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An Alternative Approach to Data Fusion in Remote Sensing

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Abstract

The usage of various image data sources makes remote sensing a very effective tool in the monitoring of the environment. Remote sensing images can be described by three main dimensions: spatial resolution, spectral characteristics and temporal frequency. In monitoring tasks, it is usual to use several images of different kinds — multispectral and panchromatic satellite images, aerial photos and radar images.

Image fusion aims to integrate the advantages of spatial, spectral and temporal characteristics of several images. In current applications, the most often used data fusion procedures improve the spatial characteristics of a multispectral image via "merging" it with a higher spatial resolution (usually panchromatic) image.

This paper will describe another approach of image fusion. Operational — mainly agricultural — monitoring applications will be presented that heavily rely on the usage of different kinds of satellite images. In each of these applications the *temporal dimension* has a fundamental role.

1. The Principles of Remote Sensing

Remote sensing is a very effective tool in the monitoring of the environment. Remote sensing imaging systems measure the electromagnetic radiation reflected from (or emitted by) the Earth's surface. Beyond the visible light, the infrared bands play a crucial role in remote sensing. This article will mainly deal with applications that use visible, near infrared and middle infrared bands, where the source of radiation is the Sun, and we measure the radiation reflected from the Earth's surface. For a detailed introduction to remote sensing and its applications, see Richards [1] or McCloy [2].

The ratio of reflected and incident radiation — the *reflectance* — strongly depends on the land cover and the wavelength. The *reflectance function* of a given land cover gives the reflectance with respect to the wavelength. Every land cover category has its own characteristic reflectance function, which depends on the phenological phase and the maturity of the vegetation.

The sensors of remote sensing acquisition systems measure the radiation in several wavelength intervals (sampling windows; see Fig. 1), from which the reflectance function can be partially restored and the land cover and its physical status can be determined. The measured values are stored in a *remotely sensed image*, a kind of digital image. A multispectral image can be regarded as a matrix, whose elements are the units of sampling, which correspond to a given spot of the surface. These elements themselves, called *pixels*, are vectors of the intensity values recorded by the different sensors.

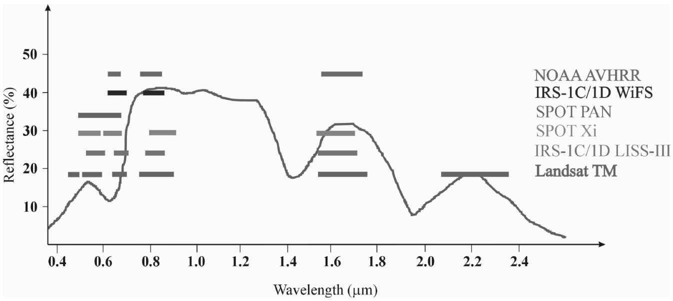


Figure 1: The typical spectral reflectance curve of green vegetation and the sampling windows of some satellite sensors

The remote sensing images can be described by three groups of properties. Two parameters belong to the *spatial properties*. The area coverage is the size of the land piece covered by the image. The pixel size is the area of the surface spot belonging to one pixel, that is of the elementary mapping unit. The *spectral properties* contain the electromagnetic wavebands used and the radiometric resolution, that is the number of quantization levels of the measured radiation intensity. The *temporal properties* consist of the temporal resolution, which indicates the frequency of possible acquisitions of the same area, and the time elapsed from the acquisition to the availability of the image data.

Beside the current advanced digital image processing techniques, remote sensing uses further special methods to use various image data sources in a coherent system and to extract valuable information from them. By image sources multispectral and panchromatic satellite images (the latter means one-band image, taken primarily in the visible interval), aerial photos (the carrier of the camera is an airplane instead of a satellite) and radar images (instead of the Sun, the source of the radiation is an instrument next to the camera) are meant. Before starting the analysis of the images, some *preprocessing steps* have to be carried out. By geometric and radiometric correction the raw input images are transformed into a common spatial and spectral system. However, the *integrated usage of various data sources* usually means more than just transforming the input images into a uniform system.

Instead of "overcoming" the differences of the images, we want to jointly utilize the advantages of each individual data source. That is, the difference in their characteristics can often be considered an advantage rather than a drawback.

For example, in the Control with Remote Sensing of Area-Based Subsidies programme several kinds of high resolution multispectral images are used for visual evaluation. During the geometric correction, the "native" pixel size of each image is kept instead of resampling the images to a uniform pixel grid. The visual delineation of agricultural parcels does not require the images to have the same pixel size — higher accuracy can be reached in the case of higher spatial resolution images, but lower resolution images are also usable with lower precision. For example, a cloudy SPOT 5 image with 10 m resolution is properly complemented by a cloudfree Landsat TM image with 30 m pixel size.

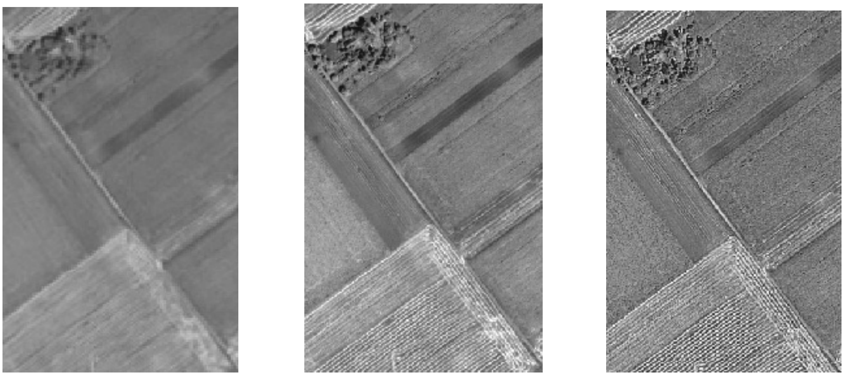
2. The Different Approaches to Data Fusion

The end of the last section has shown we have seen an obvious example of the simultaneous usage of different data sources. This section will describe the general meaning of the image fusion. Then, the most often used applications, the pixel-based fusion methods will be shortly introduced. Finally, an alternative data fusion approach will be presented, in which the time dimension is highlighted, and which plays an emphasized role in some agricultural monitoring programmes.

In this article, within the data fusion the authors will deal with image fusion, involving remotely sensed images, mostly satellite images. *Image fusion* refers to procedures that integrate the advantages in the spatial, spectral and temporal characteristics of several image data sources. Within the topic of remote sensing, both "data fusion" and "image fusion" are used interchangeably for the same operations. Although there are general methods to use together several types of images, but the implementation — with special emphasis on the preservation of the advantageous properties of each image — highly depends on the actual inputs.

The most often used image fusion procedures are the *pixel-based fusion methods*, which deal only with the spatial and spectral properties. Their aim is to improve the spatial characteristics of a multispectral image via "fusing" or "merging" it with a higher spatial resolution (usually panchromatic) image; see Fig. 2. Wald [3] gives a comprehensive survey on pixel-based fusion methods. The improvement can mean the increasing of the spatial resolution, or the emphasizing of the boundaries of the objects, the direction of the linear elements, or the texture. While improving the spatial properties of the multispectral image, its spectral characteristcs usually have to be preserved. Some examples of the pixel-based fusion methods are the IHS (Intensity-Hue-Saturation), the PCA (Principal Component Analysis) and the WS (Wavelet Substitution) transformation. With the exception of the IHS transformation, the spectral characteristics of the multispectral image are kept.

The following will present another approach to image fusion. The most important feature is that the time dimension is much more involved than in the case of pixel-based fusion methods. Several satellite images — usually of different kind —



Multispectral (colour, 2.4 m) | Panchromatic (greyscale, 0.6 m) | Merged (colour, 0.6 m)

Figure 2: An example of pixel-based fusion methods

are simultaneously used in an application, but it is not necessary to derive intermediate "fused" images. Instead, the usage of several images — and the difference between their characteristics — is "built in" into the model. To give a description analoguous to that of the pixel-based fusion, it can be said that the temporal enhancement of some images is done via the substitution of the weaker spatial or spectral characteristics with better temporal resolution. The usual situation is to have one or a few images with higher spatial resolution and/or better spectral characteristics and a series of images with weaker spatial or spectral properties. The latter carries the additional temporal information.

The proper incorporation of temporal information has a fundemental role in the agricultural applications, or more specifically, in the crop development monitoring.

For the differentiation among crops it is only rarely enough to have one image. Instead, the temporal progress has to be examined in the different wavebands, within the year. For this purpose, several images, taken in proper time periods, are needed. For example, in a dominantly agricultural area, usually one or two images are enough to make a distinction between winter and summer crops. But if one wants to differentiate among the crop species, several spring and early summer images have to be used for the winter crops, and late summer images are needed as well for summer crops.

The crop development assessment is also carried out via the examination of the temporal progress within the year, but more frequent acquisitions are necassary for this purpose, and instead of the measured values in the different wavebands, mainly a vegetation index is used. In some applications, the investigation is not bounded to one year; instead, it is vital to compare the status of the vegetation between different years. In this case, a data set is needed that is coherent over several years.

3. The Alternative Data Fusion Approach in Operational Remote Sensing Projects

This section will introduce some operational agricultural programmes. It is common that they heavily rely on the usage of different kinds of satellite images, and they use the alternative data fusion approach presented in the previous section. The task is usually to observe the status or development of the vegetation. The involvement of time dimension can be important either in the differentiation among several land cover categories or in crop development assessment. The only exception is flood monitoring, where the subject of observation is water surface, but this is the project where the importance of time dimension is the most obvious. The projects to be presented are carried out by the Remote Sensing Centre (RSC) of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI).

3.1. The Operational Crop Monitoring and Production Forecast Programme

The fundamental project of FÖMI RSC was the National Crop Monitoring and Production Forecast Programme (CROPMON). The research and operational applications started in 1980. They were driven by current agricultural requirements. The CROPMON project was operational from 1997 to 2003. It provided county and country level crop maps and production forecast for the eight main crops (winter wheat, winter barley, spring barley, maize, silage maize, sunflower, sugar beet, alfalfa), by a strict schedule across the vegetation period. The CROPMON methodology, reviewed in [4], is still applied in other applications.

The crop area assessment is based on the quantitative analysis of high resolution (HR) multispectral images (Landsat TM/ETM+, IRS LISS-III, SPOT XS/Xi). Depending on the period examined, three or four images, acquired at proper dates, are used. The spectral and temporal properties of the image series serve as a proper basis to properly classify the main crops, and to distinguish them from other land cover categories. The output of the classification consists of crop maps and tabular data with the sum of crop areas.

Crop yield forecasting is based on a model developed by FÖMI RSC. It uses the crop maps that are produced by the area assessment process. The additional temporal information is carried by low resolution (NOAA AVHRR) image series. They are very cheap and are available very frequently. Roughly speaking, if weather permits, an image appropriate for yield forecasting can be acquired every day. This frequency is requried for the proper monitoring of the status of vegetation. However, an AVHRR pixel covers a much larger area than that of the HR images used for the crop mapping, as Fig. 3 shows. Therefore, it is not "spectrally clean", it may gather the radiation information from several land cover categories. It is an important sub-task to extract the spectral and temporal information that is specific to the individual crops.

To summarize, CROPMON is an innovative example of an application that uses remote sensing for both crop mapping and yield prediction.

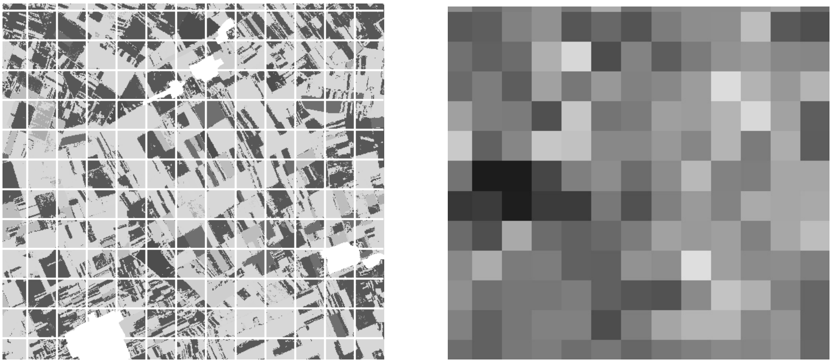


Figure 3: Illustration of the yield prediction model. A part of a crop map is seen on the left, the corresponding subset of a NOAA AVHRR composite on the right.

3.2. Programmes Related to Agricultural Subsidies

The largest part of the financial support to the EU member states is dedicated to agriculture. The Integrated Administration and Control System (IACS) is the framework for the management of the normative area-based applications, area-related animal payments and rural development claims, financed by the European Agricultural Guidance and Guarantee Fund (EAGGF). Therefore, the building up and the operation of the IACS is a key issue in the EU member states (see [5]).

The *Land Parcel Identification System* (LPIS, or MePAR in Hungarian) serves as the ground reference system for claiming and controlling area-based agricultural subsidies. The reference units of the Hungarian LPIS are *physical blocks*. A physical block is an area that is steady with respect to the agricultural cultivation, it has boundaries that can be clearly identified in the field (e.g., road, railway, canal, ditch, forest fringe), and its land use is homogeneous. A physical block may contain several agricultural parcels, possibly cultivated by different farmers. The ineligible areas (i.e., areas for which no area-based subsidies can be paid) are geometrically delimited inside the blocks. Beside the geometrical data, the LPIS database contains several alphanumerical attributes for each block: a unique identifier, the full geographical (gross) and the eligible (net) area, the categories of Environmental Sensitive Areas, Less Favoured Areas and other rural development schemes.

The geographical delineation and the attributes are pricipal in the justification of the agricultural payments: the official eligible area is determined from the geographical delimitation, and the over-declarations are detected on the basis of this value. This means that extra care has to be paid to use proper image and map data source for the LPIS creation and updating. The main data source is the coverage of digital ortho-photos, that is aerial photographs processed by a special kind of geometric correction. They usually capture the visible interval, and their pixel size is 0.5 m. During an aerial photo campaign the aim is to create a homogeneous coverage of a relatively large part of the country (from one third to the whole area), but there are limitations in the flying periods. Consequently, the return time is rather high — several years may elapse between two acquisitions of a given area.

Although ortho-photos are the primary data source in the exact delineation of the boundaries of the blocks and the ineligible areas, some auxiliary image sources are needed as well. Topographic maps help in defining steady elements. Besides, multi-annual high resolution (20-30 m) satellite image series are essential in the checking of land use categories and permanent boundaries. Although their spatial resolution is much coarser than that of ortho-photos, their spectral properties and better temporal resolution (within a year and between several years) makes them appropriate for the identification of and to distinguish among land cover categories. During LPIS building, the spatial resolution of the year 2000 high-resolution images was further improved via a usual pixel-based image fusion method, when 5 m resolution panchromatic images were merged with the original multispectral series.

The other important project related to the EAGGF agricultural payments is the *Remote Sensing Control of Area-based Subsidies* (see [6]). Farmers yearly submit applications for subsidies for their agricultural parcels. The applications consist of tabular forms and block maps with indicative drawings of the declared parcels. Data input, administrative and classical field controls are the responsibility of the Paying Agency. Remote sensing control is carried out by FÖMI. The task of remote sensing control is to check the validity of claim data: whether the declared area of the parcel is correct, whether the declared crop can be found in the parcel, and whether the parcel meets the Good Agricultural and Environmental Conditions.

Primarily, high resolution (HR) image time series are used to determine the crops, while the area measurement is done using very high resolution (VHR) images. However, these two tasks cannot be completely separated from each other. To correctly identify a parcel, one usually needs both the exact spatial data contained in the VHR images and the additional spectral and temporal information content of the HR image series. For the purposes of control, only one VHR is available in a year, and VHR images do not cover the middle (shortwave) infrared spectral band. Figure 4 illustrates the usage of different kinds of satellite images in the control.

For the crop identification, several — at least three or four — high resolution images (Landsat TM/ETM+, IRS LISS III, SPOT XS/Xi) are used in a year. Although it is not the primary task of the control to exactly tell the species of the crop found in a parcel, it has to be decided confidently whether the declared crop may be correct. For this goal the spectral and temporal characteristics of high resolution images are heavily utilized.

Before the operational usage of the VHR images, between 2000 and 2003, a pixel-based fusion method was used to improve the geometric accuracy of high resolution images. IRS PAN images with 5 m resolution were merged with the HR ones. This method significantly improved the spatial precision of images, but extra

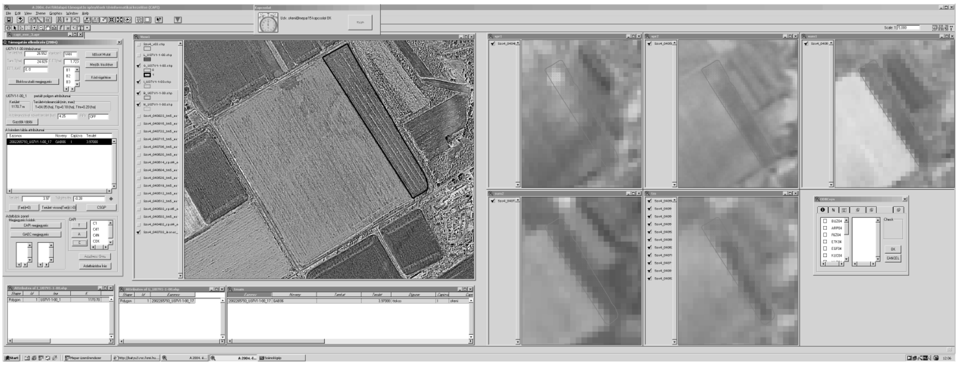


Figure 4: A screenshot of the Computer-Aided Photo-Interpretation software. (Large window on the left: VHR image, small windows: HR image time series)

care had to be taken because of the difference in their acquisition time: in some rare cases, anomalies were found in the location of the parcels in the resulting (merged) images. Due to the changes in the regulations (and more specifically, the technical tolerances) in 2004, using solely HR and PAN images is not sufficient for the adequate area measurement; instead, VHR images should be used in all cases.

Using VHR sensors in remote sensing control, multispectral and panchromatic images are acquired simultaneously, and they can be effectively used together. After the geometric correction, pixel-based fusion is applied between corresponding multispectral and panchromatic images. Because they were acquired in the same satellite pass, there is no risk of the anomalies in the location of the parcels.

3.3. Disaster Monitoring

An important group of monitoring applications is disaster monitoring. In Hungary, several natural disasters happened in the past years due to extreme weather. Therefore, flood, waterlog and drought monitoring are very important applications. These phenomena can also be monitored by remote sensing, utilizing the advantages of different optical and radar images (see [7]).

Flood monitoring and prevention is important in Hungary as 95% of its surface water flows in from abroad. In the flood monitoring, the task is to follow the extent of the inundation and to forecast its progress. In the operational applications carried out by FÖMI, this task was mainly accomplished by visual evaluation. The time dimension has dual role in this application. Firstly, frequent acquisitions are needed to continuously monitor the flood situation. Secondly, the images have to be available in short time after the acquisition.

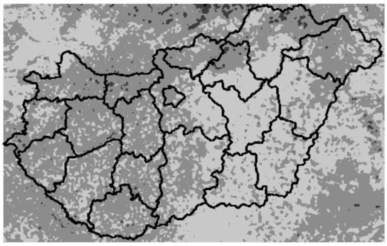
In the previous practice of FÖMI, all the possible and appropriate satellite images were used, including thermal and radar images. The importance of temporal dimension supercedes that of spectral properties (open water surfaces are well recognizable in most kinds of images) and of spatial resolution (the needed area accuracy is satisfied by any pixel size in the usual range).

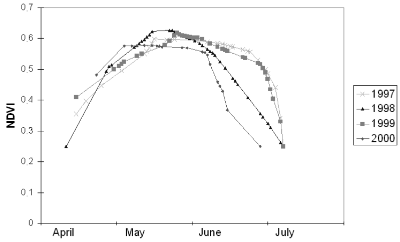
Drought monitoring was carried out in several years when drought seriously affected the growth of vegetation. This is often a retrospective monitoring, not a forecast. The remote sensing drought monitoring uses numeric, quantitative methods. The calculation is based on a vegetation index. Its physical background and implementation is similar to that of crop development monitoring, but in a "larger scale". It gives the general status of the vegetation, and it is not specific to the individual crop species. Occasionally, the elementary mapping unit of the monitoring is larger than the pixel size of the satellite images used. Temporal dimension is also used in a "larger scale", which means measurement values are examined over longer time periods (usually over weeks or decades). Although an appropriately dense time series is required for monitoring, the pixel values belonging to different days are not treated individually; instead, they are summarized over a certain time period.

The basis of the drought monitoring is the comparison of status of the vegetation at different dates — either between different periods of the same year, or between different years, as seen in Fig. 5. In general, remote sensing evaluates the status of the vegetation via quantities derived from physical measurements. In the specific case of development assessment and drought monitoring, this evaluation is rather sensitive to the proper knowledge of the correspondence between physical properties and values stored in the images. This is particularly true when different kinds of images are used. The derivation of compatible data sets from different sensors is called inter-calibration, and can be viewed as a case of image fusion. With proper usage of several sensors, more dates can be utilised in the examined periods, and the scope of the monitoring can be extended to several years — another issue of the temporal dimension.

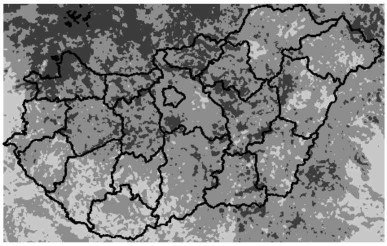
4. Conclusions

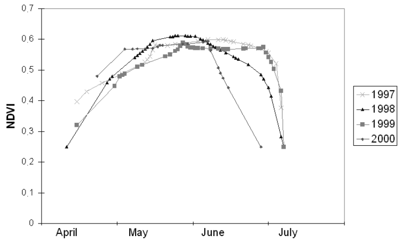
Several applications have been reviewed that illustrate the alternative fusion method based on the better integration of temporal information contained in satellite image series. Three aspects of the relevance of time dimension can be emphasized. Firstly, in the case of *frequent availability*, there are more data based on "real" measurements, and there is less need to interpolate the missing values. Besides, if the presence of clouds is an issue, then in a denser series of images there is a bigger chance to find appropriate coverage for the whole examined area. This aspect is very important in CROPMON, flood and drought monitoring, and in ragweed (ambrosia) control. Secondly, the *time needed to get the data after the acquisition* is also important in real time monitoring applications: first of all in flood monitoring, and in CROPMON. Thirdly, in some cases the time dimension is not only important within one year, but also the changes also have to be examined between years, which requires a *coherent multi-annual data set,* even from different satellite sensors. This issue arises in LPIS building, waterlog and flood monitoring.



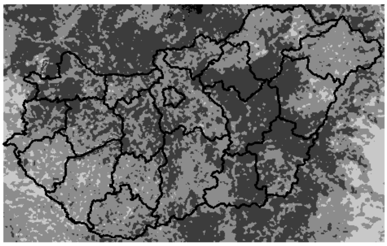


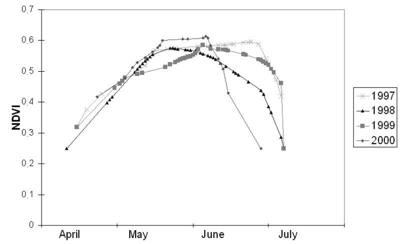
1991 Jász-Nagykun-Szolnok





1993 Hajdú-Bihar





2000 Tolna

Figure 5: Drought monitoring: the drought map of Hungary in three different years (left) and the time series of a vegetation index in three counties (right). On the maps, lighter shades indicate favourable crop development conditions, while darker shades indicate drought. On the charts, higher values of the vegetation index (NDVI) refer to more favourable crop development. The serious drought in year 2000 can be obviously seen in the figure.

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