New photogrammetric sensors for precision agriculture: the use of hyperspectral cameras

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New photogrammetric sensors for precision agriculture: the use of hyperspectral cameras

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Photogrammetric and remote sensing techniques are increasingly getting used in precision agriculture to improve monitoring and management of the crops and at the same time to increase the crop yield and reduce the environmental impacts derived from the treatments. The entire production sector can benefit from the advance in technologies and the development of lightweight sensors for UAV (uncrewed aerial vehicles) with a higher spectral and spatial resolution such as the hyperspectral sensors. The hyperspectral sensors' ability for measuring hundreds of bands has impacts on the complexity and the data processing. Indeed, it is necessary to handle a considerable quantity of acquired data and select the relevant information for interventions in the agricultural area. The aims of this work are providing a survey of the UAV-based hyperspectral sensors available on the market and their acquisition technology and a global view of possible applications in the agriculture field. Moreover, the paper highlights future research developments related to this new type of device.
Keywords: *geomatics, hyperspectral camera, precision agriculture, sensors, UAV.*

Nuovi sensori fotogrammetrici per l'agricoltura di precisione: l'utilizzo di camere iperspettrali. *Tecniche fotogrammetriche e telerilevamento sono sempre più utilizzate in agricoltura di precisione per migliorare il monitoraggio e la gestione delle colture e allo stesso tempo per aumentare i guadagni e ridurre gli impatti ambientali derivante dai trattamenti. L'intero settore produttivo può beneficiare del progresso tecnologico e dello sviluppo di sensori leggeri sviluppati per UAV (uncrewed aerial vehicles) con una maggiore risoluzione spettrale e spaziale, come i sensori iperspettrali. La capacità dei sensori iperspettrali di acquisire centinaia di bande ha, tuttavia, impatti sulla complessità e sull'elaborazione dei dati. È infatti necessario gestire una notevole quantità di dati acquisiti e selezionare le informazioni pertinenti per gli interventi agricoli. Gli obiettivi di questo lavoro sono fornire un'indagine sui sensori iperspettrali sviluppati per UAV disponibili sul mercato e sulla loro tecnologia di acquisizione, offrire una visione globale delle applicazioni di agricoltura di precisione e evidenziare gli sviluppi futuri di ricerca relativi a questo nuovo tipo di sensore.*

Comprendere la possibilità di sfruttare economicamente l'energia geotermica mediante WBHE coassiali è vincolata alle caratteristiche principali del modello fisico, applicato per stimare la quantità di calore che può essere ricavata dal pozzo.

Allo stesso tempo, a causa della continua variabilità spaziale delle formazioni geologiche nei giacimenti petroliferi, stime accurate e realistiche delle prestazioni degli scambiatori di calore non possono essere applicate senza una corretta considerazione dei parametri termofisici degli strati geologici circostanti i pozzi di idrocarburi.
Parole chiave: *geomatica, camera iperspettrale, agricoltura di precisione, sensori, UAV.*

1. Introduction

New Urban Agenda Habitat III underlines that precision agriculture is a crucial challenge for urban and regional planning in terms of productivity, environmental impact, food security and sustainability (United Nation, 2017). "Rural Development Program 2014-2020" suggests the development of innovative solutions for monitoring, conservation, sustainable development, in order to promote agriculture developments in large scale area (included peri-urban and urban area) (Joint Research Centre of the European Commission *et al.*, 2014)

However, considering the area in which precision agriculture is applied, the high demand for planning activities is related to new tools and methods for monitoring. This is valid both for urban (e.g., urban gardens and parks), peri-urban (peri-urban agricultural factory), and a rural area. Monitoring refers to the position on the ground parameters and the control and management of the state of the health of the crop and plant diseases, that involves spatial multi-scale and multi-temporal information (Pinter, Jr. *et al.*, 2003). It is necessary to underline that different levels of detail require different methodological approaches as well as platforms, sensors (in terms of spatial resolution and types), and processing algorithms.

In this scenario, one of the main activities of PIC4Ser (PoliTO Interdepartmental Centre for Service Robotics) is to develop and to improve new tools and processes related to monitoring activities in precision agriculture. PIC4Ser coordinates the complementary activities of five research groups on technologies enabling service robotics (PIC4SeR, 2017). The purpose of the Centre is the integration of innovative solutions in the areas of control, perception, artificial intelligence with attention to user interaction, security, socio-economic and ethical factors. The Centre selects different application areas: Smart Cities & Search & Rescue, Service robotics for wellbeing, Cultural heritage and Precision Agriculture (PA).

Considering the PA application fields, the idea of the Centre is to develop a multi-agent and multi-sensors platform, i.e. Uncrewed Aerial Systems (UAS), Uncrewed Aerial Vehicles (UAVs) and Uncrewed Ground Systems (UGS), which collaborate among themselves to have a different perspective and to overcome the limits of every single platform. Among these limits, there are, for example, the level of the battery, restrictive directives for the aerial vehicles flight and the reductive perspective of ground vehicles. Figure 1 shows the concept of the Centre.

This paper aims to summarize the most popular sensors used in precision agriculture applications and at the same time, define the main applications of the emerging hyperspectral sensors.

2. Sensors for precision agriculture

In PA, several applications for environmental monitoring and mapping require UAV as one of the main tools for high-resolution images acquisition (Thenkabail *et al.*, 2014). The main aims, in these fields, is the treatments reporting and managing and efficient resources handling (Honkavaara *et al.*, 2013).

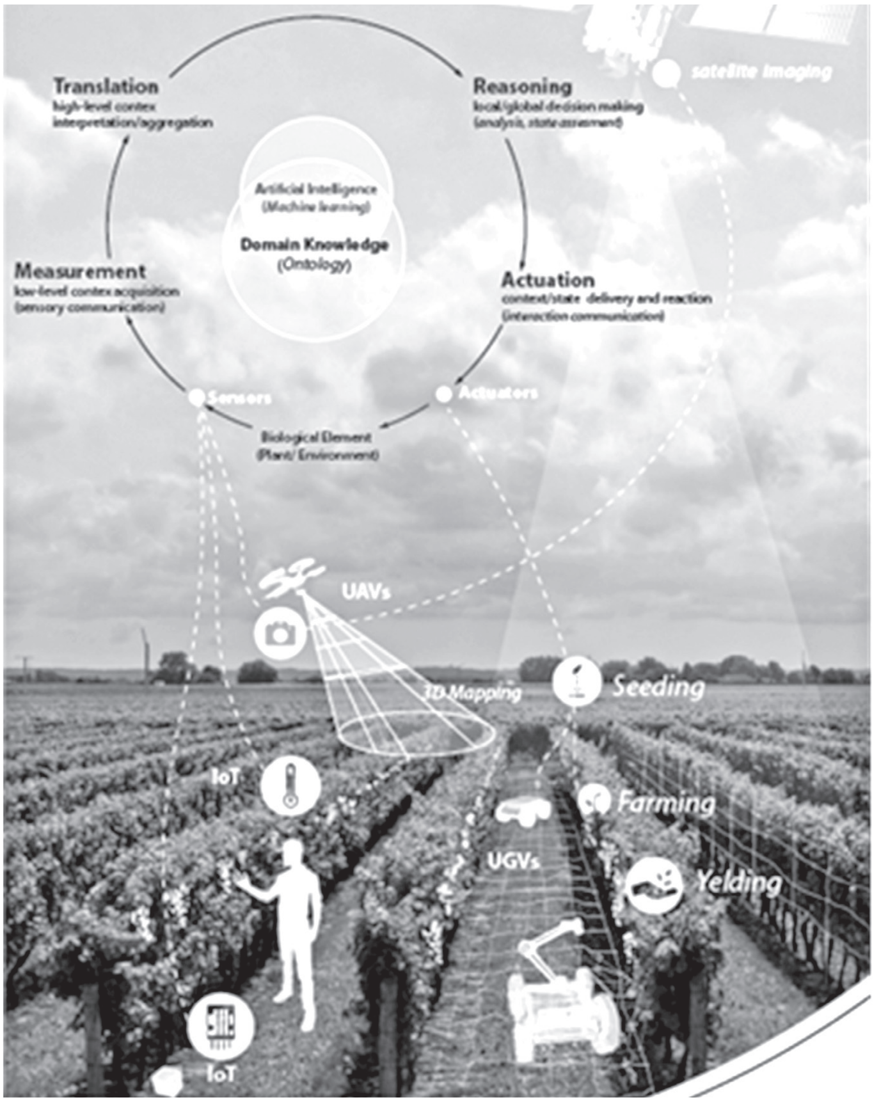

Fig. 1. The PIC4SeR concept (adapted from Musci M.A. et al., 2018).
Immagine concettuale delle attività del Centro PIC4SeR.

For these specific applications, visible bands of conventional sensors cannot properly assess the productivity and stress indicators as multi or hyperspectral sensors (Adão *et al.*, 2017, Khaliq *et al.*, 2019). The hyperspectral sensors potentiality is the capability to collect a high-resolution spectral signature (Manolakis 2003). The spectral signature can characterize objects and matters and their possible anomalies with a higher level of details than multispectral sensors.

Recently, different lightweight, frame-based hyperspectral cameras suitable for UAV surveys were developed. The primary difference among conventional hyperspectral sensors available on the market is related to the acquisition mode. There are four categories of hyperspectral cameras: whiskbroom (or point scanning), pushbroom (or line scanning), single-shot or frame-based (Adão *et al.*, 2017). The whiskbroom sensors collect all the bands following the pixel-by-pixel approach, storing the data in a band-interleaved-by-pixel (BIP) cube; pushbroom sensors acquire pixels in line-sequence, which constitute a band-interleaved-by-line (BIL) cube. The single-shot sensors collect spatial and spectral data in a within a single integration period, saving data in a band sequential (BSQ) cube. The frame-based cameras overcome the slow acquisition problem of the whiskbroom sensors, the saturation issues of the pushbroom.

Furthermore, the snapshot sensors do not require a high precision inertial platform. Ground Control Points (GCPs) can be used to provide an a-posteriori solution to external orientation parameters problem. Indeed, it is possible to estimate the camera position dur-

Tab. 1. Comparison of UAV's hyperspectral sensors.
Confronto tra i sensori iperspettrali per UAV.

Products	Resonon	Bay-spec (OCI-F-HR)	Headwall (Nano-Hyperspec)	Senop-Rikola	Specim AFX10
System acquisition	push-broom	push-broom	push-broom	frame-based	frame-based
Spectral range (nm)	400-1000	400-1000	400-1000	400-1000	400-1000
Spectral resolution (nm)	2.1	3 (nm FWHM)	6 (nm FWHM)	10 (nm FWHM)	5.5
Spatial resolution	900	800	640	1010x1010 pixel	1024
N of spectral bands	281	240	270	100-380	224
Focal length(mm)	–	–	–	8.9	15

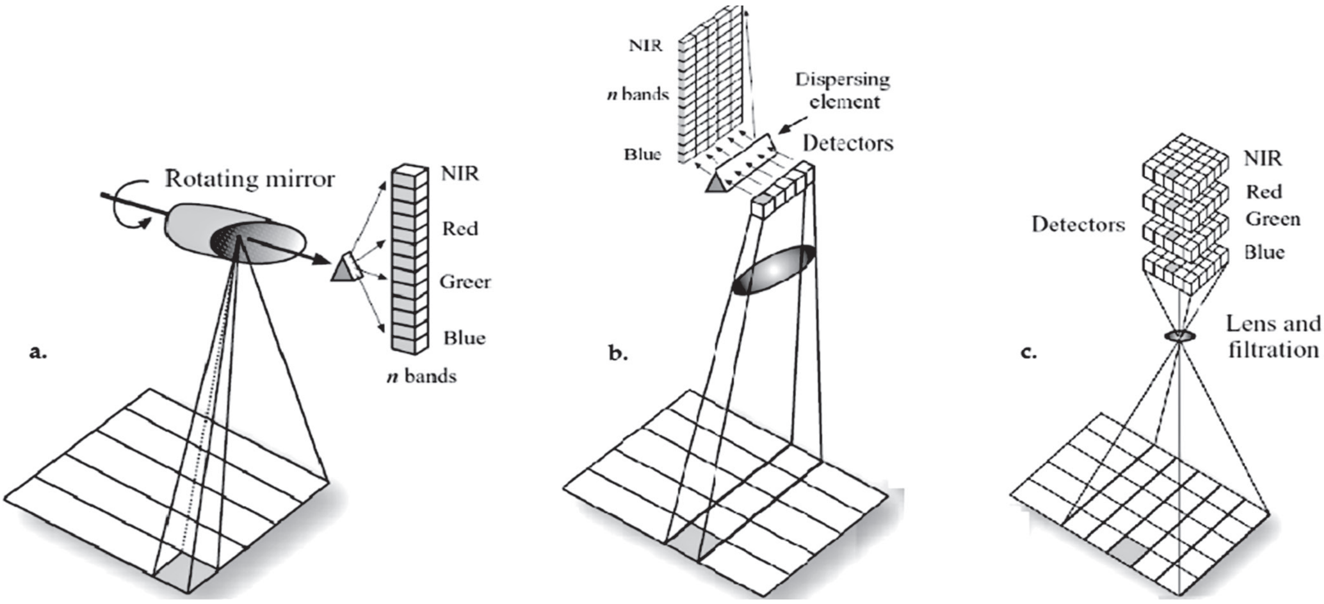

Fig. 2. Types of hyperspectral sensors: (a) whiskbroom, (b) push-broom sensors, (c) full-frame sensors (adapted from Adão *et al.*, 2017).
Tipi di sensori iperspettrali: whiskbroom, (b) sensori push-broom, (c) sensori full-frame.

ing the acquisition phase knowing the coordinates of the centre of the camera. Otherwise, it is possible to measure the coordinates of few GCPs acquired using a Global Satellite Navigation System (GNSS) receiver following the Post Processing Kinematic (PPK) or the Real-Time Kinematic (RTK) approaches.

Three main factors affect the use of lightweight hyperspectral cameras: the spatial resolution, the spectral range and compatibility with software packages. Thus, the spatial resolution is degraded to reach the high spectral resolution as specified above, and it is lower than the RGB cameras. The spectral range is constrained from 400-1100 nm or 1100-2500 nm due to payload limit compared with airborne cameras; thus, it is not possible to cover the whole spectral range. Hyperspectral cameras are less accessible and are less compatible with drones compared with the RGB and multispectral sensors.

Table 1 syntheses the main commercial hyperspectral cameras, with a spectral range between 400-1000 nm used for UAS and UGS (Adão *et al.*, 2017).

3. The use of hyperspectral sensors: applications

Lightweight imaging sensors with a spectral range between 400 and 2500nm are becoming popular in PA applications due to their capability to support rapid and non-destructive and invasive inspection and the higher spatial and spectral resolution as explained in the previous section. As reported in (Qiu *et al.*, 2018), the focus of precision agriculture techniques is on specific types of crops such as wheat, maise, sorghum, barley, tomato, bean, and grape.

Different factors related to structure, concentration and content can affect the spectral absorption or reflection features of matters (Teke *et al.*, 2013) and in some scenarios only a selected part of the spectrum is significative. UAV-based spectral methods can be employed to retrieve different types of information such as plant phenotyping and identification of growth stages, disease detection crops (Colucci *et al.*, 2020; Khaliq *et al.*, 2018; Musci *et al.*, 2020; Nguyen & Nansen, 2020; Thomas *et al.*, 2018), crop production estimation (Abdulridha *et al.*, 2020; Avtar & Watanabe, 2020).

More in details, plant phenotyping, consists of a set of morphometric and physiological parameters of plants (e.g. plant height, leaf area index (LAI), chlorophyll measurements and water stress). These parameters can also be used to establish the crop growth stage, as reported in (Tao *et al.*, 2020). (Yuan *et al.*, 2017) described a methodology to extract LAI from data acquired by a UAV-Based hyperspectral imaging system. (Tripodi *et al.*, 2018) investigated the advantages of using, among the different sensor also the hyperspectral sensors to evaluate plant phenotypes. (Feng *et al.*, 2020) used hyperspectral data to extract information about salt salinity phenotyping of the plants.

For what concern the early detection of plant diseases and pest infestation, (Abdulridha *et al.*, 2020) utilized lightweight hyperspectral camera to detect citrus canker, and in (Moghadam *et al.*, 2017), the spectral response was studied to discriminate the healthy plant from the diseased. In some cases, instead, the spectral response can be used to define the symptoms of the disease (Hillnhütter *et al.*, 2012). Finally, an example of the use of a hyperspectral sensor for crop estimation is reported by (Wang *et al.*, 2019). This paper presents a methodology for rising yield evaluation. Instead, Li *et al.*, 2020 use the hyperspectral data to predict potato crop yield.

4. Conclusions and future steps

The increasing number of studies proves the potentiality of the hyperspectral camera in precision agriculture applications in retrieving more information than other devices such as RGB or multispectral sensors. The spectral signatures, indeed, reflect the status of different targets such as plants, fruits and soil. The hyperspectral sensor can be considered as a dynamic technique that can evaluate potential problems and provide effective management solutions. The spreading boost of this technology is coming from the improvement related to their size and weight. The devices are getting smaller and lighter. The main disadvantages of the hyperspectral sensor use come from either the cost of the device and its integration on UAVs, weather and light conditions during spectral measurement, the amount of data, and the post-processing complexity.

In details, the high price of the high-resolution spectral cameras and their no full integration on UAVs compromises the use of this powerful instrument not only in research but also in the most affordable applications for farmers. The environmental conditions can affect the measurements, and this demands the development of proper methods for the acquisition process. The amount of data is strictly related to the hundreds of bands that the sensor can acquire. This influence either the storage of the data, the processing methods and the computational time. Such dimensionality requires software and programming libraries that can handle it and at the same time allow to achieve results in a short time.

To overcome these limitations, future efforts will be elaborated towards the improvement of the integration of the sensor on UAV and standardized methodology for data acquisition to reach a wider number of users. On the other side, the development of artificial intelligence-based software and techniques could help to handle the enormous quantity of data and the time-consuming process, reducing the data dimensionality or selecting the significative information.

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