Competitive Grant Report E2014-11

A smartphone-based device for measuring soil organic matter

Abstract:

The project evaluated the potential of utilizing a smartphone-based system for the in-field analysis of Soil Organic Matter. Although it demonstrated that the performance of the smartphone-based spectrometer can be comparable to commercial spectrometers, the results suggest that it is challenging to identify the spectral "signatures" of the SOM due to the morphology and moisture variation of soil samples.

Principal Investigator:

Meng Lu
Electrical and Computer Engineering
Mechanical Engineering

Co-investigator:
Richard Cruse
Agronomy
Iowa State University

Budget:
$41,694 for year one

ECOLOGY

Q Can the diffuse reflection spectroscopy in the visible spectral range can be used to analyze soil organic matter?

A The researchers developed a compact smartphone-based spectral analyzer that can be used in-field to collect reflection spectrum from soil. They expected to establish the correlation between the soil organic contents and the measured reflection spectra from soil samples.

Background

Soil organic matter (SOM) is one of the most important soil factors impacting resiliency of rain-fed cropping systems. Soils with higher SOM content offer greater crop production resiliency due to their ability to retain water, release multiple plant macro- and micro-nutrients at a desired rate, and serve as a major nitrogen source for crops. In addition, SOM is dynamic and can be impacted favorably, but more often has been affected unfavorably by a combination of soil and crop management practices.

The importance of linking farm management choices to SOM gain or loss and the resulting impact on soil resiliency and crop production stability cannot be overemphasized. Routine laboratory analysis procedures for measuring SOM, such as dichromate oxidation and dry combustion analysis of organic carbon, are complex, time-consuming, and expensive. In the search for a less expensive technology, the visible and near infrared diffuse reflectance spectroscopy has been exploited for the rapid characterization of SOM. New tools that complement the remote hyperspectral imagery sensing (HIS) and provide SOM data with high spatial and temporal resolutions could increase the knowledge about the variability of SOM in Iowa.

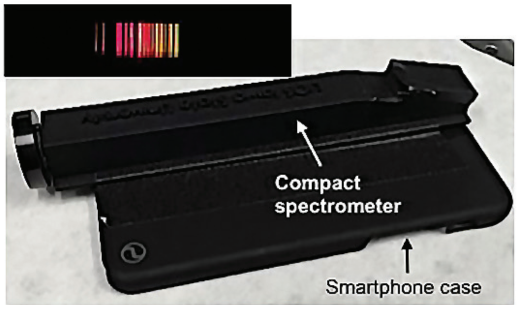
The project objectives were to:

- Develop a smartphone-based reflectance spectrometer that is capable of measuring SOM contents of topsoil and
- Establish the correlation between the SOM contents and reflection signatures from soil samples.

Approach and methods

The fabricated smartphone-based spectrometer consists of a 3D printed cage and several low-cost optical components. The performance of this compact spectrometer appears comparable to the bulky commercial optical spectrometers. In contrast to the commercial spectrometers, the footprint of the project's smartphone-based module is significantly smaller. The built-in camera of the smartphone can collect the reflectance from soil and display the data on the smartphone for real-time analysis.

To improve the reliability and the accuracy of the reflectance measurement, the researchers fabricated a sample chamber in conjunction with the smartphone-based



Smartphone-based spectrometer.

spectrometer. The chamber effectively blocks the ambient light, and thus, improves the repeatability of the reflection measurements. The soil sample is placed on the bottom of the enclosed chamber and the 3D printed measurement chamber connected to the spectrometer. A high power (100 mW) white LED is installed inside the chamber. The intense light from the LED can improve the signal-to-noise ratio and speed up the data acquisition process. The spectrometer and sample chamber were fabricated using a 3D printing service (Shapeways, Inc.) for the total cost of less than $50.

Results and discussion

The smartphone-based spectrometer was applied to measure the reflectance from soil samples provided by Lee Burras of the ISU Agronomy Department. The researchers measured the same soil samples with different moisture percentages (0, 10 and 30 percent).

The overall reflection intensity decreases when the moisture content increases. The reflection spectra were collected when the soil sample was illuminated from the normal direction. The reflectance from soil varies with regard to the angle of incidence. The PIs measured the same dry soil sample by setting the excitation light at different angles (0°, 20°, and 40°). The results show that the reflectance exhibits a strong dependence on the angle of the light.

The reflection variation as a function of the angle of incidence is due to the surface roughness of the soil sample. In order to eliminate the effect of surface morphology, it was necessary to process the soil sample to even out its surface before taking the reflectance measurement. In addition, the sample should be completely dried to obtain a consistent reading from the actual soil material. The goal was to identify the spectral signatures at the wavelengths used in the Krishnan's model. (Krishnan's model predicts percentage of organic matter content using reflectance values at two particular wavelengths.) However, due to the variation in the collected spectra, the PIs were unable to correlate the measured reflectance and the soil SOM using the Krishnan's model. The results suggest that soil samples should be pre-processed before attempting to take the reflection measurement.

Conclusions

The PIs took advantage of the recent developments in photonics and mobile computing to demonstrate a portable system that has the potential to provide SOM information based on a simple reflectance measurement. The results included:

- A low-cost smartphone-based spectrometer: The optical performance of the spectrometer is as good as the benchmarks of a commercial spectrometer.
- A smartphone APP: The application can guide the user to perform a reflection measurement and analyze the reflection spectrum in real time: The Krishnan's model has been embedded in the iPhone APP. The APP can identify the reflection's coefficients near $\lambda 1$ = 623.6 nm and $\lambda 2$ = 564.4 nm and thus calculate the SOM contents of the sample.
- Reflection spectra from soil samples: Preliminary results were collected for soil reflectance measured under different test conditions.

The project results suggest that the sample preparations, including surface polishing and drying, are the key steps to the success of the project. The application of soil analysis based on the reflectance is challenging. The researchers were unable to identify the spectral signatures at the wavelengths used in earlier research studies. Therefore, the future development of this technology should focus on developing a strategy to process soil samples taken from field sampling.

Education and outreach

The M.S. thesis of Benjamin Jin Seong Ch'ng, titled "Development of Smartphone-Based Spectroscopy Instruments for Diagnostic Test Analysis," was an educational output of the project. A journal paper is being prepared on "A Portable Fluorescence Polarization Sensor Using a Smartphone."

A presentation on the project was made by the PI during the 2016 ISU Scholars' Day February 20. Approximately 50 high school students and their families visited the PI's lab during the day. The PI explained the motivation and progress of the smartphone-based sensors, including the topsoil erosion issue, the importance of soil organic matters to agriculture, and some technical advances in the mobile sensing system. Several students tested the portable spectrometer using their smartphones.

Leveraged funds

No additional funds were leveraged by this project.

For more information, contact:
Meng Lu
3216 Coover Hall
Iowa State University
Ames, Iowa 50011
(515) 294-9951
e-mail:
menglu@iastate.edu