko and V. I. Shuplyak, 2001b, "Video-spectral-polarimetric aviation system for the control of forests condition". The All-Russia Scientific Conf. 'Remote sensing of terrestrial covers and atmosphere by space means', 20-22 June 2001 (Murom, Russia), pp. 193-196.

3. B. I. Belyaev, J. V. Belyaev, V. M. Zalyotny, A. A. Kazak, L. V. Katkovsky, T. M. Kurikina, V. I. Shuplyak, 2001c, "Spectral-polarization methods for monitoring of the damaged forest territories". The All-Russia Scientific Conf. 'Remote sensing of terrestrial covers and atmosphere by space means', 20-22 June 2001 (Murom, Russia), pp. 197-202.

4. H. Cetin, 2004, "Comparison of spaceborne and airborne hyperspectral imaging systems for environmental mapping". Proc. XXth ISPRS Congress, 12-23 July 2004 (Istanbul, Turkey), http://www.isprs.org/istanbul2004/comm7/papers/247.pdf.

5. J. M. Ellis, H. S. Dodd and W. Creek, 2001, "Applications and lessons learned with airborne multispectral imaging". http://www.hjw.com/pdf-articles/airborne-digital-apps1.pdf

6. P. Gong, S. A. Mahler, G. S. Biging and D. A. Newburg, 2003, "Vineyard identification in an oak woodland landscape with airborne digital camera imagery". International Journal of Remote Sensing, 24, No. 6, 1303-1315.

7. F. A. Gougeon, 1997, "Recognizing the forest from the trees: individual tree crown delineation, classification and regrouping for inventory purposes". Proc. 3rd International Airborne Remote Sensing Conference and Exhibition, 7-10 July 1997 (Copenhagen, Denmark), pp. 807-814.

8. ITRES, 2002, ITRES Research Limited, "Compact Airborne Spectrographic Imager CASI-2" (Calgary, Canada), http://www.itres.com.

9. L. V. Katkovsky, B. I. Belyaev, J. V. Belyaev, T. M. Kurikina, A. A. Kazak and S. V. Khvalej, 2004, "Spatial and spectral extrapolation of forest remote sensing data". Proc. 2nd All-Russia Scientific Conf. 'Remote sensing of terrestrial covers and atmosphere by space means', 16-18 June 2004 (St. Petersburg, Russia), v. 1, pp. 159-163.

10. J. H. Lumme, 2004, "Classification of vegetation and soil using imaging spectrometer data". Proc. XXth ISPRS Congress, 12-23 July 2004 (Istanbul, Turkey), http://www.isprs.org/istanbul2004/comm7/papers/16.pdf.

11. J. Puumalainen and P. Susila, 1999, "Possibilities of digital aerial imagery for forest monitoring". Proc. Conf. 'Remote Sensing and Forest Monitoring', 1-3 June 1999 (Rogow, Poland), http://rogow99.sggw.waw.pl/

12. P. S. Thenkabail, R. B. Smith, and E. De Pauw, 2000, "Hyperspectral vegetation indices and their relationships with agricultural crop characteristics", Remote Sensing of Environ, v.71. p. 158-182.

13. V. C. Vanderbilt, V. Ambrosia, and S. L. Ustin, 1998, "Diurnal reflectance changes in vegetation observed with AVIRIS". 7th Annual JPL Airborne Earth Science Workshop, 12-16 January 1998 (Pasadena, CA), http://www.cstars.ucdavis.edu/.