POTENTIALS OF THE VNIR AIRBORNE HYPERSPECTRAL SYSTEM AISA EAGLE

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Abstrakt

Senzory používané v leteckém hyperspektrálním dálkovém průzkumu (obrazové spektroskopii) jsou schopny snímat obrazová data skládající se z desítek až stovek úzkých spektrálních pásem ve viditelné a infračervené části spektra. Takovéto množství úzkých a na sebe navazujících spektrálních pásem umožňuje vyvinout metodické postupy, které dokáží identifikovat různé objekty na zemském povrchu a s vysokou přesností určit jejich fyzikální a chemické vlastnosti. Možnosti využití hyperspektrálního dálkového průzkumu pro vědecké i komerční účely je značně široké. Počínaje aplikacemi pro zemědělství, lesnictví i ostatní přirozenou vegetaci (např. precizní zemědělství, odhad biomasy, mapování druhové skladby, odhad aktuálního zdravotního stavu vegetace), geologii (např. mapování degradace půd, určení minerálního složení), po limnologii (např. hodnocení kvality vody) a jiná odvětví.

Od roku 2004 Ústav systémové biologie a ekologie AV ČR v.v.i. (USBE) disponuje leteckým hyperspektrálním senzorem AISA Eagle. Systém AISA Eagle byl vyvinut finskou společností Spectral Imaging (Specim Ltd.). Systém je letecky provozován ve spolupráci s firmou Argus Geo Systém s.r.o. AISA Eagle je elektronický stírací skener se spektrálním rozsahem od 400 do 1000 nm, s maximálním spektrálním rozlišením 2.4 nm, a možným prostorovým rozlišením od 0.4 m do 6.0 m. V průběhu snímání je spektrum štěpeno do úzkých spektrálních pásem a snímáno pomocí CCD matrice. Výstupem je 12-ti bitový záznam.

Letecký obrazový systém se skládá z kompaktní hlavy obsahující hyperspektrální senzor, GPS/INS jednotky, akvizičního PC a senzoru snímajícím dopadající ozáření (FODIS). Systém v kombinaci s vhodnými programovými nástroji je schopen produkovat plně zpracované letecké snímky (georeferencované hodnoty vyjadřující odrazivost na úrovni zemského povrchu nebo letadla) v téměř reálném čase. Nicméně kvalitu provedených radiometrických, geometrických a atmosférických korekcí leteckých hyperspektrálních dat je nutné vždy ověřit. Za tímto účelem se souběžně s leteckým snímkováním provádí sběr kontrolních dat, tj. měření optických charakteristik vybraných povrchů pomocí spektroradiometru FieldSpec-3 a zaměření souřadnic kontrolních bodů pomocí geodetického GNSS systému TOPCON. V současné době, pracovní skupina dálkového průzkumu vegetace ISBE je schopna provést kompletní leteckou/pozemní hyperspektrální kampaň včetně standardního zpracování obrazových dat.

Klíčová slova: letecký hyperspektrální dálkový průzkum, obrazová spektroskopie, AISA Eagle

Abstract

Airborne hyperspectral remote sensing (imaging spectroscopy) sensors acquire images of several (from tens to hundreds) narrow spectral bands in visible, near and short infrared wavelengths. So many narrow spectral bands allowed development of the advanced methods for Earth surface object detection with high accuracy identification of their physical and/or chemical properties. Use of hyperspectral remote sensing (RS) data in scientific and even commercial applications is quite broad, starting from agriculture, forestry, and natural vegetation (precision farming, assessment of general plant status, biomass estimation, species composition mapping), through geology (mapping of minerals, land degradation assessment), up to limnology (water quality evaluation), and other domains.

Since 2004 the Institute of Systems Biology and Ecology (ISBE) (Academy of Sciences of the Czech Republic) has been operating the VNIR airborne hyperspectral sensor AISA Eagle. The AISA Eagle system, developed by Spectral Imaging (Specim Ltd, Finland) and mounted in an aircraft of the Argus Geo System Ltd., is a pushbroom imaging system with the spectral range from 400 to 1000 nm, the highest achievable spectral resolution of 2.4 nm, and spatial resolution between 0.4 m and 6.0 m. The spectral bands are during acquisition split by the slit prism and pixel-wise progressively recorded by the CCD matrix into the 12 bit digital numbers.

The entire airborne imaging system consists of a compact hyperspectral sensor head, data acquisition unit (rugged PC), GPS/INS unit, and downwelling irradiance sensor (FODIS). This assembly, complemented by the supporting pre-processing software, is capable to deliver in almost real time the orhtorectified hyperspectral images in at surface and/or at sensor level reflectance values. Nevertheless, quality of the radiometric, geometric, and atmospheric corrections of the airborne hyperspectral images must always be validated. Therefore, the ground spectral and spatial reference data are measured simultaneously with the AISA Eagle over-flights using a portable field spectroradiometer ASD FieldSpec-3 and the geodetic Topcon GNSS system. The workgroup for remote sensing of vegetation at ISBE is currently capable to facilitate the complete flight/ground hyperspectral campaign including the standard image data pre-processing.

Keywords: airborne hyperspectral remote sensing, imaging spectroscopy, AISA Eagle.

Introduction

Airborne hyperspectral remote sensing (imaging spectroscopy) sensors are able to acquire images of several (tens to hundreds) narrow spectral bands in visible, near and short infrared wavelengths of the electromagnetic spectrum. High number of narrow adjacent spectral bands allows development of advanced methods for Earth surface object detection including a high accuracy identification of their physical and/or chemical properties. Use of hyperspectral remote sensing (RS) data in scientific and even commercial applications is quite broad, starting from agriculture, forestry, and natural vegetation (e.g. precision farming, assessment of general plant status, biomass estimation, species composition mapping), through geology (e.g. mapping of minerals, land degradation assessment), up to limnology (e.g. water quality evaluation), and other domains.

Since 2004, the Institute of Systems Biology and Ecology (ISBE, Academy of Sciences of the Czech Republic) has been operating the VNIR airborne hyperspectral sensor AISA Eagle. The AISA Eagle system is being produced by Spectral Imaging (Specim Ltd, Finland) company. For the flight campaigns it is mounted and operated in aircraft of cooperating company Argus Geo System Ltd. from Hradec Králové.

Technical description

The AISA Eagle sensor is the pushbroom system which consists of a compact hyperspectral sensor head, data acquisition unit (rugged PC), GPS/INS unit, and downwelling irradiance sensor (FODIS). The system is working in visible and near infrared part of spectra (VNIR). Monitoring of the aircraft position and attitude is performed by three-axial inertial navigation GPS/INS unit. The basic technical specification of the AISA Eagle sensor is shown in table 1. Table 2 gives an overview of several potential acquisition modes of the AISA Eagle system.

Tab.1: Basic technical specifications of AISA Eagle

Spectral range	400 – 1000 nm
Spectral pixels	260
Spectral sampling/pixel	2.3 nm
Max. spectral resolution	2.4 nm
Spatial pixels up to	1024, of which 71 FODIS pixels
Spatial resolution	0.4 m – 6.0 m
Camera	Progressive scan CCD camera
Output	12 bits digital
Integration time	Settable independent of image rate
FODIS	Diffuse light collector and fiber optic cable

Figure 1: AISA Eagle VNIR airborne hyperspectral system mounted in the aircraft.

Fore optics	23 mm	17 mm	11 mm
FOV	29.9°	39.7°	58.4°
IFOV	0.029°	0.039°	0.057°

FOV ... Field of View IFOV ... Instantaneous Field of View

Tab. 2: Examples of possible set-ups of AISA Eagle

Ground pixel size	Spectral resolution	Spectral bands	FOV	Image rate	Swath width	Flight height	Flight speed
0.4 m	10 nm	65	29.9°	125.0 Hz	190 m	385 m	50 m/s
0.6 m	5 nm	130	29.9°	83.3 Hz	286 m	577 m	50 m/s
1.0 m	10 nm	65	58.4°	50.0 Hz	953 m	928 m	50 m/s
2.0 m	10 nm	65	39.7°	25.0 Hz	954 m	1426 m	50 m/s
6.0 m	2.5 nm	260	58.4°	8.33 Hz	2860 m	2790 m	50 m/s

Supportive ground measurement

The supportive ground measurements need to be acquired simultaneously (under same illumination conditions) with hyperspectral flights . They are essential for calibration and validation of the image data pre-processing procedures. They are used for: 1) atmospheric and geometric corrections of airborne images, and 2) assessment of georeferencing accuracy and quality of at-surface reflectance values. Each flight/ground campaign is specific and therefore main parameters of remote sensing data (e.g., targeting spatial resolution) needs to be based on user demands.

Preparation of a field campaign consists of following steps:

1. Basic survey of a study site from maps and aerial photographs
2. Detailed in-situ ground survey of the study site
3. Selection of reference targets for at surface reflectance verification, i.e.spatially homogenous natural or artificial ground surfaces of near Lambertian surfaces (e.g. bare soil, clay, concrete, etc.)
4. Measurement of targets coordinates by means of GNSS receiver
5. Selection of ground control points (GCP) for verification of georeferencing accuracy, i.e. natural (i.e., regular objects with high contrasts between an object and its surrounding) or artificial (i.e., bright square-shaped targets)
6. measurement of GCPs coordinates

Figure 2: Reflectance measurement of ground reference targets

Supportive ground measurement and observations during hyperspectral image acquisition

The optical properties of reference targets are measured during image acquisition by field portable spectroradiometer, e.g. ASD FieldSpec 3. Measured spectral profiles are used to verify the image data at-surface reflectance and also for additional calibration purposes. For post-processing of data from GPS/INS unit are necessary GPS observations. GPS measurements are being performed at the study site by the GNSS receiver TOPCON or can be taken from nearest CZEPOS station.

AISA Eagle data processing

Raw hyperspectral data from the AISA Eagle system need basic pre-processing in order to be useable by the end-users. Several software tools and packages have been developed for radiometric, geometric and atmospheric corrections of airborne remote sensing data. CaliGeo (Spectral Imaging Ltd.) is a software package specifically developed by SPECIM Ltd. to carry out the radiometric corrections and ortho-georectification over the raw AISA Eagle image data. The PARGE software (Schläpfer at al., 2006), produced by ReSe Applications Schläpfer and Remote Sensing Laboratories (RSL) of the University of Zurich, is specialized in orthorectification and georeferencing of remote sensing images. Finally, ATCOR-4

(Richter, 2007) was developed by ReSe and Deutsches Zentrum fuer Luft- und Raumfahrt e. V. (DLR). ATCOR-4 is the software package designed for atmospheric, topographic and BRDF corrections of airborne spectroscopy image data. Atmospheric corrections implemented in ATCOR-4 are based on physical model of atmosphere MODTRAN4 (Schläpfer at al., 2006). PARGE and ATCOR-4 were developed as a complete package for georectification and atmospheric correction of airborne hyperspectral data and they were adjusted to perform atmospheric corrections even for non-georeferenced data.

Radiometric Correction

Radiometric correction is the first step within all corrections. The acquired raw digital numbers (DN) are transformed into the physical radiometric values (radiance). The final format (units) of radiance images is represented by radiometric values $\frac{\mu W}{cm^2 \cdot str \cdot nm}$.

Georeferencing

Direct image georeferencing could be performed in PARGE or CaliGeo software. Data from the GPS/INS unit (geographic coordinates, altitude and attitude angles of the plane during image acquisition) and digital elevation model (DEM) are compulsory for georeferencing in both software packages. Airborne data are mostly affected by geometric distortions caused by variations of the flight path and the attitude of the plane (roll, pitch, heading angle). Direct georectification is performed in two successive steps. First of all, the centre coordinates of all acquired pixels are calculated, and in the second step image data are resampled into a grid of the selected coordinate system. The process of georeferencing includes geometric corrections, orthorectification and image location into a desired map projection. Currently data from the AISA Eagle system are mostly georeferenced into the UTM or S-JTSK coordinate system, but georeferencing to another coordinate system is also possible. Figures 3 and 4 gives examples of a raw and fully georeferenced AISA Eagle image subset.

Figure 3: Raw acquired image (true colors)

Figure 4: Georeferenced image (spatial resolution 0.4m, true colors)

Atmospheric Correction

Atmospheric correction is applied in order to remove effect of atmosphere (absoprption by atmospherical gasses and aerosols, etc.) and to produce at-surface reflectance from acquired airborne images. Several approaches to atmospheric correction can be employed.

1/ Empirical method
Acquired image spectra is forced to match reflectance spectra of reference target collected at the field during supportive ground measurement by means of empirical statistical relationship. At least one reference target is required for calculation of linear regeresion for each band but more reference targets result in higher accuracy of reflectance values.
2/ FODIS ratio

The whole image cube is divided by data acquired by FODIS sensor, which measure the incoming solar irradiance at the aircraft level per acquired band. The result is at-sensor reflectance (atmospheric effects caused by atmosphere between the aircraft and ground remain uncorrected).

3/ Radiative transfer models
The most common and universal approach is using one of the atmospheric radiative transfer models, e.g. ATCOR-4 coupled with MODTRAN4 atmospheric model. The ATCOR-4 software package is offering also other additional corrections of hyperspectral data like topographic correction, BRDF correction, etc.

Examples of spectral characteristic of vegetation derived from raw data (a), radiometricaly corrected data (b), and atmosphericaly corrected data (c) are shown at figure 5.

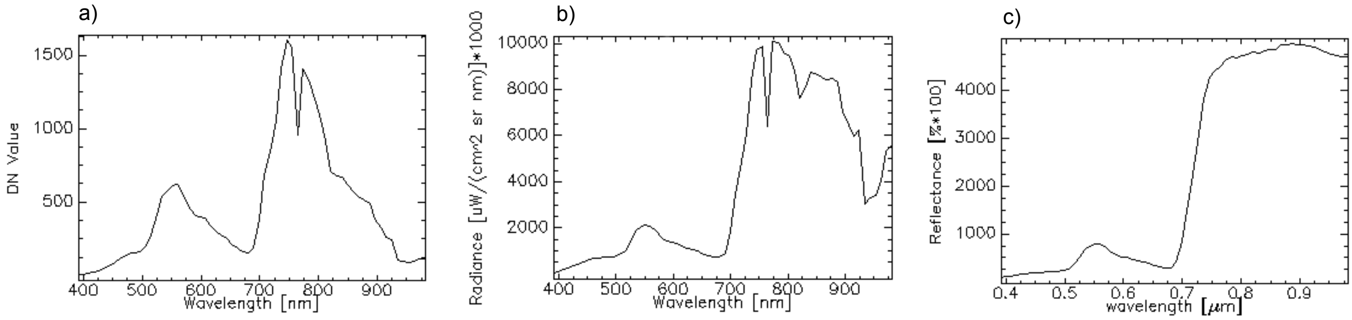

Figure 5: Spectral profile of a) raw acquired data, b) radiance, c) at-surface reflectance

Current usage of AISA Eagle at ISBE

Currently, the AISA Eagle system at ISBE is mainly used for scientific purposes. The imaging spectroscopy data are interpreted the way allowing better understanding of vegetation response to environmental conditions and mapping the current status of montane forest stands and grassland ecosystems. The core permanent research site of ISBE called Bily Kriz (located at Moravian-Silesian Beskydy Mts.) became first test site where AISA Eagle images have been acquqired at ground-based as well as airborne platforms. The AISA Eagle system is currently involved in two main research subjects; 1) identification of xanthophyll cycle and chlorophyll fluorescence of montane grassland ecosystem using ground-based AISA image acquisitions (Verrelst et al., 2007), and 2) development of physically-based algorithms to estimate total chlorophyll content of montane Norway spruce (Picea abies (L.) Karst) forest stands from airborne high spatial resolution hyperspectal images (Malenovský et al., 2007).

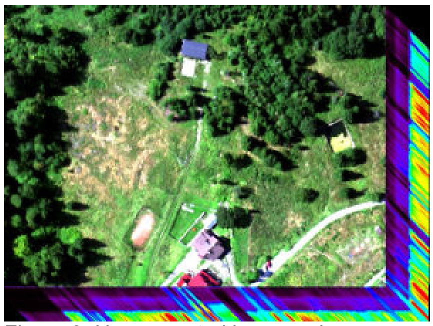
Figure 9: Hyperspectral image cube

Conclusions

The airborne data processing chain, producing georeferenced AISA Eagle images of at-surface reflectance values, has been established at the Institute of Systems Biology and Ecology. High quality pre-processing of hyperspectral airborne remote sensing data is important in order to produce the accurate thematic map products. Only then the airborne imaging spectroscopy can be operationally used for development of various applications in forestry, agriculture, ecology, geology, limnology, and other scientific and public domains.

The working group of remote sensing of vegetation at the Institute of Systems Biology and Ecology is currently properly equipped and trained to carry out the complex hyperspectral flight campaigns, employing the AISA Eagle VNIR system and other supportive instruments required for proper calibration and quality validation of the hyperspectral images.

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