Use of Very High Spatial Resolution Satellite Imagery for Thematic Applications: a Review

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Abstract – The launch, in recent years, of several very high spatial resolution satellite (VHSRS) systems for civilian use has initiated a new era in Remote Sensing and Earth Observation, creating both new opportunities and challenges. The aim of this paper is to provide an overview of the use of VHSRS imagery, with a focus on thematic applications. Thematic applications constitute the majority of the work done with VHSRS images but there are also a substantial number of photogrammetric studies and others addressing imagery properties (such as positional accuracy) or algorithms for information extraction. Within thematic applications land resources predominate, covering essentially the fields of natural resources management, spatial planning, urban areas, forestry and agriculture. The potential applications of VHSRS images have not yet been fully explored and more studies are needed to investigate further some of the enhanced characteristics but also limitations of these images.

Keywords: very high spatial resolution, satellite image, thematic application, land cover.

1. INTRODUCTION

In September 1999 the first of a series of very high spatial resolution satellites (VHSRS) was launched, initiating a new era in Remote Sensing and Earth Observation. Although very high spatial resolution remotely sensed data has been available for several decades through aerial photography, VHSRS systems provide a new source of multispectral imagery which approaches small to medium scale photography and is at the same time in digital format. This novel source of data creates both potential and challenges.

Numerous authors have mentioned the potential of VHSRS images, in a wide range of fields of application. Some examples of the expectations for the use of these images can be found in fields as diverse as (i) benthic cover characterisation (Mumby and Edwards, 2002), (ii) land cover and land use characterisation (Wang *et al.*, 2004) or (iii) digital base mapping at local scale (Davis and Wang, 2003).

However, VHSRS images shouldn't be regarded as a sort of panacea, since their emergence has created also several challenges (Goetz *et al.*, 2003), particularly in terms of image processing methodologies for information extraction. On the one hand the techniques developed for aerial photography are essentially based on visual interpretation. On the other hand, although the methods developed for lower resolution satellite imagery are automated, they often fail to capture the rich amount of spatial information contained in VHSRS images. Therefore, very high spatial resolution data in digital format requires new approaches or adaptation of conventional methodologies for information extraction (Giada *et al.*, 2003).

The prospects for VHSRS images and the substantial amount of research done until now using these images, in spite of the fact that they are relatively recent, make it appropriate to review the state-of-the-art in this matter, which, to the best of our knowledge, has not yet been done. In this framework, the objectives of this study are as follows (with a focus on thematic applications):

- Make an inventory and summarise the research done until now with VHSRS imagery;
- Identify the current research trends;
- Suggest new streams for research and/or reinforce the ones that are being followed.

The work investigated for this study covered only the use of imagery for civilian purposes, and was constituted by peer-reviewed articles published from January 1997 until October 2004.

A final note is due to clarify the terminology used in this study, since different authors use different terms (such as very high, high and fine spatial resolution) to designate the same type of images. Here the term very high spatial resolution designates satellite images from passive optical scanners, providing a spatial resolution higher than 5 m in multispectral mode.

2. VHSRS SYSTEMS

Three operational satellites fall under the definition of VHSRS adopted in this study, all privately owned: IKONOS (Space Imaging) was the first to be launched, in September 1999, followed by QuickBird (DigitalGlobe) in October 2001 and finally OrbView-3 (ORBIMAGE) in June 2003.

All of these satellite systems have sun-synchronous orbits, short revisit times (3 days or less) and a dynamic range of 11 bits. Additionally, they all have a flexible viewing angle and provide both multispectral (MS) and panchromatic (PAN) imaging modes. The spectral resolutions are very similar for

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each imaging mode, with three visible bands (blue, green and red) and one near infrared band in multispectral mode. The spatial resolutions are 0.72 m and 2.88 m for QuickBird, and 1 m and 4 m for IKONOS and OrbView-3 (off-nadir; PAN and MS, respectively, in each case).

At the commercial level, each system has different products available to users, which vary according to certain image characteristics (e.g. radiometric resolution, type and processing levels for geo-positional accuracy). In terms of data supply to customers, it is worth noticing that VHSRS only actually collect images in either of two situations: specific orders from customers and imaging according to each company's criteria. Overviews of the systems and descriptions of the products can be found in Dial *et al.* (2003) and Space Imaging Inc. (2004) for IKONOS, DigitalGlobe Inc. (2004) for QuickBird and ORBIMAGE Inc. (2004) for OrbView-3.

Unlike previous Earth Observation satellites, mostly owned by Governments, VHSRS are operated by private companies, thus being commercially explored. A striking difference between these two management approaches is the fact that image vendors may not, for commercial reasons, provide a full system characterisation (design and operation) to customers and this has created concern and scepticism among the scientific user community (Goward *et al.*, 2003).

In the case of privately owned systems there is thus the need for an independent assessment, in order to ensure that the data products delivered have in fact the specifications advertised by the vendors and in this way promote industry credibility amongst market communities (Birk *et al.* 2003). Additionally, it is also critical to have an independent and thorough characterization of the correspondent imagery products (Zanoni *et al.*, 2003). To date, the only VHSRS system for which there was an independent assessment and characterisation, is IKONOS. The Joint Agency Commercial Imagery Evaluation team constituted by different USA Government agencies, together with several USA and international Earth Science teams carried out this assessment and characterisation (Zanoni *et al.*, 2003). From the assessment of the imagery metric properties some specific technical uncertainties were detected, which were afterwards corrected by the vendor as a result of an open interaction with the evaluation teams. Both from this assessment and from the imagery characterization it was concluded that, overall, the IKONOS system supplies high spatial resolution multispectral imagery of high quality and provides a valuable source of land visible and near infrared measurements (Goward *et al.*, 2003).

3. THEMATIC EXPLORATION OF VHSRS IMAGERY

The majority of the work that is being done with VHSRS images focuses on thematic applications, although a substantial number of studies is dedicated also to photogrammetric issues, evaluation of the imagery properties and data products and development of algorithms for a better exploration of the images.

In the thematic applications of VHSRS images land resources predominate but there are a few studies in which these images are used to support water resources management, namely in water quality (e.g. Sawaya *et al.*, 2003) or in marine ecology studies, specifically in coral-reef characterisation (e.g. Mumby and Edwards, 2002). Land applications focus essentially on natural resources management and spatial planning although forestry, urban areas and agriculture are also important fields of application. Concerning natural resources and land management a wide variety of studies is covered [e.g. Cablk and Minor (2003) for watershed management; Laliberte *et al.* (2004) for change detection of natural vegetation; Wang *et al.* (2004) for coastal management]. In forestry the major issue has been to investigate the relationship between image spatial properties (specifically texture) and certain biophysical parameters [e.g. tree crown size (Song and Woodcock, 2003)]. Other studies have addressed general LCLU characterisation and diverse issues (e.g. shadow characterisation). For applications in agriculture, precision farming emerges as an important field where the potential of VHSRS images is being explored (e.g. Enclona *et al.*, 2004). In what concerns the use of VHSRS imagery in urban areas, LCLU characterization has been the major focus, either aiming at a general classification (e.g. Herold *et al.*, 2003), either at the extraction of specific urban features [e.g. buildings (Lee *et al.*, 2003)]. Small (2003) addresses specifically the characterisation of urban reflectance properties.

Overall, land studies focus mainly on LCLU characterisation but there are some that aim at characterising biophysical variables, especially in forestry [e.g. leaf area index (Colombo *et al.*, 2003)] and agriculture [e.g. crop yield (Enclona *et al.*, 2004)]. LCLU characterisation, aiming essentially at classifying land cover and/or land use types and in some cases at estimating the correspondent parameters, constitutes therefore the main common concern for the use of VHSRS images in land applications. It is equally worthwhile noticing that in land applications a few studies address specifically the extraction of large-scale features, trying to take advantage of the imagery's very high spatial resolution. Some examples are the extraction of tents in a refugee camp (Giada *et al.*, 2003), of shrubs in a desert ecosystem (Laliberte *et al.*, 2004), of buildings in an urban area (Lee *et al.*, 2003) or of mangrove canopies in a coastal area (Wang *et al.*, 2004).

Regarding the evaluation of the imagery properties and data products, the main focus is on issues related with positional accuracy, namely in view of evaluating the potential of VHSRS images for reference mapping at large-scale (e.g. Davis and Wang, 2003). In respect to the development of algorithms the majority of the papers addresses methods of information extraction.

In most cases, one single VHSRS sensor is used but there are also an important number of studies that involve different sources of remotely sensed data, either at the same or similar scale, either at distinct scales. Many of these multiple source studies aim at establishing a comparison between different VHSRS sensors or between very high and lower spatial resolution satellite imagery. An example of the former is the study conducted by Wang *et al.* (2004), where IKONOS and QuickBird performances are compared for the purpose of mapping mangrove species. The study done by Mumby and Edwards (2002) is an example of the later, where IKONOS performance for mapping coral reef habitats is compared to that of Landsat, *Système Pour l'Observation de la Terre* (SPOT) and Compact Airborne Spectrographic Imager (CASI). There are very few studies with a special focus on spectral properties, of materials and/or sensors. Herold *et al.* (2003), for example, evaluates the potential of three different sensors (one hyperspectral and two multispectral) for mapping urban areas. Thenkabail *et al.* (2004) compares the capability of four different sensors (one hyperspectral and with narrow bands, the others multispectral and with broad bands) for studying the complex biophysical and LCLU characteristics of rainforests. There are equally very few cost-benefit studies, i.e., studies that compare sensors not only in respect to their accuracy performance but also to their costs. The same applies to change detection and validation studies. The later are papers in which VHSRS images are not the study object being instead used to validate image products derived from coarser spatial resolution imagery (e.g. Morisette *et al.*, 2003).

In regard to the use of VHSRS imagery in panchromatic vs. multispectral mode, for thematic applications as well as for the development of algorithms, it was found that in general either multispectral images are used alone either in combination with panchromatic images. Few studies use solely the panchromatic band. Overall, this band is essentially used (i) for the visual enhancement of multispectral imagery, through pan-sharpening; (ii) to aid in visual-based tasks such as image interpretation; and (ii) to capture the imagery spatial properties, in view of using them as input variables (e.g. texture or objects) in information extraction methods.

The potential of VHSRS images, when compared with remote sensing sources that have been used prior to their emergence (e.g., Landsat, aerial photography), can be categorised as follows:

- Potential for performing existing tasks but at a large scale;
- Potential for performing existing tasks in an improved, expanded or more efficient manner;
- Potential for performing new tasks.

There doesn't seem to be any new application for VHSRS images. Therefore, the added value of VHSRS imagery lies essentially in performing existing tasks at a large scale (e.g. Davis and Wang, 2003) or in an improved, expanded or more efficient way, due to its novel characteristics, particularly the very high spatial resolution (e.g. Giada *et al.*, 2003).

It is also worthwhile mentioning that some of the potential applications foreseen before the emergence of VHSRS systems have not yet been fully explored or tested [e.g. some applications in urban areas mentioned by Jensen and Cowen (1999) or detection and mapping of ore deposits' features referred by Spatz (1997)].

A counterpart of the potential of VHSRS imagery is its limitations, which stem essentially from the systems' characteristics. The following disadvantages can be considered the main ones: (i) spectral resolution, namely the limited number of bands (Herold *et al.*, 2003) and the absence of a middle infrared band (Thenkabail *et al.*, 2004); (ii) high computer storage space and processing requirements (Aplin *et al.*, 1997); (iii) narrow swath width (Aplin *et al.*, 1997); (iv) high intra-class variability (e.g. Sawaya *et al.*, 2003); and (v) presence of shadows (e.g. Goetz *et al.*, 2003). Sensors with narrow swath widths acquire imagery over relatively small areas and this, as well as a high demand for computer storage and processing may have an impact on the feasibility of using VHSRS images at continental or global scales (Aplin *et al.*, 1997). For large areas, the relatively small size of the imagery constitutes a disadvantage also because there may be the need to mosaic and match scenes acquired in different conditions. Other factors that limit the use of VHSRS imagery are the high cost per Km^2 (e.g. Castro *et al.*, 2003) and the need for ordering the data products.

Finally, some considerations on the relation between VHSRS imagery and information extraction methodologies should be made. The methodologies to be used with VHSRS data are intrinsically linked with its characteristics, particularly the very high spatial resolution. For instance, information extraction methods that make use of spatial information (textural and contextual) are often used in order to take advantage of this type of imagery. This is one of the reasons why many authors consider that, to explore and process VHSRS images properly, there is a need for innovative methods or adaptation of the existing ones, namely incorporating additional spatial information in conventional methods, which are solely spectrally based (e.g. Colombo *et al.*, 2003).

4. FINAL REMARKS

From the analysis above exposed, the following research priorities can be pointed out, in view of a better use and a more thorough understanding of the capabilities and drawbacks of VHSRS images:

- Further exploration of potential applications that have not yet been fully tested;
- Further exploration of the combined use of VHSRS images together with data from sensors of different characteristics and potential (e.g. distinct spatial resolution and/or spectral properties);
- More investigation of the advantages of the combined use of panchromatic and multispectral imagery;
- Further evaluation of the potential advantages of the enhanced radiometric resolution;
- Further research of the possible limitations created by the very high spatial resolution itself (such as shadows or high intra-class variability);
- More cost-benefit studies, in order to not only compare the accuracy performances of different remote sensing data sources, but also the respective costs, in view of practical and operational matters.

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