Hyperspectral data acquisition and processing for early anomaly detection in vineyards

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Abstract: This paper proposes the use of hyperspectral data, acquired by a sensor mounted on an unmanned aerial vehicle (UAV) for early anomaly detection in vineyards. Hyperspectral data has become more accessible in the latter years, and therefore a high number of potential applications had emerged. However, to detect any slight change in vine plant´s health status, that might represent anomaly, the plants need to be monitored periodically, because of the fast-biological lifecycle. Vineyard areas are usually too big to be monitored manually, thus several remote sensing platforms are used. Traditional platforms like satellites and manned aircrafts can be applied, but they both have operational limitations and high costs. UAVs have managed to overcome those limitations by collecting data with the desirable frequency and low operating costs. Nowadays, UAVs are able to carry hyperspectral sensors that are now much smaller and cheaper. Frequent scanning of big areas by hyperspectral sensor mounted on UAV produce a large amount of data that requires a complex processing. Thus, the main objective of this study is to propose a strategy for hyperspectral data acquisition of vineyard areas followed up with proper processing techniques for early anomaly detection.

1. Introduction

A big effort needs to be put to an effective use of resources in every production. In agriculture, this trend was increased and even bigger emphasis on production efficiency started after the issues of sustainable use of land and resources were pointed out by the scientific community and policy makers (Markard, Raven, & Truffer, 2012). For a country as Portugal, where the economy highly depends on agricultural productions, an effective management of resources that are used into agricultural production is especially important. In case of wine production, Laan (2016) divided vine regions into “Old world” and “New world” vine regions. Most of the southern European countries belong to the “Old world”, being Portugal, France, Italy and Spain, countries of a big tradition of vine production for more than 2000 years (Campbell & Guibert, 2006; Fraga, Malheiro, Moutinho-Pereira, & Santos, 2012). However, in the actual scenario, even those countries have indications of struggling in sustainable wine production (Aylward, 2003). That is probably one of the reasons why the “New world” vine regions located in Australia, New Zealand, USA and South Africa, became a challenger to the “Old world” by implementing scientific approaches resulting in more effective production, even though this regions started in 1990s (Cusmano et al., 2010). A concept that aims to reach maximum effectivity in wine production is called precision viticulture (PV) (Bramley, 2010), where, ideally, the needs of each plant in a vineyard are satisfied. Vineyards are influenced by many structural factors as cropping practices or weather conditions, which make them heterogeneous (R. Bramley, 2003), causing different grapevine physiological response that directly influence the quality of grapes (Smart, 1985), making it necessary to conduct viticultural practices with consideration of spatial variability across the vineyard (Proffitt & Viticulture, 2006). Some of the authors that studied PV are (Bramley & Hamilton, 2004; Fernandes et al., 2013; Satorra, 2008) concluded that best production can be achieved by following three main requirements: right time, right amount and right place for the application of viticultural treatments, which can be achieved by fast, periodical and automatic plants monitoring and investigating the acquired data. Right time can ensure the early detection of anomalous spots, which, in terms of diseases, can limit the potential spreading and damages. The traditional manual checking of the crops in the field by agronomist and associated diagnostic test are too demanding and time consuming (Riley, Williamson, & Maloy, 2002) and could lead to late detection in big areas. Faster way of acquiring the data over the agricultural crops can be reached through remote sensing (RS) platforms, providing an opportunity to cover bigger areas with acquisition speed corresponding to the platform that is used. Unmanned aerial vehicles (UAVs) provide the needed flexibility and low operational costs making them potentially suitable for this type of applications. Right amount of treatments can be applied after correct classification of potentially dangerous anomalous parts, were detected in images captured by a scanning sensor. To make it possible to detect the anomalous parts in images in early stages, the scanning sensor needs to be setup with adequate parameters, being spectral and spatial resolution among the most relevant parameters. Low spatial resolution can bring an issue of mixed spectra in pixels which contain spectral information of more than one object or material. On the other hand, wide spectral resolution indicates that the scanning sensor is capturing images with spectral reflectance of wider part of electromagnetic spectrum, thus storing more information than common RGB images. But it is not only the range of electromagnetic spectrum that can ensure the detection of early anomalous parts, it is also the width of bands that matter (Manolakis, Marden, & Shaw, 2003). The use of hyperspectral sensors is getting popular in recent years not only because of the great characteristics they have but also because of the increased availability to more users. Thus, the use of an UAV with a coupled hyperspectral sensor appears to be the ideal combination for application of the treatments ensured by geocoded imagery data. This setup is proposed in this study for hyperspectral data acquisition over vineyard areas, with a goal of automatic anomaly detection in its early stages, following up to proposal of (Adão et al., 2017).

Successful detection and categorization of the anomalous spot can lead to reduction of pesticides and fungicides applied by using them only to the required spots and not over the whole plant as it is usually done (Viret, Siegfried, Holliger, & Raisigl, 2003). Moreover, such actions have significant environmental impacts (Christ & Burritt, 2013) making the future production less sufficient.

In next section of this document is presented the used equipment followed by preliminary results in section 3. Finally, in section 4, the main conclusions are summarized.

2. Equipment

This section briefly describes how hyperspectral data is acquired with a push-broom sensor and points-out the available UAV platforms that our research group use for carrying the sensor.

2.1. Hyperspectral data and sensor

Hyperspectral data is acquired by a passive optical camera. When they are being acquired, hyperspectral cubes are formed, as illustrated in Figure 1, which is a three-dimensional representation of the scene. Axes x and y represent the spatial dimension, meanwhile the z represent the spectral dimension. Spatial dimension corresponds to the size of the pixel that represent the spatial portion of the scene. The smaller the pixel representing portion of the scene is, the higher spatial resolution is considered. Spectral resolution consists of number of layers that are “stacked” within the cube. The bands in hyperspectral data are 5-20 nm narrow, each (Adão, Hruška, et al., 2017).

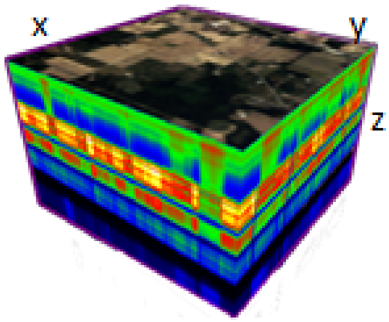

Figure 1 – Representation of a hyperspectral cube

The hyperspectral data used in this study was acquired by Headwall Photonics Nano-Hyperspec, VNIR push-broom hyperspectral sensor, presented in **Figure 2**. The sensor provides 270 spectral bands with a wavelength range 400 – 1000 nm, covering the most significant part of electromagnetic spectrum where vegetation has a considerable response. This sensor is capable to acquire 350 frames per second with a resolution of 640 pixels per line and a focal length of 12 mm.

Figure 2 – Headwall Photonics Nano-Hyperspec VNIR sensor

2.2. UAV platforms

Two types of UAV can be used by our research group to acquire hyperspectral data. A rotary-wing DJI Matrice 600 Pro (DJI, Shenzhen, China), presented in **Error! Reference source not found.** and a fixed-wing UAV, the PrecisionHawk Lancaster Mark III, presented in **Error! Reference source not found.**. Both types have their advantages and weaknesses against each other and suitability for specific application. Usually, fixed-wing platforms have a capability to cover bigger areas during a single flight, however a big corridor for proper take-off and landing operations is needed. Rotary-wing UAVs on the other hand do not require a big area for take-off and landing due to their ability to perform such operations vertically. Moreover, rotary-wing UAVs can acquire data with higher spatial resolution compared to fixed-wing platforms (Pádua et al., 2017).

Figure 3 – DJI Matrice 600 Pro

Figure 4 – PrecisionHawk Lancaster Mark III

3. Preliminary results

In this section, some preliminary results obtained from a hyperspectral data acquisition are presented.

3.1 Area of study

The data used in this research was acquired from a vineyard parcel located in the University of Trás-os-Montes and Alto Douro (41°17'13.2"N; 7°44'08.7"W), see Figure 5. Purposely, a vineyard with clearly visible heterogenicity was selected, composed of grapevines from the variety *Malvasia Fina*.

3.2 Data acquisition

When the UAV and hyperspectral sensor are used for data acquisition at the same time, the mission for both UAV and hyperspectral sensor need to be planned. The mission for UAV (DJI Matric 600 Pro) is planned by using UgCS PRO software (SPH Engineering, SIA, Riga, Latvia). This software enabled to set the required ground sampling distance, survey area boundaries and required forward and side overlap considering the sensor characteristics and the terrains altitude.

A scanning area for hyperspectral sensor is specified by using Headwall Polygon Tool web interface, see Figure 5, by creating the polygon of interest. Carefully needed to be defined especially the borders of the area, because generated are only cubes that are entirely inside the polygon. The final polygon is uploaded to the sensor by Hyperspec 3 software, which enables the communication between the sensor and the ground control station and manage the collecting of the data.

Figure 5 Polygon for hyperspectral sensor data acquisition over the studied area

Prior to the flight itself, a calibration target was placed inside the polygon region, and other operations were performed. Firstly, a white object needed to be placed in front of the sensor for calibration, which eliminated saturated areas from the hyperspectral data. The exposure calibration is crucial specially in sunny days. Next, a dark reference was acquired, which is necessary for radiation calibration during the data processing stage. After these steps, the mission is uploaded to UAV and the flight could start. After the takeoff, GPS module from hyperspectral sensor needs to be calibrated, to ensure that optimal signal is received, which is done manually by operator by flying the UAV in a “8” route. When the GPS module is calibrated, an automatic data acquisition mission inside the defined area, could start.

3.3 Data processing

The result of acquired data is a serie of cubes with a predefined size. The data is processed by Headwall SpectralView software. First, a raw data is used for generation of radiance cube and then a creation of reflectance cube. The radiance cube is generated according to the acquired dark reference, while the reflectance cube is generated according to a white reference, both acquired from a target placed in the field (see, bottom part of Figure 6). The last step of this processing chain consists in the orthorectification. Each generated cube must pass through these steps and then all the orthorectified cubes can be merged into a multi-ortho mosaic, as presented in Figure 6. After achieving this output, the data is ready to be analyzed and several computations can be done, as a NDVI calculation, see Figure 7.

Figure 6 – Generated multi ortho-mosaic

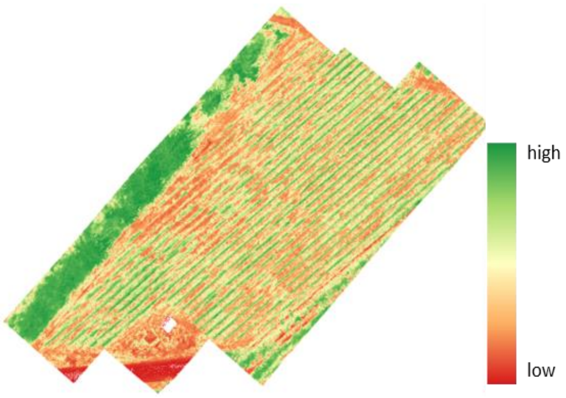

Figure 7 – Computed NDVI

It is now possible to get access to the stored reflectance of all bands that are provided by the hyperspectral sensor. Figure 8 shows different spectral reflectance of selected materials.

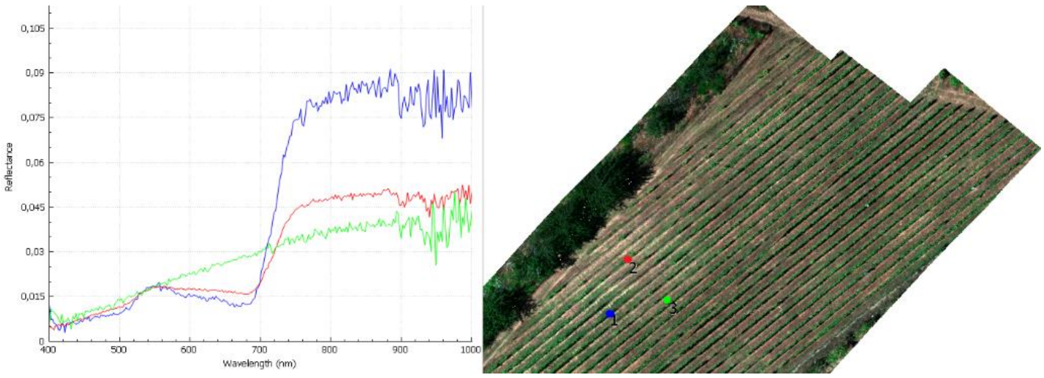

Figure 8 – Differences between spectral reflectance of highly vigour part of vineyard (blue), less vigour part of the vine (red) and soil (green)

4. Conclusion

Hyperspectral sensor mounted on the UAV provided a great potential to distinguish the small detected objects based on their spectral reflectance. With the UAV it is possible to carry out a scanning mission with desirable frequency which is mandatory for detection of early stages of anomalies. For the detection of small object, it is required to have a high spatial resolution as well, because in terms of diseases in their early stages, they are likely to appear in small areas. To achieve a high spatial resolution, it is needed to fly in low heights, approximately about 50 m (or even less), depending on the terrain conditions. For this task, rotary-wing UAV proved to be more suitable than fixed-wing UAV. This fact was caused mainly because of the lack of open space, caused by the characteristic cascade platforms of vineyards that are present in Douro region, needed for a safe landing of fixed-wing UAV. After the mission and data processing are done, resulting in final multi-ortho mosaic, automatic analyzing can be performed. For this purpose, several methods will be explored in future works. Machine learning approach is one of the methods that appears to be suitable for this task, because of its ability to handle high dimensional data.

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