STUDYING SOIL THREATS USING VISIBLE AND NEAR INFRARED SPECTRAL ANALYSIS

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ABSTRACT:

In this study, imaging spectrometry and hyperspectral remote sensing are tested as instruments for rapid mapping of soil properties over large areas. In particular, the studies carried out in order to relate soil chemical and physical properties to their spectral features are exposed; these tests, performed both in the field and in laboratory, are ancillary and preparatory for image analysis from air-borne sensors. The obtained data will be useful for assessing the risk of occurrence for typically agricultural practice-related soil threats (compaction, erosion, landslides, organic matter decline, contamination, salinization, ect.). The study was carried out in the Chianti hillsides, to the south of Firenze, where soils with agricultural suitability have a high economic value connected to the production of internationally famous wines and olive oils. Technical features of the hyperspectral sensors, as well as details on a simulating procedure for imaging sensors, are also provided.

1. INTRODUCTION

Imaging spectroscopy is a new remote sensing tool that, combining VNIR and SWIR reflectance spectroscopy of every pixel in a spatial image with high spectral resolution, contiguous placement of bands and good spatial resolution, may allow rapid and effective assessment and mapping of soil properties, reducing times and expenses of sampling and laboratory analyses.

In the last decades, the advent of modern satellite- or air-borne hyperspectral imaging systems opened interesting perspectives on the possibility of identifying a wide variety of materials on the earth surface, otherwise non-detectable through present-day, large band, low spectral resolution satellite-borne multispectral systems (Vane & Goetz, 1988; Green, 1998).

Imaging spectrometry in the VNIR and SWIR spectral ranges by means of remote sensors provides simultaneously many narrow, contiguous spectral bands and high-resolution reflectance spectra, thus allowing identification and mapping of a wide range of surface materials (Goetz et al., 1985). The use of field-portable spectroradiometers allows direct reflectance measurements, that can be used to study of the relationships between soil chemical and physical properties.
and reflectance, or as “ground truth” for validation and calibration of remotely sensed multispectral and hyperspectral data (Deering, 1989; Escadafal, 1994) and thus for the evaluation of potential application of remote sensing to the study of soil threats (e. g.: erosion, landslides).

Since pedogenesis modifies chemical, mineralogical and physical properties, thus producing typical spectral signatures that are detectable though remote sensing (Fisher, 1991), absorption features in soils result from the overlapping bands from different mineral components (clays, carbonates, iron oxides, water) and organic matter. The preliminary results and possible perspectives of a study (carried out inside the Tuscany Region Project SKY-EYE and the EU FP-7 Project DIGISOIL), focused on finding the most appropriate techniques for rapid mapping over large areas of threat-linked soil properties, are here exposed.

2. INSTRUMENTS AND METHODS

The main instruments available for this research are the field portable spectroradiometer ASD FieldSpec Pro and the imaging sensor SIM-GA, whose precise technical specifications are summarized in table 1. The Galileo Avionica Multisensor Hyperspectral System (SIM-GA), operating since 2006, is a modular pushbroom avionic hyperspectral imager, composed by two electro-optical heads in VNIR and SWIR spectral range (from 0.4 µm to 2.5 µm) and a digital acquisition system, which acquires images with a continuous spectral sampling up to over 700 channels. On the basis of this modular approach, the two optical heads are physically separated but co-aligned on a common plate and to a common inertial/GPS unit. This concept allows a flexible application-driven configuration of the instrument and its installation both on a static scanning platform for ground-based applications as well as on airborne platforms, including ultralight aircrafts. In the framework of DIGISOIL and SKY-EYE Projects, the SIM-GA configuration has been updated for the foreseen flight activity and ground-based campaigns on ground plots. The system performances and characterisation, as well as data acquisition capabilities and operability on board of the FOLDER ultra-light plane of the Earth Science Dept. of the University of Firenze, have been improved in terms of total budget for available acquisition time, total mass (SIM-GA + batteries) and power reductions.

<table>
<thead>
<tr>
<th>SIM-GA</th>
<th>VNIR Spectrometer</th>
<th>SWIR Spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Range</td>
<td>400-1000nm</td>
<td>1000 – 2500nm</td>
</tr>
<tr>
<td>Spectral Sampling</td>
<td>1.2nm</td>
<td>5.8nm</td>
</tr>
<tr>
<td>Spectral bands</td>
<td>512</td>
<td>256</td>
</tr>
<tr>
<td>Spatial pixels</td>
<td>1024</td>
<td>320</td>
</tr>
<tr>
<td>IFOV</td>
<td>0.7mrad</td>
<td>1.33mrad</td>
</tr>
<tr>
<td>FOV</td>
<td>±19.8°</td>
<td>±12°</td>
</tr>
<tr>
<td>GSD@H=1000m</td>
<td>0.7m</td>
<td>1.33m</td>
</tr>
<tr>
<td>SWATH@H=1000m</td>
<td>700m</td>
<td>425m</td>
</tr>
<tr>
<td>Digital resolution</td>
<td>12 bit</td>
<td>14 bit</td>
</tr>
<tr>
<td>Sensor</td>
<td>Frame transfer CCD</td>
<td>CMT cooled @200K</td>
</tr>
<tr>
<td>Operating Frame Rate</td>
<td>54Hz</td>
<td>27 Hz</td>
</tr>
<tr>
<td>Operating Data Rate</td>
<td>54MB/s</td>
<td>4.2MB/s</td>
</tr>
<tr>
<td>Total Data Rate</td>
<td>58.2MB/s</td>
<td></td>
</tr>
<tr>
<td>H/v</td>
<td>27s</td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th>Reflectance</th>
<th>ASD FieldSpec</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV</td>
<td>25°</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>350-2500 nm</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>3-10 nm</td>
</tr>
<tr>
<td>N° Bands</td>
<td>2151</td>
</tr>
<tr>
<td>Sampling Intervals</td>
<td>1.4 nm (350-1000 nm)</td>
</tr>
<tr>
<td></td>
<td>2 nm (1000-2500 nm)</td>
</tr>
<tr>
<td>Freq. of acquisition</td>
<td>10 spectra/sec</td>
</tr>
</tbody>
</table>

Table 1. SIM-GA and FieldSpec main technical specifications.
the field and in laboratory, using a portable hyperspectral device (ASD-FieldSpec 3 Pro), operating in the 350-2500 nm spectral range. The collected data are used to gain in understanding the spectral characteristics of soils, to relate them with soil properties (such as moisture content, CaCO3 content, organic matter content and texture) and to use this knowledge to assist in interpreting hyperspectral imagery (calibration and validation reference points in the SIM-GA field of view). For this objective, some experimental calibration relationships, based on laboratory data, have been retrieved, showing very smaller errors with respect to ground field measurements.

For laboratory soil spectral measurements, a dedicated nadir viewing set-up, including two halogen-tungsten lamps (24 V; 70 W), connected with a stabilized power supply device (TTi EX354D; Dual Output; 35V; 4A; 280W), was used. Lamps are located laterally with respect to the sample, at a distance of 60 cm and inclined at 45°. Optic fibre is in nadir position, at a height of 5-10 cm above the sample, resulting in a table-projected field of view diameter of 2-4,5 cm. For outdoor spectral measurements, when low or unsteady sun illumination occurred, an ASD contact probe with a 5W lamp was used, allowing an elliptic footprint sampling of about 12mm×10 mm.

Moreover, an end-to-end software tool (implemented in ENVI-IDL environment), for generation of simulated data from remote sensing optical and infrared instruments, is being developed and tested. The simulator is conceived as an aid to the specification and early development of new ear observation instruments, with the aim of evaluating their capability to meet the user’s requirements for defined applications and of tuning the new sensor concepts to those applications, through a process of cost/performance trade-off. High resolution imagery is used as simulation input, along with the sensor specifications. The implemented tool is based on three different core modules: (1) the scenario simulator (2) the instrument simulator and (3) the atmospheric simulator. The input data to the simulator can be either airborne reflectance images at high spatial, spectral and radiometric resolution or synthetic images. Moreover, detailed specifications of the airborne/space-borne instrument to simulate (spatial and spectral response, sampling, transfer function, noise, viewing geometry, quantization, etc.) are necessary as specific input parameters as well.

### 3. STUDY AREA LOCALIZATION, GEO-PEDOLOGIC OUTLINE AND LAND USE

The study area is located in central Italy, in the famous Chianti Region, on the hillsides about 20-30 km south of Firenze. Soils with agricultural suitability have a high economic value connected to the production of internationally famous wines and olive oils. Thus, soil threats, such as erosion and landslides, may determine remarkable economic losses, which must be considered in farming management practice. Almost all the agriculturally suitable terrains are devoted mainly to vineyards, olive groves and annual crops. The test site is the Virginio river basin. It has a length of about 23 km for a basin area of around 60,3 km². Geological formations outcropping in the area are Pliocene to Pleistocene marine and lacustrine sediments in almost horizontal beds. The soils developed in this area mostly belong to the Inceptisols, Entisols and Alfisols orders (Soil Survey Staff, 1999).

A typical Mediterranean climate prevails with a dry summer, followed by intense and sometimes prolonged rainfalls in autumn, decreasing in winter. Erosion and landslides affect each type of land use.

### 4. SAMPLING CRITERIA

In the test site we selected 8 points of measurement, where we acquired a total of
about 250 spectra, in the period comprised between July and September 2008, both in bare fibre and ASD contact probe mode and collected samples for laboratory analyses (maximum depth: 5 cm). The locations of soil samples were identified using a GPS unit. Spectral measurements were repeated in laboratory. Since sedimentary deposits in the study area are characterized by lateral-vertical facies variations (alternation of lenticular clayey-silty, sandy and pebbly centimetric to metric levels), we performed measurements and sampling only in those areas where the horizons with the most uniform grain size cropped out, in order to avoid the occurrence, for instance, of large (centimetric-decimetric) carbonate or sandstone pebbles, which might cause problems related to the representativity of laboratory samples. For every point of measurement, two spectra were acquired: one from a height of 20 cm and one from a height of 1 m, in order to test the influence of the sample representativity on the model, since the dimension of the area “viewed” by the instrument increases with increasing fibre-target distance, provided that the field of view is kept constant (25° for the bare fibre). Figure 1, for instance, outlines the close relation between spectral features with different height of acquisition. The influence of the changed shooting geometry (i.e.: different amount of electromagnetic energy reaching the sensor, changed dimension of soil sample area) is negligible.

5. DATA ANALYSIS

For all the following parameters (except organic matter content) the band-depth analysis was applied (Clark & Roush, 1984). This analysis consists of the calculation of absorption band depth relative to the reflectance continuum across the interval; the continuum can be considered as the reflectance of the background absorption and scattering materials in the absence of the specific physicochemical absorption.

In order to verify the influence of grain size on reflectance, the laboratory bare-fibre reflectance spectra of soil crushed samples (separated using sieves: 4750 μm, 425, 250 μm, 125 μm, 75 μm) were acquired. The results are showed in figure 2, where absolute reflectance values at 1630 nm are plotted relative to grain size, confirming, for a certain lithology, an exponential increasing of reflectance with the decrease of grain size, as found by many authors (Bower & Hanks, 1965; Stoner & Baumgardner, 1980; Palacio-Orueta & Ustin, 1998).
Due to absorption of electromagnetic energy by water, soil moisture causes a drop of total reflectance throughout the entire 400-2500 nm spectrum (Bowers & Hanks, 1965). The collected samples have been weighted in the field and then stored in plastic bags, carried to laboratory and oven-dried for 24 hours at 105°C, in order to determine weight loss due to natural soil moisture. Then, weight percentages of 5, 10, 15, 20 and 25 % of water were added to dried samples sieved over a 425 μm sieve and the reflectance spectra were acquired in laboratory, using artificial illumination. In figure 3 the 1460 nm normalized absorption peak depth values are plotted versus the water content. A satisfying agreement is showed between field and laboratory data, while figure 4 evidences the close relationship between moisture-related 1940 nm and 1460 nm absorption peaks depth values.

Calcium carbonate in soils generally causes increase of soil reflectance (Girard & Girard, 1989) and shows absorption bands in the SWIR region, the more evident near 2300 and 2350 nm. Calcium carbonate in soils generally causes increase of soil reflectance (Girard & Girard, 1989) and shows absorption bands in the SWIR region, the more evident near 2300 and 2350 nm.

In our study, the portion of natural soil samples passing through the 425-micron sieve was mixed with increasing amounts of a standard calcite powder (purity higher than 98%). The total concentration of CaCO₃ was calculated by adding the natural CaCO₃ content in the samples, determined with calcimetry. The comparison between laboratory and field data is shown in figure 5, where normalized absorption peak depth values are plotted versus CaCO₃ percentage, showing a very good agreement between field and laboratory data.

Soil organic carbon (SOC) deeply influences soil reflectance and colour and represents a crucial indicator of soil erosion and of soil water holding capacity and permeability.
(Palacios-Orueta & Ustin, 1998; Palacios-Orueta et al., 1999). As organic matter content increases, reflectance decreases through the whole spectral interval 400-2500 nm (Hoffer & Johannsen, 1969; Palacios-Orueta & Ustin, 1998). Moreover, according to Stoner & Baumgardner (1981) and with Latz et al. (1984), organic matter should cause a decrease in slope and a concave or linear shape of the spectrum in the range 500-800 nm. In this study, 15 soil samples from the test site were crushed and sieved over a 200 µm sieve and analyzed for SOC content using the Walkley-Black method (Walkley & Black, 1934). The results showed extremely low contents of organic matter (<0.5%). Then, pulverized material, passing through the 425-micron sieve, was added with known and increasing amounts of an agricultural fertilizer with 48% of organic matter. Spectral data showed a decrease of the slope of the interpolation line between 600 nm and 750 nm, confirming the flattening effect produced by organic matter on soil spectra (figure 6).

6. PRELIMINARY CONCLUSIONS AND PERSPECTIVES

In the framework of high resolution imagery-based SKY-EYE and DIGISOIL projects, this study preliminarily explores the relationships between spectral and physicochemical data of about 250 soil samples for the Chianti area, with the aim of finding the best-fitting spectral predictors of soil properties, that might be extracted from SIM-GA or other airborne/spaceborne sensors. Obtained results are almost encouraging for future activity, which will include hyperspectral images acquisition and ground-truth campaign in the Chianti area. Further efforts will be dedicated to other laboratory experiments and data treatment; in particular, a spectroscopy/XRD-based procedure for quantitative evaluation of clay mineral content and a multivariate statistical approach to SOC content analysis, based on a partial least square regression technique, using ParLes 3.1 (Viscarra-Rossell R.A., 2007) are being attempted.

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