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A smartphone-based soil color sensor: For soil type classification

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ABSTRACT

Soil type is a key indicator in field survey, but the current soil classification method largely depends on personal experiences of operators. Because different soils have different soil colors, soil can be classified by measuring soil colors. In this paper, we compared and analyzed the roles of the visible spectrum and machine vision adopted in soil classification and proposed a new smartphone-based, low-cost, and miniaturized soil color classification sensor. The CMOS device of the mobile phone was directly used as the sensor and the flashgun of the phone was used as the light source. The peripheral components included external lens, shading devices, and color calibration card, which were assembled on the phone directly. The colors of soil and proofread cards were acquired by the smartphone and converted into RGB signals. With RGB signals, after simple processing, rapid soil classification could be achieved.

1. Introduction

Soil classification is important for soil management and sustainable land utilization (Hartemink and Bockheim, 2013). Different soils have different compositions and different environmental and physical properties (Viscarra Rossel et al., 2006). The soil color is a comprehensive indicator of the chemical compositions and physical characteristics of soils and a large number of soil information can be effectively obtained by the interpretation of soil color. Therefore, the method of soil classification and qualitative detection based on soil colors is the most common method (Ibá Ez-Asensio et al., 2013).

At present, Munsell card is the most commonly used soil classification method (ASTM, 2008; Torrent and Barrón, 1993). Soil colors can be directly reflected by this method. Moreover, the method is also very convenient for detection personnel. However, this card divides the color space into different small sections, it is not convenient to obtain large amounts of data with modern digital technologies (Meyer and Kirkland, 1998). Meanwhile, this method largely depends on personal experiences, and under different illumination conditions, experimental personnel are prone to lead to color determination errors.

In recent years, with the development in spectroscopic techniques, some scholars utilized the visible and near-infrared spectra to identify soil types. In 1978, some researchers studied the effects of soil moisture on visible reflectance spectra (Demattê et al., 2004). With the gradual development of spectrum technologies, the soil surface reflectance spectra had been extended to the near-infrared and mid-infrared spectra.

In 2004, scholars used soil reflectance spectra in the wavelength range between 450 nm (nanometer) and 2500 nm to identify soil types. Compared with traditional methods, the visible–near infrared method allowed the same assessment results of soil types (Mouazen et al., 2007). In 2007, the visible–near infrared spectra with the wavelength range between 306.5 nm to 1710.9 nm were utilized to classify soil colors and the principal component analysis (PCA) was used to analyze the classification data. The correct resolution reached81.8%in the color space of 2.5Y (Y = yellow in the Munsell color system) and the correct resolution of 75.0% was realized in color space of 10YR(YR = yellow & red in the Munsell color system) (Volkan Bilgili et al., 2010). Bilgili and other researchers studied the soil reflectance characteristics in the spectral range between 350 nm and 2500 nm, and processed the spectral data separately with the PLSR method (partial least squares regression) and MARS (multivariate adaptive regression) method. The results showed that the MARS method had proved the better prediction rate and that the visible–near infrared spectrum method could replace the laboratory methods in the assessment of soil properties (Fystro, 2002).

The visible–near infrared spectroscopy was adopted to classify soil types and predict soil properties. Visible–near infrared spectroscopy can provide a lot of data and the provided data can be processed rapidly with computer. However, these methods require a spectrometer or the visible–near infrared light source, the whole detection system is generally large (Rossel and Chen,

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2011). Moreover, data processing requires the complex algorithms. Therefore, the traditional system is not suitable for portable field detection. Digital camera as a sensor can obtain the color information, which can be quickly converted into RGB signals (Viscarra Rossel et al., 2008). Therefore, digital cameras were adopted to discriminate soil colors and the obtained RGB signals were then converted into standard color space through the calculation (Aydemir et al., 2004; Delaney et al., 2013).

In recent years, with the popularity of smartphones, the applications with sensors based on the smartphone are increasing quickly. Detectors with smartphone have some advantages, such as good portability, low price, and convenience for the large-scaled application. The detector based on the smartphone is one research focus at home and abroad, but related studies are mostly focused on the biomedical analysis or human activity monitoring (Bourouis et al., 2013; Duarte et al., 2014; García Villalba et al., 2015; Gopinath et al., 2014; Guido et al., 2012; Guidoux et al., 2014; Heathers, 2013; Lee et al., 2013; Paalasmaa et al., 2013). It was worth mentioning that in 2013 a mobile phone was used as the sensor to classify soil colors in the laboratory and the obtained color classification results were compared with the Munsell cards. The comparison results showed that the smartphone allowed the better classification results than the Munsell cards under the controlled external illumination conditions (Gómez-Robledo et al., 2013). This study showed that the soil classification method based on the sensor of the smartphone was efficient and cheap. However, the measurement results still depend on the stability of the external light source and relevant instruments were not convenient for the application in field investigation.

In order to accelerate soil classification and realize the rapid identification of soil types in the field environment, based on visible spectroscopy and machine vision tests, we proposed a smartphone-based soil classification sensor. In this sensor, CMOS (Complementary Metal Oxide Semiconductor) units were used as the sensitive components and the flashgun of the smartphone was used as the light source. The sensor can be assembled on the phone directly as an attachment kit without any electronic accessory. To our knowledge, this was the first successful study of the soil classification based on the smartphone without passive component.

2. Materials and methods

2.1. Materials

Standard soil specimen were provided by Department of Geography in East China Normal University. Ten types of soil specimen were used: latosol, red soil, yellow soil, burozem, drab soil, podzolic soil, chernozem, desert soil, paddy soil, and purple soil. Because there are obvious different colors among various soils layers, we used illuvial layer soil as the measuring objects, which is typically in a depth of 40–80 cm below the soil surface. The characteristics of the soil, such as distribution ranges, colors, and composition, were given in Table 1. Furthermore, to test the ability of the sensor, 50 soil samples (500 samples in total) were sampled by the Beijing Municipal Agriculture Bureau from several areas in China to validate the classification results.

2.2. Acquisition of visible spectra

AvaSec-2048 spectrometer (Avantes Company, Dutch) was adopted in the detection system. The wavelength range was set as 200–1100 nm and symmetrical Czerny–Turner optical path design was adopted (the focal length of 75 mm, the resolution range of 0.04–20 nm.

AvaLight-DH-S-DUV (Avantes Company, Dutch) was used as the light source. The wavelength range of the light source was 190–2500 nm. The standard reflection probe (Avantes Company, Dutch) was adopted.

The whole experimental device was shown in Fig. 1.

Sample spectra were acquired with AvaSoft 7.6 for AvaSpec-USB2 (Avantes Company, Dutch). Integration time was 10 ms. Average times is 15. The distance between fiber probe bottom and the specimen surface was 10 mm. The angle between fiber tip and the sample surface were 90°. Fiber optic probe was fixed by clamps to maintain the same height in each measurement.

Soil spectral data was collected in ten groups. In each group, each soil type was collected for 20 times. Twenty spectral lines of each soil specimens were averaged according to the intensity of corresponding spectral line. After data processing, 10 spectral lines were acquired for each soil specimen.

Table 1
The distribution and features of the Chinese soil.

Types	Main distribution area	Soil characteristics	Color
Latosol	Hainan Island, Leizhou Peninsula, Xishuangbanna District and the southern of Taiwan	Inorganic nutrient loss, iron, aluminum residues in the soil, sticky texture, poor fertility	Brick-red
Red soil	Most region of the south of the Yangtze River and mountain region around the Sichuan Basin	Few of potassium, sodium, calcium and magnesium elements, and lots of iron and aluminum elements	Red
Yellow soil	Most region of the south of the Yangtze River and mountains in the province of Yunnan and Guizhou	Few of potassium, sodium, calcium, magnesium elements, the iron oxide was hydrated	Yellow
Burozem	Shandong Peninsula and Liaodong Peninsula	Few of potassium, sodium, calcium, magnesium elements, subacid	Brown
Drab soil	Hilly and low mountain areas of Shanxi, Hebei and Liaoning provinces, the Guangzhong plain of Shanxi province	Lots of minerals and organic matter, a small amount of calcium carbonate deposition	Drab
Podzolic soil	The northern of Da Hinggan Mountains, the certain vertical bands of the alpine and subalpine of Tibetan Plateau	Presents strong acid, rich in humus and iron. Few of potassium, sodium, calcium, magnesium elements	Dark gray
Chernozem	East and west sides of the middle and south section of Da Hinggan Mountains, the middle area of the Songnen Plain and the watershed area of the Songhua River and Liaohe River	Most abundant humus, presents neutral to slightly alkaline, contains some calcium, magnesium, potassium, sodium and other inorganic nutrients	Black
Desert soil	The west area of the Neimenggu and Gansu Province	The calcium carbonate was gathered on the surface, gypsum and salt accumulate much, the degree of soil development is poor	Light brown
Paddy soil	The plains and river valleys in the south of the Qinling-Huaihe, the most concentrated in the Yangtze River Plain	A special soil formed by the human activities., containing iron and manganese elements	Yellow-brown
Purple soil	South of the Yangtze River and the majority of the hilly in the Sichuan Basin	Rich in calcium carbonate, phosphorus and potassium elements, low content of organic matter	Purple