SUMMARY OF CAPACITIES AND POTENTIAL APPLICATIONS OF THE FIRST CHILEAN HYPERSPECTRAL SYSTEM

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Abstract

Introduction
Remote sensing is a scientific discipline that retrieves physical and chemical information of an element by detecting and analyzing its radiated energy at given spectral wavelength intervals. During the 80's decade advances in spectroscopy imagery allowed for the creation of the first airborne hyperspectral imaging spectroradiometers. Since then, they have gained increased reputation for Earth's natural resource surveys, mostly in developed countries. Currently, this technology is being implemented in Chile also, through the Prototype System of Hyperspectral Remote Sensing (Sistema Prototipo de Observación Remota Hiperespectral, SPORH). SPORH is the first Chilean initiative that offers to any interested user imagery, thematic cartography and information of the national agricultural and forest lands derived from our own hyperspectral scanner. The system has been originally designed to operate at local spatial scales in order to provide relatively economical "just in time" products to small owners (e.g., winegrowers). Nevertheless, applications at larger spatial scales will also be considered.

Objectives
The aim of this paper is first, to present the main technical properties of SPORH and then, to present a general review about hyperspectral applications on agricultural and forest lands.

Methodology
In principle, the applications of SPORH will be mainly focused on contributing to the monitoring and management of agricultural and forest lands. This will be achieved by taking advantage of the great capacity that SPORH offers to obtain detailed spectral information regarding the vegetation's physiology, with high spatial detail levels and during temporal windows associated with critical phenological stages. The methodological approaches that will be employed to obtain the first products of SPORH are reviewed here in light of continuous variables (e.g., nutritional vegetation status) and discrete variables (e.g., vegetation species discrimination). The above-mentioned implies to relate vegetation properties sampled in the field with reflectance data obtained from SPORH by predictive and correlation models and automatic classifiers.

Results and Conclusions

The spectral, spatial, radiometric and temporal properties of SPORH are encouraging to carry out novel applications such as those mentioned in this paper. Therefore, it is expected that SPORH will provide high quality information for the national agricultural and forest lands, thus contributing to their planning, particularly at local spatial scales.

Introduction

We can experience nature because we have senses such as vision. From this perspective, the human eye is a “remote” type sensor, because permits us to derive information of a given element without needing to contact it. To do this, it detects the radiation reflected from the element’s surface. Nevertheless, human eye is only sensitive to a small range of spectral wavelengths, known as visible dimension (i.e., light). This dimension is composed by the blue, red and green regions, named so because of the distinctive colour that human eye sense from each one. Based on the same principle as human vision, the remote sensing discipline derives physical and chemical information of an element, not only from visible dimension but from many other spectral ranges (Lillesand, *et al.*, 2004; Aronoff, 2005).

In the early 80’s, advances in spectroscopy and remote sensing techniques and technologies gave rise to the hyperspectral imaging, that is to say, the capacity of acquiring and analyzing images across hundred of contiguous spectral sampling intervals (i.e., bands). Since then, hyperspectral remote sensing has vastly proved its usefulness to study the Earth’s natural resources in-depth. As its name suggests, hyperspectral imagery is “over” or “above” the capacities of panchromatic and multispectral imagery, because it contains much more bands than traditional remote sensing products. More bands means more potential information about the physical and chemical composition of the element, and hence a greater knowledge of its nature. Since many compounds of a given element produce distinctive signals at very narrow wavelengths (≤ 10 nm), only by using hyperspectral sensors we can identify it (Lillesand, *et al.*, 2004; Lucas, *et al.,* 2004; Borengasser, *et al.*, 2008).

For vegetation-related surveys, hyperspectral remote sensing provides information about several physiological and structural parameters of the plant. Foliar content of pigments (e.g., chlorophyll, carotenoid, anthocyanin and xanthophyll), nutrients (e.g., nitrogen and phosphorus) and water, as well as canopy foliage amount, can be measured with great accuracy at specific visible and infrared hyperspectral bands. These measurements have shown to be closely related to nutritional and productivity status, growth and developmental stage, photosynthetic rate and capacity, and healthy or stressed status of the plant (Gamon, *et al.*, 1992; Vogelmann, *et al.*, 1993; Fillela and Peñuelas, 1994; Peñuelas, *et al*. 1993, 1994, 1995, 1997; Gitelson and Merzlyak 1994a, b; Blackburn, 1999; Gamon and Surfus, 1999; Serrano, *et al*. 2000, 2002; Gitelson, *et al*. 2001, 2002; Sims and Gamon 2002, 2003).

The Prototype System of Hyperspectral Remote Sensing (Sistema Prototipo de Observación Remota Hiperespectral, SPORH) is a Chilean initiative currently being impemented by Oterra, Universidad Mayor, and Infraeco, Aretech Group. It consists of a hyperspectral scanner mounted, primarily, on an ultralight aircraft for imagery acquisition of the Earth's surface. The project seeks to offer to any interested user imagery, thematic cartography and information of the national agricultural and forest lands derived by our own hyperspectral remote sensing means. The system has been originally designed to operate at local spatial scales in order to provide relatively economical "just in time" products to small owners (e.g., winegrowers). Nevertheless, applications at larger spatial scales by using conventional aircrafts (e.g., Twin Otter) will also be considered. The first images to test the SPORH capacities will be acquired during the summer of 2009-2010 in the central zone of the country. The aim of this paper is (1) to present the main technical properties of SPORH, and (2) to present an overview of hyperspectral applications on agricultural and forest lands.

Methodology

A systematic bibliographical review of scientific journals (ISI (Information Sciences Institute)-indexed mostly) and books related to hyperspectral remote sensing applications was carried out during the preparation and the current stage of the project. The aim was to perform a rigorous selection of novel hyperspectral applications in the agricultural and forestry fields, in order to assess their usefulness for the project's concerns and their potential replication by using SPORH. Revisions of studies that have used instruments with similar technical properties to ours were privileged. These properties were mainly based on the spectral sensitive, spectral resolution, radiometric resolution, spatial resolution and transport platform of the scanner.

Contact with several authors of scientific articles, as well as the research and technical staff of international agencies such as EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), Sao Carlos, Brazil, and Norsk Elektro Optikk, Lørenskog, Norway, permitted a further insight into methodological topics of the applications of interest.

A pilot project carried out in Ciprés de la cordillera (*Austrocedrus chilensis*) forests by using satellite hyperspectral imagery (Peña and Altmann, 2009), was the first approach of Oterra to an application of this type of technology within the Chilean territory (to our knowledge, this was the first national hyperspectral-based study). The results showed good correlations between some hyperspectral-derived vegetation indices and tree stress symptoms sampled in the field. The above-mentioned contributed to support our future efforts for SPORH implementation.

Technical properties of SPORH

The main instruments that SPORH comprises are (1) a Hyspex VNIR-1600© hyperspectral imaging spectrometer, (2) an Imar iTraceRT–F200-E© direct positioning system, and (3) a Flightstar-IISC© ultralight aircraft. The scanner is spectrally sensitivity to wavelengths located between 400 and 1,000 nm (i.e., visible and near infrared wavelengths). This spectral range is divided into 160 bands, thus rendering bandwidths of 3.7 nm. In each band, radiation levels (i.e., voltage) are measured in a scale of 4,096 values in $W/m^2 \times nm \times sr$ units (i.e., 12 bit depth). A linear array of 1,600 voltage detectors and a field of view of 17° allows the scanner to acquire high spatial resolution images (i.e., hyperspatial) even sweeping an area far away from the ground. The direct positioning system integrates an inertial measurement unit (IMU) and a global positioning system (GPS). This high precision navigation system permits recording the precise three-dimensional orientation of the scanner at each exposure and to calculate their position and attitude for the subsequent image geometric correction (i.e., georreferencing and orthorectification) with accuracies of less than 10% of a pixel.

The ultralight aircraft power supply at cruising speed (150 w) makes the continuous operation of the instruments without batteries possible. Its minimum speed (72 km/h) ensures the acquisition of high radiometric quality and spectrally integral images even at very low flying heights (e.g., 100-200 meters above the ground). Its weight capacity (220 kg) allows transporting the instruments (≈ 40 kg) the pilot and one more crew even. Its flight autonomy (3.5 h) favours the image acquisition at the time of the best terrain relief illumination and solar radiation intensity (i.e., ± 2 h from solar cenit). Its relatively low consumption of fuel (ultralight = 10 l/h, conventional aircraft = 40 l/h) in addition to the availability of more than 350 national aerodromes (without considering any flat land that could serve as a runway), give it great spatial coverage and great chance to fly an area “just in time” (e.g., within the temporal window associated with a specific developmental stage of vegetation), at relatively low costs. Moreover, its simple structure made up of light materials (e.g., aluminium, fiberglass, polyester) make it possible to transport it by land by using conventional motorized vehicles. Complementary operations consider mounting the scanner on conventional aircrafts provided by the Aerophotogrammetric Service (Servicio Aerofotogramétrico, SAF) in order to acquire images at spatial scales prohibitive for the ultralight aircraft.

Hyperspectral applications on agricultural and forest lands

Scientific literature provides a large amount of studies that have used hyperspectral data to study the Earth’s natural resources. In the case of agricultural and forest lands, hyperspectral applications can be divided in those focused on the extraction of information related to continuous variables and to discrete variables. One of the most studied continuous variables is the foliar content or concentration of pigments and nutrients. The remotely sensed estimation of such leaf`s biochemicals has proven to be very useful for the condition assessment and the monitoring and management of several crops (e.g., corn, soybean, rice, wheat, potato, cotton) (Blackmer, *et al*., 1996; Osborne, *et al*., 2002; Read, *et al*., 2002; Zhao, *et al*., 2005; Haboudane, *et al*., 2004; Stroppiana, *et al*., 2006; Jain, *et al*., 2007), grasses (Sembiring, *et al*., 1998; Mutanga, *et al*., 2003) and woodlands (Kokaly and Clark, 1999; Dury and Turner, 2001; Kokaly, 2001; Coops, *et al*., 2003a; Ferweda, *et al*., 2005; Min and Lee, 2005; Huang, *et al*., 2007). By means of this application, information associated with the preventive and corrective actions and treatments that should be taken to avoid vegetation stress, the prediction of yield surpluses or shortfalls, and the right moment at which selective harvest should be made, has been able for large cultivated areas and at relatively low costs (Aronoff, 2005). In a similar way, the estimation of leaf's biochemical has contributed to detect and track symptoms induced by biotic stressors on vegetation, providing encouraging information for the damage assessment over large and inaccessible forested areas (Treitz and Howarth, 1999; Coops, *et al*., 2003b; Entcheva Campbell, *et al*., 2004; Stone and Coops, 2004; Peña and Altmann, 2009).

Procedures have been focused on relating reflectances to leaf`s biochemicals in order to find the spectral wavelengths more related to their abundance changes (Bauer, 1985; Blackburn, 1999). To achieve this, arithmetic combinations of bands have been correlated to foliar pigment or nutrient concentrations, or fertilization rates, sampled in the field. These combinations are known as spectral indices, and the difference between two bands, normalized through division by the sum of those bands (i.e., normalized difference index) has demonstrated to be a formula that works well across many agricultural and forest land types, though many others have been successfully tested in specific study cases (Sembiring, *et al*., 1998; Jain, *et al*., 2007; Read, *et al*., 2002; Haboudane, *et al*., 2004; Ferweda, *et al*., 2005; Zhao, *et al*., 2005; Stroppiana, *et al*., 2006). Another method commonly used to relate reflectances to leaf`s biochemicals has been the multiple linear regression analysis, which attempt to find the best bands combination for predicting variations of a dependent variable. Stepwise and Partial Least Squares models have rendered strong coefficients of determination, particularly when mathematically transformed reflectances (by logarithm, derivative, inversion or continuum removal techniques) have been used (Blackburn, 1999; Kokaly and Clark, 1999; Dury and Turner, 2001; Kokaly, 2001; Osborne, *et al*., 2002; Read, *et al*., 2002; Coops, *et al*., 2003a; Jarmer, *et al*., 2003; Huang, *et al*., 2004; Min and Lee, 2005; Huang, *et al*., 2007).

Regarding discrete variables, land use/land cover and species classifications conform the bulk of hyperspectral applications on vegetation resources. Image's classification is undertaken by applying algorithms that attempt to discriminate the variability of the surface elements. To do this, they statistically analyze the reflectance curves from the targets of interest in order to find distinctive spectral signals that allow their discrimination. Novel classifications have been successfully carried out in agricultural lands, with the purpose of discriminate grape varieties in vineyards (Lacar, *et al*., 2001; Ferreiro-Armán, *et al*., 2006), as well as crop types (Clark, *et al*., 1995). In both cases, classifications have reached very high accuracies with regard to the real spatial distribution of the targets (i.e., ground truth data).

Conclusions

This paper synthesizes the main applications of hyperspectral imaging to agricultural and forest lands, and highlights some of the more successful methodological approaches performed in this matter.

Hyperspectral imaging is a new technology in Chile that currently is being implemented through SPORH. The spectral, spatial, radiometric and temporal properties of SPORH are encouraging to carry out novel applications such as those mentioned in this paper. Therefore, it is expected that SPORH will provide high quality information for the national agricultural and forest lands, thus contributing to their planning, particularly at local spatial scales.

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