Portable snapshot spectral imaging for agriculture

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Summary

High-resolution proximal and remote sensing applications can consolidate sustainable, prevention- and precision-oriented crop management strategies to decrease production risks. This paper shows significant perspectives, own developments and technical aspects of high resolution remote sensing in the context of field applications. Moreover, we provide an overview of snapshot hyperspectral imaging and potential field video sensors to identify areas of interest for their future development. One of the main conclusions of our paper is that non-scanning snapshot hyperspectral imaging technology may enable researchers to overcome the gap in the "point to image" transition of field sensing, while providing a flexible solution for regular variable-rate applications.

Keywords: snapshot spectroscopy, hyperspectral imaging, optical sensors, remote sensing

Introduction

There is a great potential for agricultural land use practices to increase information availability in everyday farming through the use of proximal- and remote sensing techniques (Mulla, 2013). Spectral optical sensors or spectral imaging is a powerful bio- and geochemical analysis tool that can have a crucial role in the early detection of crop management risk factors, such as soil nutrition supply, pests and diseases (Dammer et al., 2009), and in the prevention or minimization of field scale chemical treatments.

The real benefit of proximal- and remote sensing is the capability to characterize spatial or field variability that cannot be parameterized more effectively by any other way (Usha and Singh, 2013). High-resolution spectral imaging provides the opportunity for both research and industry to develop novel approaches and technologies for putting prevention oriented and site-specific crop management into practice.

Spectral sensing of the last decades established a spectral information pool of agricultural and field objects, which should be adapted and customized to crop management. Recent developments in optical sensor technique stimulated new platform achievements. The platform liberalization benefits from the existing spectral knowhow and enriches this at different spatial, spectral and temporal scales. This multi-scale data challenges the application and data provider community. Field hyperspectral imaging is predominantly a scientific tool, which should be accessible for non-scientific users as well. There is a demand on sensor mobility and flexibility to which special attention will be probably given in the next future.

This paper presents the potential of snapshot imaging spectroscopy for applications in the field. We intentionally narrowed the spectral region to VNIR to stay spectrally comparable to the contemporary silicon based sensing technique. This technology is widely used, since it is advantageous to operate and manufacture. It shows limitations in spectral extension, although the economic aspects compensate for this and motivate new application areas with field working demands. We also present own research in proximal soil and vegetation sensing with a novel snapshot imaging spectrometer.

Material and methods

Until recently, light-weighted spectral scanners were not widely used because of technical limitations. First successful fix-wing miniature spectral scanning measurements in crop management were achieved by Zarco-Tejada et al. (2011). The light-weighted scanners (<2 kg) are mainly working in the spectral range from 350 to 1100 nm. These typically utilize the push-broom spectral imaging technique.

Hyperspectral cameras with push-broom scanning principle interacts less successful with random platform movements and are complicated to be used as hand-held imagers, on multicopters (UAV) or on vehicle-based platforms (tractors). Setting-up an air-borne imaging spectrometer on the ground was the beginning of near-ground or field imaging spectroscopy. A scanning imaging spectrometer shows limitations in a field set-up since spectral scanning is performed by a rotation stage, which is a time-consuming process and restricts the platform mobility and flexibility. However, spectral imaging scanners are definitely the most suitable sensors for satellite and conventional air-borne platforms, for mobile ground- or near-ground applications (tractor, track, UAV, other vehicle-based, hand-held, or for randomly moving objects, etc.) other imaging techniques are needed. Non-scanning hyperspectral imaging has been recently introduced for outdoor applications. This kind of spectral imaging is often called "snapshot imaging spectroscopy" (Hagen et al., 2012; Jung and Vohland, 2014) and it has a different principle from the push- and whiskbroom sensors.

Mobile field imaging spectroscopy requires sensors that can control and track random platform- and object movements, are flexible and easy to operate. Non-scanning hyperspectral imaging is preferentially used by unmanned airborne and terrestrial vehicles since proximal- and remote sensing applications must cope with even less than 0.5–2.5 m^2 field phenomena in the future. This development opens the door for small-scaled farm applications as well.

Results and discussion

Our working group at the Institute of Laser Technologies in Medicine and Metrology (ILM) at the University of Ulm and the Cubert GmbH, Germany developed a miniaturized snapshot hyperspectral camera. A hyperspectral non-scanning or snapshot camera is generally designed to utilise the instant spatio-spectral surplus of real-time data acquisition. It means that all spectra and image pixel are taken at the same time. A silicon CCD chip with a sensor resolution of 970×970 pixel captures the full frame images with a dynamic image resolution of 14 bit. In normal sun light situation, the integration time of taking one hyperspectral data cube is about 1 ms. The main technical properties of the developed hyperspectral camera can be seen in *Table 1*.

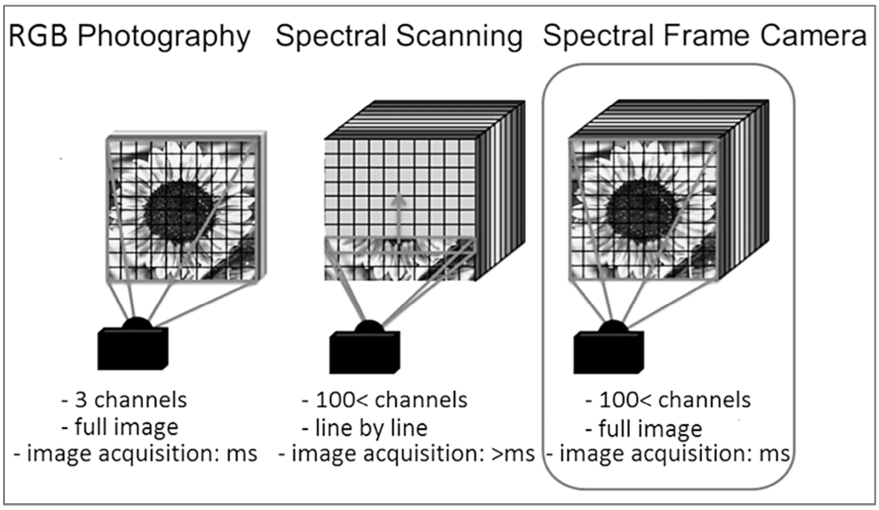
Table 1. *Main parameters of a UAV enabled snapshot spectral camera*

Properties	Parameters
Weight	<1 kg
Number of bands	100<
Spectral resolution	<10 nm
Integration time	<5 ms
Image frequency	10 Hz<
Spectral range	400–1000 nm

The camera is able to capture more than 15 spectral image data cubes per second, which facilitates hyperspectral video recording. The camera records hyperspectral full-frames with 137 spectral bands in a range of 450–950 nm. The hyperspectral data cube has a spectral resolution of 4 nm. This novel technical approach targets the time critical applications both in laboratory and in the field, it is also called spectral frame camera (*Figure 1*).

A snapshot spectrometer enables high-rate spectral images to even generate spectral video sequences that are an obvious advantage in on-line process monitoring and controlling of production phenomena both in field and in-door. The number of spectral sensing applications is rapidly growing, sometimes even faster than the associated industrial research and development to explore it. For instance, hyperspectral remote sensing both imaging and non-imaging for UAV (unmanned aerial vehicle) platforms suggest very promising solutions for agriculture (nutrition maps, vitality and stress maps, etc.), while still facing challenges for usability and feasibility. The platform liberalization (space- and airborne, remote-controlled fixed-wing, rotary wing, hand-held, tractor-mounted etc.) in remote sensing has enabled an eased technique access for professional groups (Bendig et al., 2012). Some general issues like reliable spectral libraries for time-critical agricultural processes, the BRDF (bidirectional reflectance distribution function, Schaepman-Strub et al., 2006) models of mobile platforms or the paradigm change from reflectance to radiance measurements are open questions and need to be analysed to avoid frustrations at either the end users' or the decision makers' side. An immediate positive effect of the multiple platform development is the increased sampling potential in time, space and chemistry, which will enhance statistical outcomes and lead to better predictions or decisions.

Figure 1. *Comparison of spectral imaging techniques*



Conclusions

Temporal resolution is an important driver in agricultural proximal- and remote sensing that controls the flexibility and data availability in time. Phenological changes are primary indicators of the production that should be regularly observed and monitored. For instance, periodical returns of satellites typically cannot be customized and the air-borne campaigns with high-temporal resolution are very cost-intensive and complex. Considering the application areas of proximal- and remote sensing, agriculture is one of the most time-critical application fields. The entire sector and production is based on time-critical processes including sowing, growing, plant protection, fertilizing, irrigating and all management decisions, which should be sensed at higher temporal rates to overcome present limitations, and allow targeted technological decisions. The temporal resolution affects process accuracy as well, which is better achieved by snapshot imaging spectroscopy.

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