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PERSPECTIVES OF HYPERSPECTRAL DATA APPLICATION FOR VEGETATION STUDIES

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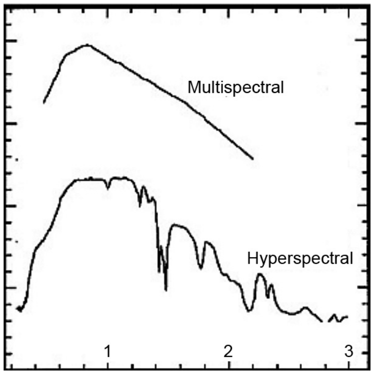
Abstract: In this paper the possibilities of hyperspectral data processing are investigated regarding the application of these images in natural and ecological applications. A short overview is given of the available methods for interpretation purposes and special attention is paid on how the unique properties of hyperspectral data are affecting the choice of suitable methods for processing. Further steps required for developing a set of application dependent image processing chain is also addressed with the aim of applying both spatial and spectral information contained in datasets. A broad identification of possible processing chain is discussed with the aim of developing more standardised and application suited way of processing of the large data volumes. Automatic or semi-automatic procedures are proposed and key steps are identified that could lead to high quality mapping products by means of digital signal processing. This work is to be continued with testing the performance at different stages of interpretation while different techniques are used, and a document is to be supplied through HYPER-I-NET with the collection of results and application specific suggestions regarding hyperspectral data application for vegetation monitoring purposes.

Introduction

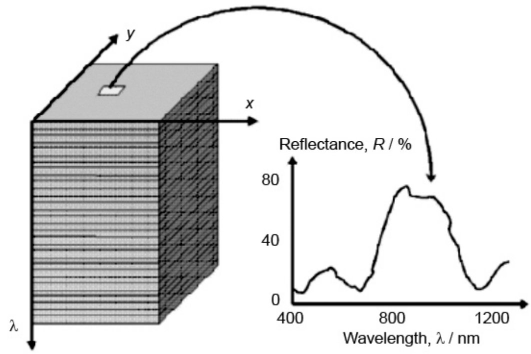
Hyperspectral sensors (often referred to as Imaging spectrometers) are instruments that acquire images in many, very narrow, contiguous spectral bands throughout visible, near-IR, mid-IR and thermal-IR portions of the spectrum (Lillesand 2004). These systems typically collect 200 or more bands of data, which enables the construction of an effectively contiguous reflectance spectrum of every pixel in the scene. These characteristics make it possible to discriminate among features of earth surface that have diagnostic absorption and reflection properties over narrow wavelength intervals that are not present if relatively coarse bandwidths of conventional multispectral scanners are used (Richards 2006). The concept is illustrated in Figure 1 (a). For a given geographic extent the data can be viewed as a cube, having two dimensions representing the spatial position and one that represents wavelength as shown in Figure 1 (b).

Even displaying hyperspectral data is a challenging task because of the difficulties in selecting the appropriate and most informative bands to display. Regarding the quality and data producing capabilities of hyperspectral sensors, user community now can obtain extremely useful information from the big data volumes.

Although hyperspectral data posses the possibility of good quality data interpretation, current computational systems are unable to meet the demand of operational users, and lag far behind hyperspectral sensors in their ability to process the large data volumes (Plaza et al. 2003). This issue is more related to the lack of efficient techniques and algorithms required to interpret hyperspectral datasets with sufficient level of details and accuracy. These highlight the need for new algorithms and practical techniques to be designed, thus making possible the high quality analysis of images that are acquired by imaging spectrometers.



(a)



(b)

Figure 1 Difference among hyperspectral and multispectral datasets (a) The diagram shows the measured brightness values that a pixel contains on an image and concept of Hyperspectral data cube, (b). Each layer on the axis of wavelength is containing pixel brightness information measured at the corresponding ground location

1. ábra A hiperspektrális és multispektrális adatsorok közötti különbségek (a) A diagram mért fényességi értékeket mutatja, amelyeket egy pixel tartalmaz egy képen, (b) A hiperspektrális adatkocka koncepciója. A hullámhossz tengelyen feltüntetett minden réteg pixel fényességi adatokat tartalmaz, amelyeket a hozzá tartozó földi állomáson mértek

Purpose and scope

This paper benefits from the results of a research project funded as support action by the European community, entitled HYRESSA (HYperspectral REmote Sensing in Europe specific Support Actions). This project already addressed the issues about the data processing of hyperspectral data by means of a dedicated expert workshop, hold at DLR premises in July 2006. HYRESSA findings are summarised in the final report of that workshop (HYRESSA SWOT and User Needs workshop report 2007) and suggest the definition of a two stages chain, the structure of which is also graphically presented in the following figure.

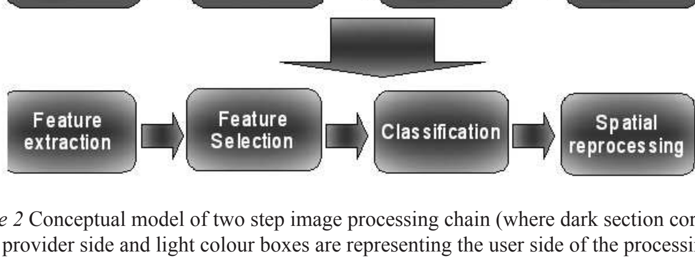


Figure 2 Conceptual model of two step image processing chain (where dark section corresponds to the provider side and light colour boxes are representing the user side of the processing chain)

2. ábra A kétlépéses képfeldolgozási lánc fogalmi modellje (ahol a sötétebb részek a szolgáltatói, a világosabb dobozok pedig a felhasználói oladlát képviselik a feldolgozói láncnak)

The first part of the chain is devoted to the so called provider's side, and highlights the needs for addressing some of the problems that prevent hyperspectral data to be widely used in applications. The relevant processing steps are:

- radiometric calibration, where new algorithms need to be developed, e.g. for thermal sensors;
- geometric correction, where the lack of precise DEMs does not allow to have consistent products;
- atmospheric correction;
- objective evaluation of product accuracy, where the sector suffers from the lack of standards for data format and metadata description.

However, once the data of interest has been pre-processed and corrected, there is a need to extract relevant information from the collected data sets. The second part of the data processing chain (user's side) will therefore deal with four more steps, described in the following paragraphs.

- data transformations, where the goal is to decrease data dimensionality and the amount of redundant information within the data by applying feature selection, feature extraction or transformation techniques such as for instance Principal Components transformation.
- data corrections with the need of defining BRDF and its effects, especially in areas where the viewing angle may be extremely diverse, such as urban areas, forests or very steep terrains; The effect occurring because of the varying illumination and sensor incident angle over the scene can be also modelled using the Bidirectional Reflectance Distribution Function (BRDF) where further investigation is needed to determine the effects of objects with significant vertical extent. Many BRDF models and libraries are available and will be investigated within the HYPER-I-NET project.
- spectral matching, with the need of having centralised libraries for many different materials;
- classification, with the possibility to take into account not only spectral characteristics but also spatial relations among neighbouring pixels/materials;
- feature detection, with the need to define precisely characterized and accurately validated high level products.

According to this in the paper a short overview of pre-processing is given, but the document is instead devoted to the definition of a data analysis chain, aimed at very general mapping products by means of atmospherically, radiometrically and geometrically corrected hyperspectral data. According to the different scientific applications, the steps highlighted in this procedure can and should be specified more in detail.

Image correction and registration

When image data is recorded by the sensors on a satellite or an aircraft it can contain errors in geometry and the measured brightness values of the pixels (radiometric and geometric errors). Hence, every kind of remotely sensed data needs to be calibrated in order to avoid inaccuracies during interpretation procedure (Richards 2006). Anomalies can occur on image data because of several reasons (Grauch et al. 2002). The effect of atmosphere on image data such as atmospheric absorption and scattering can be mitigated using readily available radiative transfer models such as MODTRAN (Berk et al. 1998) and 6S (Vermote et al. 1997). Geometric correction of images is most often carried out by using Ground Control Points (GCPs) and mapping polynomials to restore geometric integrity of data.

Data processing and interpretation

Assuming all the error corrections have been performed, the data becomes suitable for further interpretation by means of a semi-automatic or automatic procedure. The need for such automatic methods is based on the dimensionality of the data, already noted in the introductory section. The richness of the data with respect to spectral information might be complemented by an equal richness in spatial contents, if the ground resolution is fine, e.g. in hyperspectral airborne campaign results. It becomes thus of primary importance to understand how these data may be analysed and the processing steps that are most suitable for a given information extraction purpose. According to the general chain proposed in figure 3 in the following paragraphs we consider a feature extraction step first, a feature selection step as second, and a classification step as third and last element.

Multiple choices of methodology for feature extraction exist. Rule-based expert systems are Often used for selecting spectral features and starting from the seminal papers by Srinivasa 1991 and Srinivasa and Richards 1993, rule-based procedures have been implemented in many situation for hyperspectral processing. Other choice is the application of source separation, when for all pixels the spectral signature that describes identically a material is aimed to be detected Chang et al., 2007). These methodologies are often referred to as endmember extraction and spectral unmixing algorithms. Also different transformation techniques are often used prior to classification procedures with the aim of rising classification accuracy. To this aim, several feature extraction approaches have been proposed for remote sensing data using transformations (Fukunaga 1990). Some of them are often labelled as “dimension reduction techniques”, including Principal Component Analysis (PCA) (Landgrebe 2003), independent component analysis (Hyavarinen et al. 2001) and projection pursuit (Landgrebe 2003). Discriminant Analysis Feature Extraction (DAFE) (Landgrebe 2003) and decision boundary feature extraction (DBFE) Lee and Landgrebe 1997) are also available for transformation purposes. In order to use spatial information during image processing (Ramstein and Raffy 1989, Serra 1989, Woodcock et al. 1988) some methods such as co-occurrence texture analysis (Haralick et al. 1973) and the semivariogram analysis (Matheron, 1997) can be used. It is also possible to carry out multi-scale analysis of image data throughout mathematical morphology and image segmentation (Soille 2003, Benediktsson et al. 2003).

The aim of feature selection is to be able to maintain the selected set into a reasonable dimensionality, but also to adapt to different problems. Many different statistical indexes for feature selection have been proposed and should be compared, due to problems in different statistics of spectral and spatial features. With a small region of competition the ideal separability measure would be high, the likelihood distributions would have minimal overlap and the classes should be easily separated in classification. Examples of such separability measures can be found in Table 1.

Table 1 Separability indices for feature selection (Richards 2006)
1. táblázat Az elválaszthatóság indexszámai a meghatározandó foltok elválasztásához (Richards 2006)

Index	*Calculation*
Euclidean Distance Separability Index	*The squared value is given by the Pythagorean distance between the class means*
Mahalanobis-Distance Separability Index	*computed as the square of the distance between the two classes expressed in terms of the variances*
Transformed Divergence	*based on similar concepts than the Mahalanobis distance but able to achieve superior performances as a measure of separability*
Jeffries-Matsushita (J-M) Distance Separability Index	*very similar to the Transformed but with problems related to the fact that it tends to over-emphasize the results for small interclass separations and under-emphasize the results for the greater separations*
Bhattacharyya Distance	*appropriate to inter-class separability problems than the Divergence when the class probability distributions are broad*
Histogram Distance Index	*based on the separability of the histograms instead of the probability or likelihood functions and aimed at computing histogram separability is extracted by quantifying their overlapping*

Data classification procedure is a complex task even with the application of data volume reduction techniques that was described in above paragraphs. The application of methods relying on statistical distribution of training data is very limited because of the large data dimensionality in terms of spectral resolution which demands significant amount of training pixels across the scene (Richards 2006). Based on this problem, methodologies that do not rely of statistical probabilities based on training data distributions are more preferable to use. These include the Spectral Angle Mapper (SAM), Support Vector Machines (SVM) and different multi source, non-parametric approaches such as Neural networks (NN) or decision tree classifiers (DTC) (Richards 2006). The classification can be purely based on spectral information or spatial data can be imported as additional information into the classification process.

SAM is a typical example of a supervised classification algorithm based on spectral features only. For two, non-negative, M-dimensional spectra, x and y, the angle between them is computed by means of the following analytical expression:

$$J(x,y)=\arccos\left(\frac{\langle x,y\rangle}{\|x\|.\|y\|}\right)$$

where <.> represents the dot product. From its mathematical definition, SAM possesses unique and very interesting properties. The first one is the invariance to Multiplicative Scaling, and the other is that it is a non-additive and non-monotonic distance metric. Thus, the addition of more spectral bands does not always guarantee an increase in angle. An example of SAM-based analysis of hyperspectral data for recognising asbestos covers of urban structures is available in Marino et al., (2000). SVMs also can be used with promising results but the implementation is more complex than SAM (Gualitieri et al. 1998). In the same time it is possible to apply when very limited amount of training data is available (Lillesand 2004, Richards 2006). The advantage of Neural Networks and DTCs are that they are powerful techniques when different sources of information are to be combined even when the combination is done in a non-linear fashion. This includes the application in mixed approaches like the below detailed spectro-spatial classification procedures (Richards 2005).

Among the approaches proposed to take into account the spatial features, the most used one is based on Markov Random Fields. Alternative approaches may be based on spatial reprocessing of the spectrally classified data by means, for instance, of a spatial pattern classification or applying filters, whose inputs are the percentages of pixels in a w × w window around the current pixel positions assigned to each class by the first classifier (Gong and Howarth 1992). The most discussed option from the research point of view of the classification step are methodologies combining spectral and spatial properties (Gamba et al. 2004). In general, they can be subdivided into three different groups:

- refined spatially-aware classification of spectral features (e.g. object-oriented classification);
- spectrally-aware classification of spatial features (e.g. morphology-based methodologies applied to original data);
- mixed approaches (e.g. morphology after spectral transformation, spatial refinement of spectro-spatial results).

These methodologies seem to be very promising in the development of a processing chain of hyperspectral imagery in the future but also highlight the need for designing new algorithms that can be used for classification.

Conclusions

Hyperspectral imagery has great possibilities in natural resource applications. The ability to distinguish a large number of different land cover types coupled with the possibility of identifying sub-pixel properties and distribution of different materials make possible the usage of hyperspectral sensors not just for quantitative analysis of vegetation cover but also for the qualitative assessment of land cover types and underlying surface parameters.

Hyperspectral data becomes more and more widely used in different applications but there is a lack of standard definition of processing methodologies. An application-dependent processing chain definition seems to be adequate in order to meet the needs of both the provider- and user side of scientific community. An application Theoretical Baseline Document is being developed for the identification of possible algorithms of each step of the processing chain that can be considered depending on the application. Further investigation of the optimal processing chain definition is crucial in order to apply the datasets efficiently and gain sufficient level of accuracy and details trough image processing.

As hyperspectral imagery enables the detailed analysis of surface characteristics more efforts should be put into the identification of possible applications in natural and ecological sciences.

Although individual applications have established rules and methods for interpreting image data, the lack of standards makes it difficult to compare results of different applications. Further investigation addressed to accuracy assessment of image interpretation is necessary in order to be able to estimate the results of qualitative analysis procedures. As a final remark the availability of high spatial and spectral resolution imagery the availability of good quality public spectral databases could further improve the possibilities of hyperspectral data applications.

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HIPERSPEKTRÁLIS ADATOK FELHASZNÁLÁSÁNAK PERSPEKTÍVÁI A VEGETÁCIÓS VIZSGÁLATOKBAN

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Összefoglaló: Jelen cikkben röviden bemutatjuk azon rendelkezésre álló módszereket, melyek alkalmasak hiperspektrális légi-, és űrfelvételek feldolgozására. Munkák célja az, hogy egy olyan átfogó jellegű módszertant dolgozzunk ki, mely segítségével hatékonyan és egyszerűen lehet hiperspektrális felvételek segítségével felszínborítási, illetve földhasználati térképeket előállítani. Napjainkban a hiperspektrális szenzorok egyre elterjedtebbek, mégis az alkalmazási köre az általuk készített felvételeknek elég szűk, és rendszerint az alkalmazott módszertan rendkívül specifikus az adott alkalmazásra nézve. Ezeket alapul véve munkánk célja az olyan hatékonyan alkalmazható algoritmusok és módszerek azonosítása, melyek alkalmasak egy általánosabb értelemben vett térképezési folyamat elvégzésére hiperspektrális felvételek segítségével. Fő hátránya az ilyen felvételeknek az egyéb például multispektrális felvételekkel szemben, hogy a képekben hatalmas adatmennyiség kerül tárolásra rögzítve a felvett felszín visszaverődési tulajdonságait akár 200–300, igen keskeny hullámhossz-tartományon is. Ezen adatok feldolgozása jelentős nehézségekkel jár, hiszen az egymáshoz közeli frekvenciákon sok redundáns információ található. Jelen kutatásunk első lépéseként az alkalmazható módszerek körét vizsgálta és próbálta leszűkíteni azon eljárások körérem melyek továbblépést jelenthetnek egy általánosan is alkalmazható térképezési eljárásban felszínborítási, illetve földhasználati térképek előállítására. A cikk röviden áttekinti a rendelkezésre álló releváns módszereket, és a rövid bemutatás mellett javaslatokat fogalmaz meg az alkalmazhatóságuk formájáról, előnyeiről és esetleges hátrányairól. Mivel a cikk terjedelme nem engedi meg, hogy teljes és átfogó képet adjunk a lehetséges módszerekről, így jelen cikkben azon eljárások kerülnek bemutatásra, melyek már egy előzetes tesztelési folyamat eredményeként kiválasztásra kerültek. Az itt bemutatott módszerek és eljárások alkalmazásával a jövőben egy olyan összetett adatfeldolgozó rendszer kialakítása a célunk, mely eléggé rugalmas a felhasználók számára, ugyanakkor rendkívüli hatékonysággal képes a felvételek interpretálására és a térképi termékek előállítására. A teljes kutatási munka anyaga a HYPER-I-NET program keretei között kerül majd a későbbiekben bemutatásra.