A NOVEL COMBINED OPTICAL METHOD FOR OBJECTIVELY MAP SOIL IN A NEAR REAL TIME DOMAIN

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ABSTRACT:

The present study demonstrates a new concept for mapping soil, toward developing a semi-automated method to in situ classify soil. The concept is based on use of optical sensors that operate from both air and ground domains. The airborne sensor is based on imaging spectroscopy (IS) technology whereby every pixel in the image is characterized by a reflectance spectrum. The ground sensor is based on the Penetrating Optical Sensor (POS) technology whereby the optical head penetrates to the soil profile. This concept was examined over a selected field in Ashdod, a southern city in Israel. The IS data used was acquired from air scanner (AISA-ES) and POS data acquired from an ASD spectrometer over selected drill hole locations in a selected field. Five soil properties were evaluated at every drill hole depth using the Near Infra Red analysis approach (NIRS). The POS information enables obtaining an objective description of the soil profile, which was found to be more accurate than a traditional profile description using open trenches. For every selected point, six soil properties (specific surface area, organic matter, hygroscopic moisture, field moisture, carbonates, and iron oxide content) were evaluated. This information enables one to generate 5 depth layers (20-cm intervals) of the field by interpolating all points together. The 3D information provides new insight into the soils and opens up new frontiers for automatic soil mapping missions. Based on this study, further work is required in order to correlate the 3D information obtained by the IS and POS with any soil classification nomenclature system (e.g., USDA).

1. INTRODUCTION

The conventional soil survey mission is performed by using extensive field observations (sometimes very subjective) and a follow-up laboratory analysis, which adds valuable information about the soil's properties in question (USDA, 1999). The currently used classical soil survey is a rather complicated, expensive, and time- and money-consuming process. Consequently, there is a great demand for an alternative method to map soils rapidly and accurately. We suggest here to combine two spectral-based approaches to replace the conventional soil mapping process. They are as follows: 1) a ground approach based on the recent innovative method developed by Ben-Dor et al. (2008) that describes the soil profile by a Penetrating Optical Spectroscopy (POS) approach using fiber spectral assembly, ASD spectrometer, and NIRS models, and 2) an airborne approach that describes the soil surface by Imaging spectroscopy (IS) technology. The IS approach serves as a convenient method that might replace the traditional, ancient air photo method, providing cognitive and quantitative spatial views of the areas in question, and the POS may replace the wet laboratory measurements and the subjective field observation of open trenches. The purpose of this study is thus to demonstrate the integration between these two spectral-based methods (POS and IS) for mapping soil digitally, rapidly, and cost effectively in a 3D view.

2. MATERIAL AND METHODS

2.1. The Study Area

An area of about 4000m^2, characterized by alluvial soils, was selected to carry out this demonstration. The area is a bare filed situated in Ashdod, a southern city in Israel. Selected for its agriculture activity (seasonal wheat and cotton crops), the area was covered by one strip of the airborne imaging spectrometer, AISA-ES, and later also by conventional and POS soil survey approaches.

2.2. Airborne Data

The AISA-ES airborne sensor is a programmed imaging spectrometer consisting of two sensors mounted on the same optical bench and aligned to look at (almost) the same focal plane. The sensors are Eagle for the VIS region and Hawk for the SWIR region (See SpecIm homepage at http://www.specim.fi/). We used 180 bands (60 in the VNIR and 120 in the SWIR), which acquired information from 7,000 feet, providing a pixel size of 3 m. After the data acquisition (on August 2007), the raw data were converted into reflectance values using a combined ACRON and Empirical Line method. The reflectance obtained was validated against ground spectra of several selected targets. The reflectance image was used to generate a surface map that was based on the surface spectral information.

2.3 POS – data

The POS measurements were carried out by using a 3S-HED assembly (Sub Surface Spectral Head Device) to spectrally view and interpret the borehole's walls from inside using fiber optic sensing and an illumination head. This device is hooked to a 25^o bare fiber optic of an ASD field spectrometer that is sensitive to the VNIR-NIR spectral region (350-2500nm). The spectral information was modeled against the soil chemistry by using the NIRS approach (Ben-Dor and Banin, 1995). A detailed description of the 3S-HED concept can be found in Ben-Dor et al. (2008). Measurements were taken in intervals of 20cm from the surface down to 100cm (limited by the fiber optic length).

2.4 Way of operation

Eighteen boreholes were dug according to the surface IS-based map along the area. For every depth, the soil properties were estimated using the NIRS models. Based on this information, we generated a surface soil property map for every depth layer for five soil properties (see below). In addition, the soil color was estimated using a digitally based calculation of the VIS region. Each drill hole was vertically described and classified according to a certain soil order. At several locations, the soil profile description of the drill hole (based on the POS method) was compared to the tradition soil profile description using open trenches.

2.5 Using the spectral-based model NIRS to evaluate soil properties

One hundred and sixty soil samples, taken from Israeli soils, were used to generate the spectral models based on the NIRS approach. For that purpose, we used the surface reflectance and its equivalent wet laboratory information. The soils were analyzed in the laboratory for six soil properties that are considered to be important for the soil survey mission and were determined in the laboratory: Soil Moisture (SM), Organic Matter (OM), Hygroscopic Moisture (HIG), Field Moisture (FM), Soil Carbonate Content (SCC), Specific Surface Area (SSA), and iron oxide content (Fed). The models were validated in several drilling points against the (true) chemical properties from the area.

2.6 Spatial processing of the soil drill information

Every depth for a given property's layer, using all POS points, was interpolated by *Kriging* manipulation to provide a spatial layer view of the property in question. Five layers per property were generated at 20-cm intervals (to a depth of 100cm), all together, summing up to 25 layers. The layers were projected on a DTM map of the area that was generated by using the GPS measurements that were taken during the POS field measurements.

2. RESULTS AND DISCUSSION

Figure 1 presents the proposed paper concept, where a new spectral-based approach has replaced the traditional soil mapping approach that used open trenches and laboratory work.

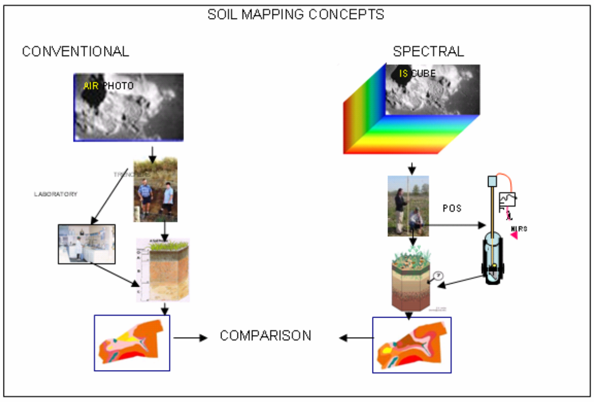

Figure 1: The concept of the optically based approach to map soil against the traditional way (Acknowledgement is given to Dr. J. Dematte for part of the illustration)

In general, the airphoto is replaced by an imaging spectrometer view that provides not only a cognitive presentation of the area; it also enables accurate classification of the soil surface based on its spectral properties. This information is then used to select the proper location for the drilling holes. In these points, the POS approach is used and the entire soil profile is described qualitatively and quantitatively in situ. An equivalent activity, using the convention approach, is characterized by opening trenches and sending the soils to the laboratory, which is a time- and money-consuming process. Finally, soil maps (or profile descriptions) are generated and a comparison between the two methods is possible. Tables 1 and 2 present a detailed description of four soil profiles, as obtained from the POS approach, for four different soils selected to validate the approach. Table 1 presents the traditional soil profile descriptions obtained from trenches that were opened at nearby positions and Table 2 presents the optical (POS) profile descriptions

Horizon	Depth (cm)	Description
		Rhodoxeralf
A	0-40	Bare cover, small amount of dry weed, no carbonate content, dry soil, color 2.5 YR 4/8 red, sandy texture.
Bt	40-55	Elovial horizon, accumulation of clay and iron oxides, no carbonates, color 2.5 YR 3/6 dark red.
B	55-80	No carbonates, sandy soil, color 2.5 YR 4/6 red.
C	80-100	Sandy soil, brighter color, higher humidity, color 5 YR 4/6 yellowish red.
		Haploxeralf
A	0-20	The surface is covered with wild vegetation, high carbonate content, clay loam texture, color 10 YR 6/4 light brown.
B	20-70	High carbonate content, decreased organic matter, sandy clay loam texture, a high concentration of carbonate pebbles in the horizon, color 10 YR 6/4 light brown.
C	70-90	Sandy soil texture, decreased carbonate content, color 10 YR 8/8 reddish yellow.
		Haploaquept
A	0-15	Very rich in organic matter, dark color, rich in carbonates, loam sandy texture, color 10 YR 4/1 dark gray.
A3	15-50	Very rich in organic matter, high soil moisture, loam sandy texture, color 10 YR 4/1 dark gray.
B	50-80	High water table and bad drainage in the soil increase the moisture; the horizon contains evidence of its original lake materials as shells. Drastic change in color; color 10 YR 7/1 light gray.
C	80-100	Highly rich in carbonates, high moisture, contains free water, very bright color 10 YR 8/3 very pale brown, clay loam texture.
		Chromoxerert
A	0-65	Rich in organic matter, high carbonate content, clay texture, color 10 YR 4/3 brown.
AC	65-100	Rich in organic matter, high soil moisture, clay texture, color 10 YR 3/3 dark brown.

Table 1: Traditional soil profile descriptions, as was done in the field in nearby trenches

As seen, the two tables are in good agreement; however, when using the POS approach, the information is more detailed. Bearing in mind that the POS information was obtained objectively in situ, we can conclude that the optically based approach is a much more effective method for carrying out soil survey missions than the traditional method. Since the POS technology permits many measurements in the space domain, interpolation maps may be generated in the field to provide a spatial view if the soil entity is in question. In the current study, we used an unsupervised technique applied to the IS image, which resulted in 6 classes using the ISO Data classifier.

Figure 2 provides the IS classified image with all drill hole locations and the topography overlaid. These locations were selected based on the surface units they represent. Figure 3 provides an example of a soil profile (#1) for these six soil properties.

Horizon	Depth (cm)	Description
		Rhodoxeralf
A	0-20	Low organic matter (0.32 gkg-1), the soil does not contain carbonates, the soil is sandy with a low specific surface area (69 m² g-1), low moisture (0.92 gkg-1), iron oxides (0.56 gkg-1), color 10R 4/6 red.
AB	20-40	Low organic matter (0.30 gkg-1), increased soil moisture (2 gkg-1), SSA (76 m² g-1), iron oxides (0.58%); color 10R 4/8 red.
Bt	40-60	Elovial horizon; there is an accumulation of clay minerals, an increase in SSA (85 m² g-1), and increased iron oxides (0.5 gkg-1); organic matter (0.29 gkg-1); color 10R 4/ 8 red.
B3	60-80	Decreased clay minerals, SSA (27 m² g-1) and iron oxides (0.5 gkg-1), organic carbon (0.29 gkg-1), color 7.5 YR 6/6 reddish yellow.
C	80-100	Low organic matter (0.27 gkg-1), little content of clay minerals, SSA (26 m² g-1), decreased iron oxides (0.3 gkg-1), color 7.5 YR 6/6 reddish yellow.
		Haploxeralf
A	0-20	Rich in organic matter (2 gkg-1); high carbonate content (26 gkg-1); soil moisture (3.7 gkg-1); iron oxides (1.3 gkg-1), SSA (102 m² g-1, color 10YR 6/3 pale brown.
AB	20-40	A slight decrease in organic matter (1.3 gkg-1), a decrease in iron oxides (0.8 gkg-1), an increase in soil moisture (5.2 gkg-1), an increase in clay minerals SSA (134 m² g-1), the color is the same as the A horizon, color 10YR 6/3 pale brown.
B ca	40-70	Accumulation of carbonates (28 gkg-1), low organic matter (0.6 gkg-1), soil moisture (4.5 gkg-1), decreased clay minerals SSA (72 m² g-1) that will make the texture more sandy loam, color 10YR 6/3 pale brown.
C	70-80	Low organic matter (0.44 gkg-1), carbonates (24 gkg-1), low iron oxides (0.46 gkg-1), decreased soil moisture (2.7 gkg-1), the texture is more sandy loam SSA (54 m² g-1), color 10YR 6/4 light yellowish brown..
		Haploaquept
A1	0-20	Highly rich in organic matter (4 gkg-1), rich in carbonates (44 gkg-1), soil moisture (17 gkg-1), SSA (54 m² g-1), iron oxides (0.6 gkg-1), color 10YR 4/1 dark gray.
A3	20-50	High carbonates content (61 gkg-1), high organic matter (3.1 gkg-1), iron oxides (0.6 gkg-1), SSA (75 m² g-1), color 10YR 4/1 dark gray.
B	50-70	Increased soil moisture (22 gkg-1), decreased iron oxides (0.14 gkg-1), a slight decrease in organic matter (1.9 gkg-1), very high carbonate content (71 gkg-1), soil moisture (22 gkg-1), SSA (55 m² g-1), color 2.5Y 8/4 pale yellow.
C	70-100	Very high carbonate content (66 gkg-1), high soil moisture (25 gkg-1), SSA (46 m² g-1), low content of iron oxides (0.05 gkg-1), the color is very bright; color 2.5Y 8/4 pale yellow.
		Chromoxerert
A	0-70	Rich in organic matter (2.5 gkg-1), carbonate content (8 gr kg-1), high soil moisture (18 g kg-1), iron oxides (0.63 g kg-1), the texture is clayey SSA (280 m² g-1), the color of the soil is dark; color 10YR 4/3 dark grayish brown.
AC	70-100	Organic matter (2.1 g kg-1), decreased carbonates (4 g kg-1), high soil moisture (21 g kg-1), clay texture SSA (310 m² g-1), iron oxides (0.86 g kg-1), color 10YR 3/4 dark yellowish brown.

Table 2: Optically based soil profile descriptions, as was done in the field using 3S-HeD in drills

As seen, the profile information provides greater understanding of the soil profile that can be further used to evaluate the soil order. Using the layers of all samples for each property enables a spatial overview of the soil profiles in vertical layers. Figure 4 provides *kriging* interpolation profile maps for SSA as an example. The SSA was selected because it is highly correlated with other soil properties in Israeli soils such as hygroscopic moisture, clay content, and water retention (Banin and Amiel, 1970). As seen, the SSA property changes vertically quite smoothly (as excepted from *vertisol*), providing a spatial view of this property never before obtained.

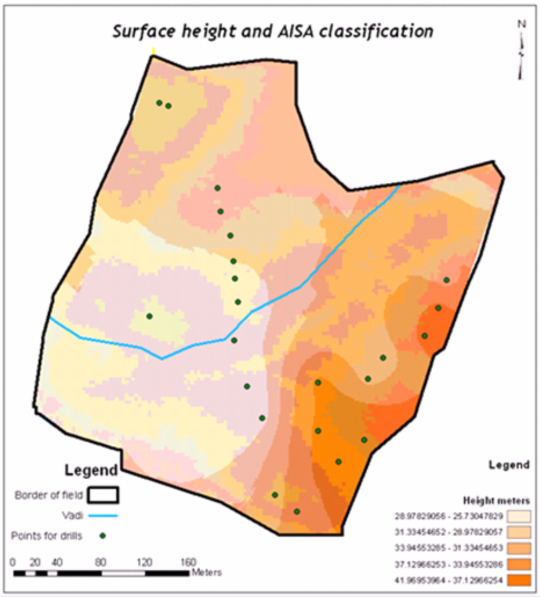

Figure 2: The ISO-Data classification of the area using the IS reflectance image overlain on the topography image of the area. Also given are the drilling point positions

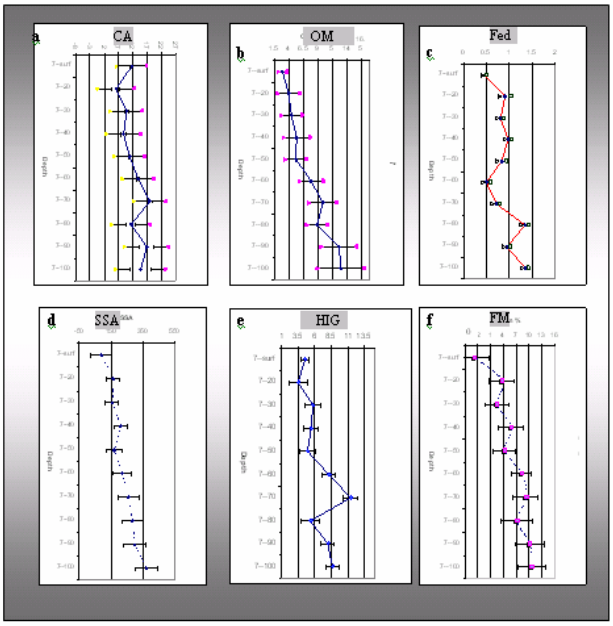

Figure 3: Profile description of the six soil properties, as obtained from the NIRS approach using the POS method (a=carbonate -CA, b=organic matter –OM, c= iron oxides-Fed, d=specific surface area – SSA, e= hygroscopic water –HIG, f = field moisture – FM)

Similar to the SSA interpolation maps, every depth was processed to yield a 3D map for other soil properties. The overall information was used to provide a new view to describe the soils within the area in question. As demonstrated previously, an extra layer can be obtained from the POS activity by adding the GPS measurements to the *kriging* interpolation to generate DTM information. Including the topography information along with a quantitative description of the soil surface (using the IS technology) as well as the soil profile (using the POS approach) may be further used to classify the soil pedons to an agreed-upon soil order. This stage will enable the projection of all digital information on a classic soil map that will consist of the hierarchy of soil orders. This stage, however, requires more study and all layers will need to be programmed to match the USDA (or similar) definition system of the soil orders. This activity requires digitizing the USDA user guide manual in such a way that the spectral–spatial layers (IS, POS, and GPS based) will be able to be defined by the proper (and accurate) pedogentic root tree approach. Although this stage still lies ahead, the present approach suggests that we are very close to achieving that end. In other words, a first step toward fully automating the soil mapping mission has been completed. Utilizing the optical method is very simple and does not require professional soil surveying skills. Since it is a purely technical, scientifically oriented method, it can be used to collect many samples quickly and use by other applications such as precision farming and environmental watching.

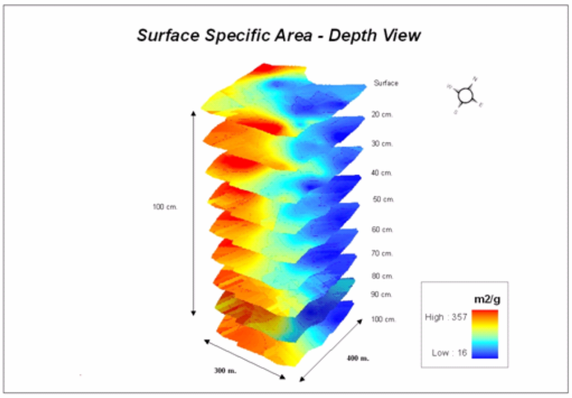

Figure 4: A cube (layer stack) description of the SSA property throughout the soil areas studied

3. SUMMARY AND CONCLUSIONS

Combining optically based sensors that operate from both air and ground domains can provide important information about the soil entity. The new POS approach enables the soil profile to be conveniently evaluated for a soil mapping mission. Instead of opening trenches, which involves subjectively describing the profile in the field and sending soil samples to the laboratory, the POS approach with NIRS analysis enables *in situ* soil profile recognition rapidly and effectively. The POS results provide new insight into the soil properties on a spatial basis and may be used in the future to automatically define the soil pedon in the field. Further study is thus required to correlate the spectral data information to the exact soil classification system that is commonly used.

ACKNOWLEDGMENT

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