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Vicarious radiometric calibration of a multispectral sensor from an aerial trike applied to precision agriculture

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ABSTRACT

This article proposes a vicarious calibration as a radiometric calibration method using an onboard multispectral sensor and a low-cost manned aerial platform, PPG (powered paraglider) trike. The statistical analysis of the errors shows the precision reached with this methodology. The greatest advantage offered by this type of manned platforms is its flexibility of flight, autonomy and payload capacity, allowing multiple sensors to be integrated without constraints to weight and volume. The results were validated at two different heights in order to verify the solution obtained with the method, demonstrating the insignificance of relative atmospheric influence between the aerial platform and ground using this platform according to the radiative transfer model on a clear and sunny day. At the same time, the study aims to develop a new trend for remote sensing that will assists in decision making for the sustainable management of extensive crop areas using low-cost geomatic techniques. As a result of the radiometric calibration process, georeferenced images with different vegetation indices over vineyards are obtained.

1. Introduction

The possibility of loading multispectral cameras on low-cost manned aerial platforms such as PPG trikes enables highly accurate radiometric studies to be performed. Therefore, it is desirable that the sensor should be subjected a calibration in which the radiometric behavior of each pixel in the different regions of the spectrum is analyzed, using as "ground truth" the radiance obtained on different targets with the calibrated spectroradiometer (Honkavaara et al., 2009). The basis of this behavior lies in the fact that each body has a typical and different pattern of reflected/emitted energy when it is influenced by electromagnetic energy, which distinguishes it from other materials (Chuvieco and Huete, 2009) depending on atmospheric conditions and the sensor characteristics (Biggar et al., 2003).

The main limitation of PPG trikes to make use of methodologies based on quantitative remote sensing is the need to develop radiometric calibration methodologies to obtain validated radiance data. As advantages, PPG trikes are able to acquire higher spatial, spectral and mainly temporal resolution data with a lower associated cost (Hailey, 2005) and, also, the relative atmospheric corrections required for validating the radiance data are likely to be insignificant on a clear and sunny day. The high spatial resolution data available from conventional platforms, such as satellites and manned aircrafts, is usually limited to a Ground-Sample Distance (GSD) of 50 cm/pixel. Instead, PPG trikes are capable of flying lower than a conventional manned aircraft and therefore acquire images of higher resolution, reaching up to 5–10 cm/pixel. In addition, the ease of flight planning permits better temporal resolution than classic photogrammetric flight planning (Hernandez-Lopez et al., 2013). In satellite systems, temporal resolution is limited by the coverage patterns of the satellite's orbit, involving lengthy periods in the delivery of the results (unfavorable temporal resolution) (Berni et al., 2009). Regarding unmanned aerial systems (UAS), the payload capacity and volume of onboard sensors as well as the limited flight autonomy means that the mapping and monitoring of large surfaces and ground covers are unviable. Last but not least, the progress of microelectronics in the field of navigation equipment (GNSS/IMU-Global Navigation Satellite System/Inertial Measurement Unit) has made it possible to provide these low-cost manned platforms with a quality solution to determine the spatial and angular position of the sensors and consequently their trajectory.

A key factor in the suitability of close-range remote sensing for vegetation analysis (i.e. precision agriculture) is based on the fact that such sensing procedures are non-destructive and non-invasive, providing similar accuracy to destructive field methods (Zhang and Kovacs, 2012). More specifically, the spectral signature

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of a given crop is directly related to its phenological, physiological and morphological characteristics, such that any change in the plant will also disturb its reflectance (Lass and Callihan, 1997; Schmidt and Skidmore, 2003). These differences in the intrinsic spectral behavior of each species allow their discrimination and mapping by analysis techniques and digital classification. This is why the spectral signatures of different types of vegetation can be assessed, supported by vegetation indices and the subsequent biophysical magnitudes used in agricultural applications.

The most widely used and most familiar vegetation index is the Normalized Difference Vegetation Index (NDVI) developed by Rouse et al. (1974), which is based on contrasts between maximum absorption in the red spectral region, because of chlorophyll pigments, and maximum reflection in the infrared region, caused by the cell structure of leaves and reflection of the cover due to its structure. Despite its intensive application, in cases of dense covers or those consisting of several layers the NDVI becomes saturated, such that a non-linear relationship with biophysical parameters such as the Leaf Area Index (LAI) (Baret and Guyot, 1991) is seen. The next generation of vegetation indices were developed taking into account the linearity of the cover fraction and the leaf area index, but normalizing soil brightness and color (Gilabert et al., 2011). As implied by their name, these indices refer to the soil and include the Soil Adjusted Vegetation Index (SAVI) (Huete, 1988) and the Modificied Soil Adjusted Vegetation Index (MSAVI) (Qi et al., 1994).

Other indices have been designed taking into account the spectral behavior of the soil in study areas, maintaining the sensitivity to biophysical magnitudes such as the Generalized Soil Adjusted Vegetation Index (GESAVI) (Gilabert et al., 2002). GESAVI showed good results for its linearity with LAI and soil noise reduction, simulating reflectances with radiative transfer models and with experimental data. A study by Broge and Leblanc (2001) addressing radiative transfer models has shown that the MSAVI is the best LAI estimator in terms of sensitivity-to-cover effects, variations in the cover parameters and the spectral properties of the soil. In the present work, the above vegetation indices were calculated in order to show the potential of multispectral calibrated images in agronomy.

Many studies have been carried out using multispectral and hyperspectral aerial and satellite images in the evaluation of crops (Herwitz et al., 2004; Chen et al., 2006; Zarco-Tejada et al., 2004). In fact, some authors have published works that, using multispectral, thermal or other conventional cameras on board small aircraft or unmanned helicopters, demonstrate the viability of these as platforms for image acquisition for plant studies (Esposito et al., 2007; Xiang and Tian, 2007; Turner et al., 2011; Zhao and Peng, 2006). However, to date there are no studies in which low-cost manned platforms such as PPG trikes have been used for crop monitoring. These offer an ideal platform for the study of large extensions of crops due to the above requirements.

The purpose of this article is to evaluate a new methodology aimed at acquiring georeferenced multispectral data of high spatial resolution after a radiometric calibration of the multispectral sensor for the monitoring of crops and the detection of areas with pathologies or hydric and nutritional deficiencies. To validate the methodology, a cultivated area of 5.4 ha was studied via aerial-trike overflights at different heights, using open-source software and tools. Thus, for vicarious calibration a GNU Octave (GNU, 2013) code was implemented.

The article is structured as follows: after the Introduction, Section 2 defines the method of vicarious radiometric calibration. In Section 3, the instruments used and the method developed are described. The experimental results and their discussion are given in Section 4, and the most significant conclusions are outlined in Section 5.

2. Vicarious radiometric calibration

The analysis of data captured by multispectral cameras requires prior knowledge of the radiometric calibration parameters of each channel to obtain correct interpretations. The calibration method chosen here was vicarious calibration (Dinguirard and Slater, 1999; Hernández-López et al., 2012), which involves performing an absolute radiometric calibration under flight conditions in an *in situ* radiometric measurement campaign. In this mode, the absolute method based on radiances was chosen because the digital level (DN) that defines each pixel is directly related to the radiance detected by the sensor (Hiscocks, 2011). The method based on radiances is theoretically more accurate than those based on reflectance, because it has an uncertainty of approximately only 2.8% as compared with 4.9% for the latter case (Biggar et al., 1994). This lower value is derived from the calibration and stability of the spectroradiometer required for calibration.

To carry out the radiometric adjustment, low-cost surfaces compared to other more expensive lambertian ones, have been selected as the ground control targets (invariant targets) to approximate comparable and homogenous spectral behavior under nadir observation angles to flight measurements (Davranche et al., 2009). In addition, via various laboratory tests and field studies the invariant reflective capacity for a period of time in which these surfaces were not damaged was confirmed. From the multispectral aerial images, the digital levels of these targets can be extracted and the radiance measured is obtained with the spectroradiometer on the ground, establishing a linear model for each spectral band of the sensor. To assess the effects of the atmosphere in terms of radiative transfer, the 6S Model (Vermote et al., 1997) was implemented, which transforms the radiance measured at the ground into that obtained at the height of the sensor. Finally, the results were validated with natural and artificial check targets (pseudo-invariant targets), contrasting the radiances calculated by the calibration parameters with those measured directly in the field.

Fig. 1 shows the workflow followed in the radiometric calibration process.

3. Materials and methods

3.1. Materials

The following equipment was employed for data acquisition:

- A GNSS device, Leica 1200. This consists of a RTK dual frequency receiver and geodetic GPS L2C and double dual-frequency antenna with L2C and serves to georeference control and check targets.
- A six-channel multispectral camera: Tetracam Mini-MCA. Each of the six channels of the camera is constituted by a CMOS (Complementary Metal–Oxide–Semiconductor) sensor and a filter with a preset performance against the spectral range. The spectral response of CMOS sensors is not uniform due to quantum efficiency and sensitivity. Neither do filters exhibit homogeneous transmission between each other. The effect of the combination of CMOS and the six filters results in a reduction in camera radiance, different per each wavelength. The camera specifications are defined in Table 1. The choice of the filter wavelengths (detailed in Table 2) was optimized for the evaluation of the particular behavior of the vegetation, avoiding areas of atmospheric absorption.
- A manned aerial platform supported by a powered paraglider (PPG) trike built by Airges. Its technical specifications are shown in Table 3. The Mini-MCA camera was loaded onto the PPG trike using an auto-stabilized mounting platform.