

# 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  $\mu\text{m}$  to 2.5  $\mu\text{m}$ ) 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.

SIM-GA		
	VNIR Spectrometer	SWIR Spectrometer
Spectral Range	400-1000nm	1000 – 2500nm
Spectral Sampling	1.2nm	5.8nm
Spectral bands	512	256
Spatial pixels	1024	320
IFOV	0.7mrad	1.33mrad
FOV	$\pm 19.8^\circ$	$\pm 12^\circ$
GSD@H=1000m	0.7m	1.33m
SWATH@H=1000m	700m	425m
Digital resolution	12 bit	14 bit
Sensor	Frame transfer CCD	CMT cooled @200K
Operating Frame Rate	54Hz	27 Hz
Operating Data Rate	54MB/s	4.2MB/s
Total Data Rate	58.2MB/s	
H/v	27s	

ASD FieldSpec		
Refl	FOV	25°
ecta	Spectral Range	350-2500 nm
	Spectral Resolution	3-10 nm
	N° Bands	2151
	Sampling Interval	1.4 nm (350-1000 nm) 2 nm (1000-2500 nm)
	Freq. of acquisition	10 spectra/sec

Table 1. SIM-GA and FieldSpec main technical specifications.

nce measurements were performed, both in

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, CaCO<sub>3</sub> 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 earth 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 km<sup>2</sup>. 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

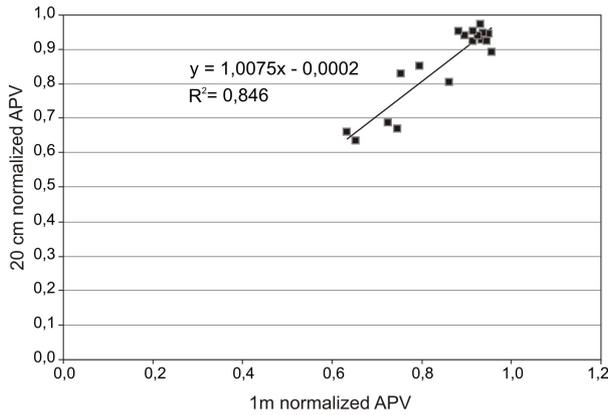


Figure 1. Relation between normalized absorption peak values (at 1460 nm) of spectra acquired from 20 cm and 1 m above the soil.

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  $\mu$ m, 425,  $\mu$ m, 250  $\mu$ m, 75  $\mu$ m) 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; Palacios-Orueta & Ustin, 1998).

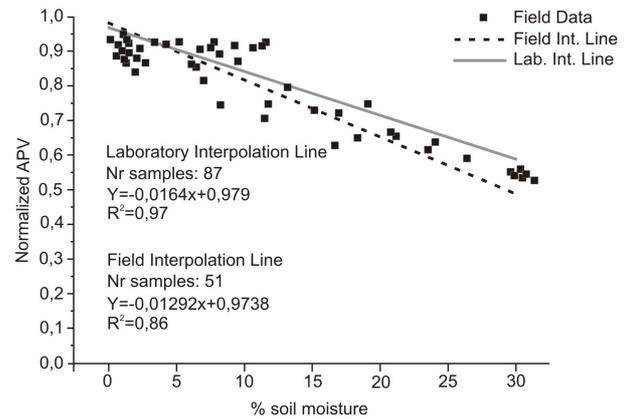


Figure 3. Normalized absorption peak values (at 1460, after Bower & Hanks, 1965) versus soil moisture (%).

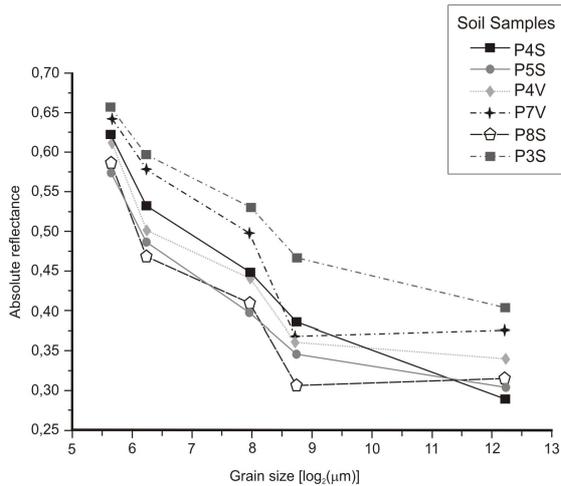


Figure 2. 1630 nm absolute reflectance values versus grain size.

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

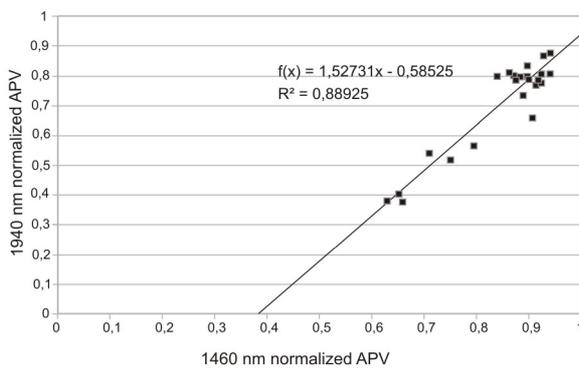


Figure 4. Comparison between normalized absorption peak depths for typical soil water spectral features at 1940 nm and 1460 nm.

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

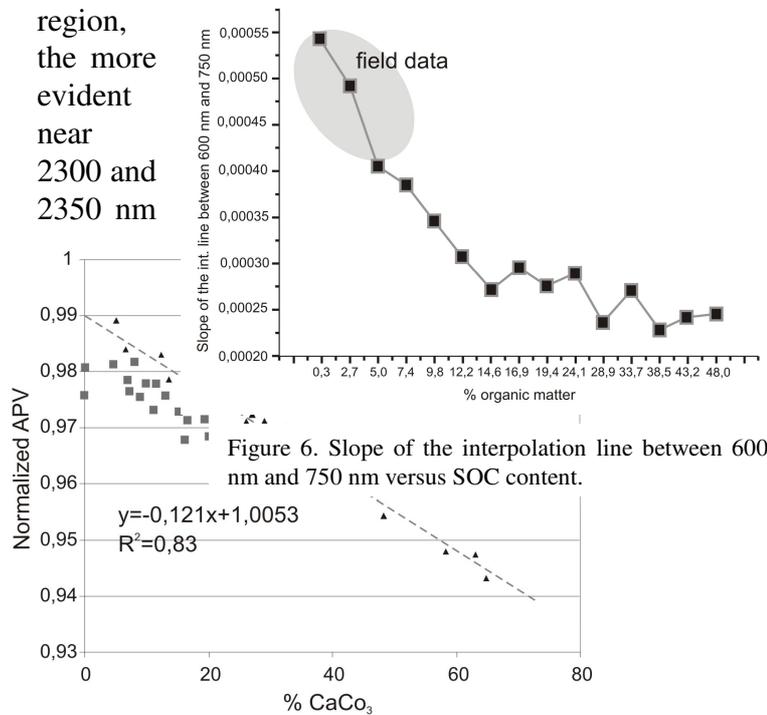


Figure 6. Slope of the interpolation line between 600 nm and 750 nm versus SOC content.

Figure 5. Normalized absorption peak values (at 2436 nm) vs calcium carbonate content (%). Field data acquired in contact probe mode, in order to reduce noise in spectrum tails.

(Hunt & Salisbury, 1971).

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 CaCO<sub>3</sub> was calculated by adding the natural CaCO<sub>3</sub> 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 CaCO<sub>3</sub> 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  $\mu$ m 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 air-/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.

## REFERENCES

- Bowers, S.A., Hanks, A.J., 1965. Reflection of radiant energy from soil. *Soil Science*, 100, pp. 130-138.
- Clark, R.N., Roush, T.L., 1984. Reflectance spectroscopy: quantitative analysis techniques for remote sensing applications. *Journal of Geophysical Research*, 89, pp. 6329-6340.
- Deering, D.W., 1989. Field measurements of bidirectional reflectance. In: Asrar, G. (ed.), *Theory and Applications of Optical Remote Sensing*. Wiley and Sons, New York, p. 14-61.
- Escadafal, R., 1994. Soil spectral properties and their relationships with environmental parameters: examples from arid regions. In: Hill, J., Mégier, J. (eds.), *Imaging Spectrometry - a tool for environmental observations*. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 71-87.
- Fisher, A.W., 1991. Mapping and correlating desert soils and surfaces with imaging spectrometry. In: *Proceedings of the third airborne visible/infrared imaging spectrometer (AVIRIS) Workshop*, JPL Publication, 91, pp. 23-32.
- Girard, M.C., Girard, C.M., 1989. *Téledétection Appliquée. Zones tempérées et intertropicales*. Masson, Paris, 260 p.
- Goetz, A.F.H., Vane, G., Solomon, J.E., Rock, B.N., 1985. Imaging Spectrometry for Earth Remote Sensing. *Science*, 228 (4704), pp. 1147 – 1153.
- Green, R.O., 1998. Imaging spectrometry and the Airborne Visible/Infrared Imaging

Spectrometer AVIRIS. *Remote Sensing of Environment*, 65, pp.227-345.

Hoffer, R.M., Johannsen, C.J., 1969. Ecological potentials in spectral signature analysis. In: Johnson, P.L. (ed.), *Remote sensing in ecology*. University of Georgia Press, Athens, pp. 1–29.

Hunt, G.R., Salisbury, J.W., 1971. Visible and near-infrared spectra of minerals and rocks - 11: Carbonates. *Modern Geology*, 2, pp. 23-30.

Latz, K., Weismiller, R.A., Van Scoyoc, G.E., Baumgardner, M.F., 1984. Characteristic variations in spectral reflectance of selected eroded alfisols. *Soil Science Society of America Journal*, 48, pp. 1130-1134.

Palacios-Orueta, A., Ustin, S.L., 1998. Remote sensing of soil properties in the Santa Monica Mountains – I: Spectral Analysis. *Remote Sensing of Environment*, 65, pp. 170-183.

Palacios-Orueta, A., Pinzon, J.E., Ustin, S.L., Roberts, D.A., 1999. Remote sensing of soil properties in the Santa Monica Mountains – II: hierarchical foreground and background analysis. *Remote Sensing of Environment*, 68, pp. 138–151.

Soil Survey Staff, 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. *Agriculture Handbook*, 436. United States Department of Agriculture, Natural Resources Conservation Service, 871 p.

Stoner, E.R., Baumgardner, M.F., 1980. Physicochemical, site, and bi-directional reflectance factor characteristics of uniformly moist soils. LARS Technical Report 111679, Purdue University, West Lafayette, IN, USA.

Stoner, E.R., Baumgardner, M.F., 1981. Characteristic variations in reflectance from surface soils. *Soil Science Society of America Journal*, 45, pp.1161-1165.

Vane, G., Goetz, A.F.H., 1988. Terrestrial imaging spectroscopy. *Remote Sensing of Environment*, 24(1), pp. 1-29.

Viscarra Rossel, R.A., 2007. Robust modelling of soil diffuse reflectance spectra by bagging-partial least squares regression. *Journal of Near Infrared Spectroscopy*, 15, pp. 39-47.

Walkley, A., Black, I.A., 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37, pp. 29-37.

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