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Field radiometric calibration of a multispectral on-the-go sensor dedicated to the characterization of vineyard foliage

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ABSTRACT

The accurate assessment of the vigor and disease impact is a major challenge in precision viticulture. It is essential for managing phytosanitary treatments. Up to now, some remote sensing techniques such as aerial imagery and handheld optical sensors have been applied to grapevine characterization. However each technique provides limited, specific information about foliage. To broaden the characterization of the foliage, we developed a proximal integrated, multispectral imaging sensor that operates in the visible and near-infrared bands. It is mounted on a track-laying tractor equipped with a Greenseeker-RT-100, coupled with a GPS-RTK. As the sensor is very sensitive to the ambient light, a radiometric calibration is required: it allows producing absolute reflectance images, using a color chart. If the chart is hidden by leaves, for instance, the images are corrected using the linear interpolation method. The adaptive radiometric method is evaluated as a function of the number of neutral patches selected on the color chart during the linear regression process and the efficiency of the spatial interpolation method is assessed using a leave-one-out-cross-validation (LOOCV) method.

The radiometric calibration is validated by comparison of NDVI maps produced by imagery and by the Greenseeker, a commercial system. In the early stage of berry formation, we examined and quantified the spatial patterns and demonstrated a low-cost imagery method that is capable of analyzing correctly the vigor. This corroborates the efficiency of the calibration method encouraging the use of multi-spectral imagery for other vineyard applications, such as the characterization of physiological status.

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1. Introduction

Precision agriculture can be defined as a set of methods that improves farm productivity by assigning specific attributes to individual production areas (Robert et al., 1994; Pierce and Nowak, 1999; McBratney et al., 2005). A four-stage process is traditionally depicted: observation of crops over time with sensors, interpretation of georeferenced data, evaluation for agronomic management, and in-field implementation (Bramley, 2001; Bramley and Lamb, 2003; Mathews, 2013). When adapted to grapevine management, precision agriculture is called precision viticulture (Bramley and Proffitt, 1999; Tisseyre et al., 2007). It allows characterizing the within-field variability (Bramley and Lamb, 2003) using appropriate proximal, airborne or spaceborne remote sensing techniques (Strever, 2007; Mulla, 2013). Multispectral or hyperspectral sensors may generate their own light sources (e.g., active sensors as the Greenseeker RT-100 or the Multiplex) or use natural light (e.g., passive sensors such as imaging systems). One can measure the reflectance, transmittance and fluorescence of plants using both types of sensors and extract information about their internal biophysical and biochemical properties (Gitelson and Merzlyak, 1996; Moran et al., 1997; Johnson et al., 2003; Goutouly and Cerovic, 2008; Whalley and Shanmuganathan, 2013; Quemada et al., 2014). In particular, the reflectance signal allows the computation of vegetation indices such as the reflectance ratio (Mulla, 2013; Quemada et al., 2014) or the normalized difference vegetation index (NDVI) (Choudhury, 1987; Solari et al., 2008) which are related to plant status: nitrogen, chlorophyll content, green leaf biomass.

As far as vineyard is concerned, Whalley and Shanmuganathan (2013) reviewed the main parameters that are used to manage within-field variability. Other authors explored variation yield (Bramley, 2001), disease detection (Sankaran et al., 2010), or vine vigor (Lamb et al., 2001; Hall et al., 2002; Johnson, 2003; Cerovic et al., 2009). To date, only a few aerial studies have focused on grapevine foliage architecture (Moran et al., 1997; Mathews and Jensen, 2013). This has motivated the development of proximal sensing devices for a better positioning of the acquisition system for foliage observation (Debuisson et al., 2010) and real time

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management of within-field variability (Bramley, 2001; Mulla, 2013). The Greenseeker is one of the most popular proximal sensor used to appraise vine vigor (Mazzetto et al., 2009) especially at early growth stage. Several studies have shown its efficiency to monitor grapevine growth but with many precautions (Drissi et al., 2009; Mazzetto et al., 2010) and its reliability for in-field acquisition (Kim et al., 2012; Kipp et al., 2014). In the past, different visible imaging systems have been tested and results were promising (Tregoat et al., 2001; Lloret et al., 2011; Diago et al., 2012; Rodríguez-Pulido et al., 2012). A review of the wine literature seems to demonstrate that multispectral imaging systems, which are mainly used for remote sensing applications, have been considered for the first time in 2012 as mobile proximal sensors to detect grape leave diseases in field conditions (Tirelli et al., 2012). Two main problems may prevent the use of mounted proximal multispectral imaging systems: the difficulty to control ambient light variation during the measurements and the determination of a reliable method for foliage identification. Indeed, natural light variations make it difficult to process images due to the presence of shadows, saturated pixels.

Beyond the development of a highly multi-purpose proximal imaging system to monitor grapevine growth (leaf, vine shoots and wood pruning ...), this article presents a new calibration method for visible and near-infrared images to consider ambient light variation. The following sections describe the experimental field and the development of the sensors mounted on a track-laying tractor. A particular attention has been paid to the radiometric calibration which relies on a color chart that is visible in the images. For images with unusable chart, an extended correction is proposed. In the last section the NDVI results are evaluated against the NDVI values provided by the Greenseeker RT-100 system. The assessment of the performance of the radiometric calibration method is based on a statistical method (ANOVA) from both NDVI results (imaging system vs Greenseeker).

2. Materials and methods

We first present the experimental field (Section 2.1), the experimental set-up and the associated technical constraints (Section 2.2). The system requires geometric (Section 2.3) and radiometric corrections to produce reflectance images (Section 2.4). Second, we detail the image processing chain for the estimation of NDVI (Section 2.5) and NDVI maps (Section 2.6).

2.1. Site description and data collection

The experiment took place in the experimental site (Plumecoq) of the CIVC institute (Comité Interprofessionnel du Vin de Champagne) located in Chouilly, France. The surface area is 0.72 ha (150 m long by 50 m wide) and all grapevine varieties were planted in 1996 with spacing between two rows of 1.10 m. According to the topography and the orientation, three main grapevine varieties have been planted in a Latin Square pattern to minimize the influence of heterogeneous agronomic effects (Vilain, 2012): Pinot Noir (PN), Chardonnay (CH) and Meunier (Mn). Fig. 1 shows the organization of the plot and the varieties are planted over three blocks called later in the article "top", "middle" and "down" according to the slope level of the hill (Fig. 1). Thus these three blocks, composed of the three Champagne varieties (PN, CH and Mn), represents nine sub-plots of 0.08 ha (50 m long by 16 m wide).

The field is made of 45 rows divided in three blocks of 15 rows each according to the grapevine variety (CH, PN and Mn) and the slope level (top, middle, down). Data collection was performed over a single, cloudless day during July 2013 starting at approximately 11:00 am, around solar noon to avoid shadows. The dataset is composed of 5356 images and it takes about one hour to cover the area. The phenological stage for all varieties is the early berry formation (BBCH stage N°71, Meier, 2001). An historical acquisition protocol was conducted: measurements were carried out from top to bottom of the field starting in the block of Chardonnay variety (CH Top) and ending in the block of Chardonnay variety (CH down). Moreover, in the past, the CIVC institute has developed a specific route protocol assuming that the exhaustive observation of 2 non-consecutive rows (continuous acquisition of images along the row) was representative enough of 5 row data. Consequently, 6 rows were acquired for each block of 15 rows. In the entire field, a total of 18 rows over 45 were then studied.

2.2. Experimental set-up

Fig. 2 presents the acquisition system mounted on a track-laying tractor assuming a constant tractor speed of 1 m/s. It consists of a visible-near-infrared multispectral camera (AD-130GE, JAI), a localisation system for data georeferencing (GPS-RTK, Trimble) at a frequency of 10 Hz and a computer to control the camera and to save the data. In order to validate the protocol developed to deduce the vegetation indices from the image acquisition, we also mounted a Greenseeker RT-100 (Trimble) which acquires data at a high frequency of 50 Hz. This active sensor is made of two LEDs (light emitting diodes) in the red (656 nm) and near-infrared (770 nm) spectral regions to estimate vine vigor using NDVI (Drissi et al., 2009). The Greenseeker field of view was 700 mm (height) by 20 mm (width).

The multispectral camera is a prism-based 2-CCD progressive area scan camera, 8-bits encoding. This particular design captures simultaneously visible and near-infrared light spectrums using a single prism that splits the light gathered by the lens. Light is redirected to two CCD sensors (1296 $\times$ 966 pixels) to be recorded. It allows the synchronized acquisition of RGB (from 450 nm to 700 nm) and NIR (from 750 nm to 850 nm) images. Each CCD (4.86 mm $\times$ 3.62 mm) is designed by Sony's ICX447 CCD series. The image acquisition frequency is 3 Hz and it corresponds to around 3 images per meter. Aperture and exposure time are fixed by the operator before the dataset acquisition. Aperture is chosen according to the ambient light characteristics. Exposure time is set close to its minimal value (approximately 1/625 s) in order to avoid blurred image. Sensor's gain (ISO speed) is controlled in real time by the laptop according to the luminance of the central region of the image (1/3 of the height and 1/3 of the width of the image) and it is adjusted in case of underexposure or overexposure.

The short distance between vine rows (<1.10 m) implies that the camera is positioned at a short distance from vine foliage (<0.60 m). For that reason we used a wide angle lens (focal length of 2.8 mm) that produced 902 mm (height) by 670 mm (width) field of view. Fig. 3 shows an example of a snapshot image (RGB and NIR) of vine foliage: most of the leaves that are interesting in terms of foliage development are visible. A *ColorChecker ("MacBeth")* Chart was placed in the background to perform radiometric calibration (see Section 2.4).

We used an umbrella (1) to avoid overexposure of parts of the image, and (2) to minor the presence of projected shadows on an image, which would degrade image quality and complicate the reliability of information extracted from it. In the same way, a black panel (Figs. 2 and 3) was installed in the background to focus measurement on grapevine and facilitate the image processing. All the height of images were resized according to the size of the black background panel (770 mm (h) $\times$ 560 mm (w)) observed in the images. Indeed as the black background panel is fixed on the tractor, it is always visible at the same place on all the images of

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