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Fine tuning of the SVC method for airborne hyperspectral sensors: the BRDF correction of the calibration nets targets

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ABSTRACT

This paper presents measurements of the azimuth and zenith angle-dependence of the targets that are used for supervised vicarious calibration (SVC) methodology of hyperspectral sensors. Surface radiance measure at-sensor from airborne instruments, such as the AisaDUAL and HyMap sensors, show an apparent noise and shift that limit the information content and even impair the collected data (after removing the atmospheric attenuation). The drift from actual radiance is contributed by various sources; e.g., atmospheric gases and aerosols, and sensor stability. Yet one of the major contributors to it during nadir scanning is the directional effect of target reflectance at variable illumination geometry, also known as Bidirectional Reflectance Distribution Function (BRDF). The SVC method, which is based on ground dark nets of varying densities, was able to correct for the above factors and recalibrate the sensor's radiance during data acquisition. The main assumption of the SVC method is that the net targets are a Lambertian surface. In this paper, the BRDF measurements of the SVC net targets were carried out using a goniometer and controlled laboratory conditions. These measurements revealed anisotropic properties of the nets targets, which were further introduced to the radiometric calibration process are significant, especially with the high density nets (> 50% black net cover). The paper presents a look-up-table of the BRDF correction coefficient factors for each net target (identified and separated by its density and mixing level once placed over a bright background) at various zenith (from − 10° to − 30°) and azimuth (from 0° to 360° at intervals of 10°) angles. The coefficients were calculated for the near infrared spectral region (at 981 nm), and should be applied to the full-reflected spectral range across visible, near and shortwave-infrared wavelengths (400–2500 nm). The acquired results in this empirical study showed that the SVC calibration nets targets are characterized by incoherent BRDF effect. The darker and denser calibration targets absorb the down-welling radiance, and thus, reduce the amount of intermediate multiple scattering, normally accrued in all other (less dense) examined targets. The impact of target density on the BRDF correction coefficient and its dependence with illumination zenith and azimuth angles is studied and presented. The correction coefficient factors obtained in the laboratory were implemented in two real airborne hyperspectral campaigns of two different sensors: AisaDUAL and HyMAP over the same calibration site. The proposed BRDF SVC net corrections enables fine-tuning of the vicarious calibration procedure, while increasing the quality of the radiometric data. Thus, it is recommended to use the BRDF coefficients obtained in this paper for any airborne hyperspectral sensor that uses the SVC method in order to achieve better calibration accuracy.

1. Introduction

The major efforts invested by the remote sensing community into calibration and validation of sensors is vast (Gatebe and King, 2016; Singh et al., 2016; Nag et al., 2015). Many studies use ground-truth measurements to quantify spectral reflectance properties of the earth's surface materials and reduce uncertainties in the derived thematic products. In this regard radiometric and atmospheric corrections are playing a major role. Vicarious calibration is a well-known technique where well-characterized targets are used to correct and validate remote sensing sensors and its at-sensor radiance and reflectance responses. This effort is particularly important where the accuracy of both radiometric and atmospheric corrections tightly connected to spectral characterization of the ground calibration targets and are sensitive not

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only to their chemical characteristics but also to their physical ones such as: texture, grain-size variation and density (Dematte et al., 2010; Helfenstein and Shepard, 2011; Hapke, 2012), and geometry. Directional reflectance can affect the extraction of structural/physical details from unidirectional imagery data that is defined by flight geometry and data acquisition configurations. This parameter can strongly affect the quality of at-sensor radiometric calibration and bias the coefficients calculated directly from the acquired airborne imagery data in vicarious fashion. As a result, the poor radiometric data render accurate reflectance extraction using atmospheric correction methods.

A recently published SVC method examined several scenarios (Brook and Dor, 2011; Brook and Ben-Dor, 2015). In general, the SVC Method employs black agricultural nets (size of each net is about 15 m × 40 m) of various densities that are placed on homogeneous bright surfaces (e.g., dune or coastal sand, bright concrete or gravel). These targets are used as ground calibration areas for the vicarious calibration procedure, known as the SVC Method. The SVC Method applies several radiometric and atmospheric coefficients (gains and offsets) retrieved directly from the imagery and from the ground-truth data and calculates the atsensor radiance. The SVC Method presented a significant improvement of recalibrating (vicariously) airborne hyperspectral sensors in a near real-time.

The assumption of the SCV method was that the nets targets represent isotropic/Lambertian surfaces and the SVC Method never directly treated the angular distribution of reflectance or corrected it. The only consideration was to fold the nets in the direction of the sun azimuth. In a recent study, Brook and Ben-Dor (2015) examined the effect of flight direction over the net targets and the scene in question, and showed the importance of observation geometry. Moreover, the last showed that the ground-truth spectral measurements have to be consistent with the flight direction. These findings are evidenced by the dependency of the SVC nets targets and the illumination zenith and azimuth angles.

The phenomena of the BRDF and its connection with systematic measurements were conceptually identified by Nicodemus (1977) and used afterward by others (e.g., Feingersh et al., 2010). Further development of the BRDF correction concept was reported by Martonchik et al. (2000), later by Di Girolamo (2003) and further by Hapke (2012) who included calculations of horizontally heterogeneous surfaces, the illumination and measurement areas. The BRDF effect and its influence on illumination in measured reflectance data has been studied in detail by numerous studies (Lyapustin and Privette, 1998; Schaepman-Strub et al., 2006; Bachmann et al., 2014; Schläpfer et al., 2015). Despite efforts and developments, the majority of the reported studies are not considering the physical conditions of measurements and the corresponding response of at-surface reflectance.

The assumption of a single direction of the incident beam toward the optical sensor on an airborne platform is erroneous, as the natural irradiance is a complex phenomenon with strong physical underpinnings. Indeed, it is composed of a direct component and a diffuse component scattered by the atmosphere and the area nearest to the measured ground target. Thus, the BRDF effects on spectral disturbance are subject not only to atmospheric conditions and topography, but also to surface reflectance properties; e.g., pore sizes and microscale roughness/texture.

Since the BRDF reflectance cannot be quantitatively measured by means of satellite remote sensing directly, but only approximately evaluate an observed ground target, different approaches are needed. To cope with it, the realistic albedo products are achieved from airborne remote sensing data, assuming that it provides the most accurate irradiance (atsensor radiance) and detailed sensor geometry. Numerus models for BRDF correction methods have been developed in the past two decades, yet all follow two distinct approaches: one is based on coherent backscattering from Maxwell's equations (Mishchenko et al., 1999; Tishkovets et al., 2011), and the other is based on radiative transfer models (Hapke, 2012).

The first category is focusing on the topographic correction of terrain imagery. The most well-known methods are cosine correction and empirical correction, also known as “C-correction” (Teillet et al., 1982; Borel and Gerstl, 1992; Richter et al., 1997; Meister et al., 1997; Li et al., 2012), that assess incidence-angle-dependent BRDF effects by calculating alteration of direct and diffuse reflectance at different incidence angles. The reflectance above areas with low local solar elevation angles or large local solar zenith angles, are used by topographic correction methods. The illumination of Lambertian surfaces are typically corrected by a “C-correction” calculated as the ratio between measured at-sensor radiance from inclined surfaces and the cosine of the incident angle (Richter et al., 1997; Teillet et al., 1982; Li et al., 2012).

Another technique in this category is an empirical approach that corrects the off-nadir reflectance (which can be at-sensor radiance) by the corresponding scan-angle dependent brightness coefficients with nadir values (Rautiainen et al., 2008; Itten et al., 2008). These methods are useful to correct incidence-angle dependent BRDF effect along with the observation-angle dependent BRDF effect (Schläpfer et al., 2015).

To that direction Feingersh et al. (2009), have demonstrated a method in which a lookup table of correction coefficients were extracted from laboratory measurements with a goniometer and selected targets (grass, sand asphalt). These coefficients were further used to correct the anisotropic variation of the image based on the similarity of each pixel geometry to the laboratory records. This method demonstrated a significant and effective correction of the BRDF effect and based on that approach the BRDF correction code “BREFCOR” was generated.

The second category is applying phenomenological physics of radiative transfer model with empirical local (mostly limited) modifications, known as Hapke model (Hapke, 2012). This model can produce predictions of particle sizes and absorption characteristics by providing the scattering of light from granular materials under investigation based on its spectral responses. The model will perform its results under the following limitations, the material must be considered densely packed with random particle medium. However, the model has been undependable once the issue was to extract information about the physical properties of unknown targets from reflectance measurements (Helfenstein and Shepard, 2011), in particularly difficulties to address the relationship of reflectance and physical properties of the material.

Cierniewski et al. (2010) reported that hyperspectral images of soil surface at micro-relief scale show spectral variation caused by illumination angles of the surface. In this context, a strong negative correlation between particle size (sand targets) and BRDF has been established (Xie et al., 2006; Georgiev et al., 2009) across visible and near infrared (VNIR) spectral region. However, for several samples, especially sand and gravel, the BRDF changes and present reflectance depression as the surface density increases (Bachmann et al., 2014). Moreover, the authors have proved that the phase function varies in response to variations in the target's pore shape and size.

Investigating the reflectance variations of the SVC net targets, associated with the illumination zenith and azimuth functions is the main interest of this paper. The main assumption is that incorrect radiometric data might lead to significant differences between the exact correction coefficients; e.g., radiometric and atmospheric gains and offsets, broadly applied in the original SVC Method. The radiometric mechanisms, related to differences in interpreting the relationship between the BRDF model and the scattering properties of media that are aggregates of very large black calibration nets (Brook and Dor, 2011) with varying pore shapes and sizes, is important. This paper presents a far- and near-field laboratory study to define the exact BRDF characteristics of the net targets used in the SVC protocol, and suggests a set of coefficients for a substage process in the SVC correction scheme that suppresses any possible ambiguity and assures accurate and realistic at-sensor radiometric values.

Accordingly, this study will first present the experimental

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