ISPRS Journal of Photogrammetry and Remote Sensing 114 (2016) 102–114

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

The use of suitable pseudo-invariant targets for MIVIS data calibration by the empirical line method

Alessandro Mei *, Cristiana Bassani, Giuliano Fontinovo, Rosamaria Salvatori, Alessia Allegrini

National Research Council of Italy, Institute of Atmospheric Pollution Research, Via Salaria Km 29, 300, Monterotondo, RM, Italy

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form 30 November 2015
Accepted 18 January 2016
Available online 18 February 2016

Keywords:
Empirical line method
Pseudo-invariant target
MIVIS

ABSTRACT

The Empirical Line Method (ELM) enables the calibration of multi- and hyper-airborne/satellite image converting DN or radiance to reflectance values performed by using at ground data. High quality outcome can be reached with the selection of appropriate Pseudo-Invariant Targets (PIT). In this paper, spectral variability of "usual" (asphalt and concrete) and "unusual" (calcareous gravel, basaltic paving, concrete bricks, tartan paving and artificial turf) PITs is retrieved for ELM application. Such PITs are used to calibrate the Multispectral Infrared and Visible Imaging Spectrometer (MIVIS) airborne sensor in 12 different Runs. Firstly, processing of field spectral data enables the evaluation of pseudo-invariance of targets by studying their spectral changes in space and in time. Finally, these surfaces are used as Ground Calibration (GCT) and Validation Targets (GVT) in ELM. High calibration accuracy values are observed in Visible (VIS) range (98.9%) while a general decrease of accuracy in Near-InfraRed (NIR) (96.6%) and Middle-InfraRed (SWIR) (88.1%) are reached. Outcomes show that "usual" surfaces as asphalt and concrete and "unusual" surfaces such as tartan can be successfully used for MIVIS image calibration.

1. Introduction

The calibration of remotely sensed data removes atmospheric effects and maximizes their quantitative utility for land cover changes monitoring or quantitative analysis (Gao et al., 2006; Karpouzli et al., 2003). Several methods are implemented to retrieve surface reflectance from at sensor radiance such as the covariance matrix method (Ferrier, 1995), the dark pixel/histogram method (Chavez, 1996; Themistocleous and Hadjimitsis, 2013) or physically based algorithm (Bassani et al., 2010). An alternative approach is the Empirical Line Method (ELM), which allows to calibrate multi- and hyper- spectral data from raw DNs or radiances to reflectance values (Ben-Dor et al., 2004). The ELM offers relatively simple calculation of surface reflectance if invariant in-space and in-time target measurements are available. Calibration surfaces with different albedo (dark and brighter) are normally used.

Generally, different authors settle that ground target selected surfaces should be homogeneous, pixels sized, with different albedo and ideally spectrally featureless (Clark et al., 2002; Ben-Dor et al., 2004).

Asphalt and concrete surfaces are often suggested appropriate as ground calibration targets in the visible and the near-infrared spectral domain (Lawless et al., 1998), while analysis carried out from ground measurements shows significant spectral variability (Lacherade et al., 2005). Clark et al. (2011) and Puttonen et al. (2009) show that the use of Pseudo-Invariant Targets (PIT), such as asphalt surfaces, without detailed knowledge of specific site's characteristics is not recommended and it is advisable to make field measurements simultaneously or very close to the imagery acquisition time. While several studies suggest the suitability of these kinds of targets to use in ELM by BRDF measurements (Clark et al., 2011; Casselgreen et al., 2007; Sandmeier and Itten, 1999), there is still a gap of knowledge and confusion regarding their spectral and physical features. In fact, while in Themistocleous et al., 2012 black and gray asphalt and concrete surfaces can successfully be used as pseudo-invariant targets throughout the year, Clark et al. (2011) considers new asphalts too spectrally dark to be a calibration target and weathers can quickly modify them.

Due to relevant effects such as solar angle, wear and moisture that influence reflectance of ground targets, the evolution of their temporal spectral stability represent a crucial issue. As demonstrated by Anderson and Milton (2006), the comparison of asphalt and concrete absolute reflectance at short-term and long-term

* Corresponding author.
E-mail address: alessandro.mei@iia.cnr.it (A. Mei).

http://dx.doi.org/10.1016/j.isprsjprs.2016.01.016

shows high differences and suggests that calibration reflectance factors do not remain stable over time. Nevertheless, there is a need to minimize the temporal delay between field measurements and sensor overpass. As asphalts and concretes, some sandy targets can be significantly affected by precipitation, and their use as a ground reference target have a relevant impact on the method used for reflectance retrieval from at sensor signal (Themistocleous et al., 2013). The influence on spectral signatures of moisture in different asphalt aggregate mixture samples was evaluated and confirmed in Mei et al., 2012. In Mei et al. (2011, 2014a), a spectral variation through time is showed: older asphalts should be considered invariant for a few weeks while the newest can modify their spectra in a few days. Moreover, in Anderson et al. (2003) and Anderson and Milton (2006), surfaces exhibit measurable changes in reflectance over time-scales thus showing that these surfaces cannot be assumed to be keeping stable over time.

For aerial image calibration purposes, several authors suggest to improve knowledge of PIT to create a database including a spectral library. Target characteristics stored allow efficient and *ad hoc* suitability evaluation for image calibration or validation use (Peddle et al., 2001; Bojinski et al., 2003). With the advent of airborne sensors with higher spectral and spatial resolution, there is a need to re-evaluate the ELM potentiality for reflectance values retrieval (Gao et al., 2009).

The ELM needs accurate ground truth data such as spectral measurements of impervious surfaces to use as pseudo invariant targets. These targets need to be spectrally stable (invariant) over time and space and clearly identifiable on imagery. Their selection efficacy is evaluated by the use of several sensors such as IKONOS (Karpouzli and Malthus, 2003; XU and Huang, 2008), SPOT (Clark et al., 2011), Landsat TM (Hadjimitsis et al., 2009), Landsat ETM (Themistocleous et al., 2013), Worldview 2 (Staben et al., 2011) and CASI (Anderson et al., 2003) for the empirical line method application.

For ELM, different numbers of reference field spectra ranged between 2 and >100 are used by different authors (Vaudour et al., 2014; Hamm et al., 2012; Themistocleous et al., 2012; Karpouzli and Malthus, 2003; Smith et al., 1999; Ferrier and Wadge, 1996), and accuracies ranging from 20% to a few per cent are reported. The simplest approach is to use one target and to assume that a dark ground surface will produce a value of zero for DN/radiance ratio. Errors in a 15–20% margin have been reported when this approach is used (Freemantle et al., 1992). Generally, as reported by Baugh and Groeneveld (2008), studies that use a larger number of calibration targets report better accuracies, and suggest that a greater number of targets allow to obtain a lower correction error. Besides, this trend is related to various aspects such as the ground targets selection and sampling method.

In this paper, the suitability of "usual" (asphalt and concrete) and "unusual" (calcareous gravel, tartan, basaltic bricks and artificial turf) ground reference surfaces are evaluated for the reflectance retrieval by the ELM. By the use of a large ground measurements dataset, the evaluation of their spectral variance in-space and in-time allows to delineate their pseudo-invariance and define appropriate PITs. Finally, a selection of suitable surfaces is evaluated and ELM applied for 12 MIVIS Runs while image validations are performed considering those wavelengths that best represent absorption and reflection peaks of considered PITs spectra.

2. Materials and methods

2.1. Study area

The study area consists of generally suffering of anthropogenic activities such as mining and illegal waste dumping which have high environmental impact in neighboring areas. The area is located in Southern Italy (Campania District). The area is centered at latitude 4,519,207 N and longitude 451,839 E (WGS 84/UTM zone 33 N EPSG: 32,633) (area extent about 17 km × 13 km) and is referred to the South urban area of the City of Naples and to the peri-urban area at fringe of the Mount Vesuvius National Park (Fig. 1). Because of the absence of ground targets with adequate dimensions and characteristics, the inner area of the National Park is not taken into consideration for this study.

2.2. Field data

Field spectra are acquired using a FieldSpec 3 (A.S.D.) spectroradiometer in two different campaigns (clear sky conditions), respectively on the last days of July and the first days of September 2010, between 11:00 and 14:00 h local time. The instrument measures light intensity in the range between 350 and 2500 nm using an optical fiber bundle that collects the reflected radiation with a 25° conical field of view. It uses three detectors spanning, respectively, the visible, near-infrared (VNIR) and short-wave infrared (SWIR1 and SWIR2) with a spectral sampling interval of 1.4 nm for the VNIR and 2 nm for the SWIR detectors. The spectroradiometer is set up on reflectance-mode and a Spectralon panel, assumed as Lambertian surface, is used as white reference.

For this study, 101 sites are investigated which corresponds to 303 targets. These targets are organized by 243 asphalts and 60 other different surfaces. Targets are classified as "usual" (asphalt and concrete) and "unusual" (calcareous gravel, tartan, basaltic bricks and artificial turf), depending on frequency of their employment in literature as calibration and validation ground reference data. Each target is composed by 9 sub-targets which corresponds to 90 spectral signatures (10 signatures for each sub-target). For each investigated site, 1–4 homogeneous targets are selected. Each sub-target dimension is set considering image spatial resolution (3 m × 3 m) while each target is set to be 3 times bigger (9 m × 9 m). An example of the sampling grid is given in Fig. 2a. Each corresponding spectral signature corresponds to the average of 10 acquisitions.

In order to get more accurate ancillary data for subsequent analysis, a 40 cm × 40 cm reference ruler is used for acquisition of pictures associated with spectral and ancillary data. The ruler consists of 5 cm white and black stripes which are used as dimensional scale. The distance of optical fiber to targets (68 cm) is selected considering the inner area of the ruler (1600 cm^2) and a Ground Instant Field of View (GIFOV) radius of 15 cm (Fig. 2b).

The location of each site and target is recorded with a GPS Garmin *e*trex while each sub-target position is measured with a distantiometer Leica Disto A8. The GPS coordinates allow to place on imagery targets with an error of about 5 m while the distantiometer allows to make accurate positioning of sub-targets in imagery with high accuracy. This combined referencing system allows to implement ELM with a per-pixel approach, as suggested by Hamm et al. (2012).

Considering different field light conditions, the white normalization tool of a Nikon Coolpix S560 digital camera is used to obtain comparable pictures. For this purpose white ruler stripes are used as reference. The camera is fixed on a tripod and each picture is taken at 68 cm from the target. This geometrical set-up is chosen considering the ruler's external dimensions and the FieldSpec field of view in order to have a picture area to be representative for each spectral signature. At the same time, the maintenance of a shooting distance from the target allowed to standardize the photo acquisition.

For a better efficiency selection of calibration (CAL) and validation (VAL) targets, additional ancillary characteristics are acquired. In particular, concerning the physical characteristics of targets, such as particle size and morphology, the methodology used in