Uncertainties assessment in orbital or airborne sensors absolute calibration

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Abstract

The electro-optical sensor absolute calibration (orbital or airborne) aims to transform the digital numbers present in the images into physical quantities. The orbital sensor calibration procedure frequently considers a reference surface on the ground. Radiometric measurements are taken from this reference surface and the results are compared to those acquired by the sensors to be calibrated. Obviously the complete calibration procedure includes uncertainties that have to be estimated in order to provide confidence to the sensor data. This work aims to evaluate the main uncertainties involved in the process of absolute calibration of eletro-optical sensors in the visible, near and middle infrared regions of the electromagnetic spectrum.

Keywords: absolute calibration, electro-optical sensor, uncertainty, Tuz Gölü

1. Introduction

The absolute calibration of airborne and orbital sensors is a prerequisite to use their data at quantitative approaches. The absolute calibration aims converting the Digital Numbers (DNs) of the images into physical quantities. The orbital sensor calibration procedure frequently considers a reference surface on the ground. Radiometric measurements are performed on reference surfaces during the sensor overpass. These radiometric measurements are converted to radiance and it is estimated the atmosphere interference on these radiance values through radiative transfer codes and as a result radiance on the top-the-atmosphere (apparent radiance) are estimated. This apparent radiance is finally compared with the DN in the image recorded by the sensor.

Thus, in this procedure of absolute calibration is performed a series of radiometric measurements, which results should be represented correctly, ie, we must report the result quantitatively (JCGM, 2008). The complete expression to represent the measurand should estimate the value and its uncertainty. The uncertainty is a parameter that is associated with the result of any measurement and characterizes the dispersion of values that can be attributed to the quantity.

In spite of having some calibration expertise in Brazil, the absolute calibrations have not included uncertainties estimations. Therefore, to improve the calibration methods is fundamental to estimate the uncertainties in the measurements and procedures. Within this context, this work aims to evaluate the main uncertainties involved in the process of sensors absolute calibration (airborne or orbital) in the visible, near and middle infrared regions of the electromagnetic spectrum.

2. Reference Surface –Tuz Gölü

The first step to perform an absolute calibration campaign is the reference surface selection having specific and stable characteristics. Currently there are only eight surfaces considered by Committee on Earth Observation Satellites (CEOS) as official basis for absolute calibration purposes. The Tuz Gölü is one these eight surfaces and it is a dry salt lake in Turkey located at an altitude of approximately 910 m, with high reflectance in the dry season. Within the Tuz Gölü were determined eight areas of 300 per 100 meters. To facilitate the location on satellite images it has been placed two black tarpaulins near these areas.

3. Absolute Calibration Methodology

The sensor chosen to test the proposed methodology was the TM (Thematic Mapper) aboard the Landsat 5 (Chander *et al*., 2009). The TM is a sensor which records the electromagnetic energy in seven spectral bands. The methodology proposed in this paper is for bands 1, 2, 3, 4, 5 and 7 (the visible, near and middle infrared). The absolute calibration can be divided into three steps: (a) DN image analysis, (b) atmosphere characterization, and (c) surface characterization.

3.1. DN Image Analysis

The DN image analysis involves determining an average DN corresponding to the reference surface portion spectrally characterized during the fieldwork. For this study we have used TM/Landsat 5 images acquired in August 18, 2010.

The first step was visually locating the two tarpaulins and consequently the spatial location of the eight areas. We identified arrays of pixels in which these areas were included. In the case it was identified eight arrays of 9 per 3 pixels (27 pixels). The DN mean, the standard deviation and standard deviation of the mean were calculated from each array. The standard deviation of the mean represents a Type A uncertainty. However, there are additional sources of uncertainty such as: (a) scanning uncertainty; and (b) instrumental uncertainty.

The DN scanning of the imaging sensors has a rectangular distribution and the uncertainty associated is estimated according to equation (JCGM, 2008):

$$\sigma_{Scanning} = \frac{1}{2 \times \sqrt{3}} \tag{1}$$

The reference surface was chosen due to its uniformity and therefore the eight areas should have the same DN mean. Thus, it is possible fitting a constant function (mean) to the data set. In this situation, where there is some certainty about the shape of the fit it is possible to correctly estimate the uncertainties using the reduced chi-square (χ^2_{red}) value (Bevington and Robinson, 2003).

Thus, we have chosen to perform a fitting, where the function to be adjusted is a constant (DN mean of the eight areas), being that the instrumental uncertainty was estimated such the value of χ^2_{red} was equal to 1 (Bevington and Robinson, 2003).

With the three uncertainties estimated it was possible to determine the final uncertainty of DN mean, according with Equation 2.

$$\sigma_{NDmean} = \sqrt{(\sigma_{Statistics})^2 + (\sigma_{Scanning})^2 + (\sigma_{Instrumental})^2} \qquad (2)$$

3.2. Atmosphere Characterization

The complete absolute calibration procedure includes the atmosphere characterization at the time the radiometric measurements are carried out during the fieldwork (reference surface spectral characterization). Generally, the atmospheric characterization is performed using radiative transfer models that are fed by meteorological and/or climate data such as aerosol and water content. Similar atmospheric parameters can be estimated through a sun photometer that permits measuring the direct solar irradiance.

We used a multi-spectral sun photometer CIMEL operated by AERONET (AErosol RObotic NETwork) (AERONET, 2011). The equations applied for the calculations can be found in Pinto (2011).

3.3. Surface Characterization

The surface spectral characterization involves radiometric measurements to determine the mean surface Reflectance Factor (RF). The fieldwork was conducted on August 18, 2010, and the radiometric measurements were carried out from 10h30min am to 11h30min am. Within one of the eight areas 45 sampling points were radiometrically characterized. In each of these 45 sample points were performed 5 radiometric measurements using an ASD FieldSpec spectroradiometer. The radiance measurement mode was preferred and a Spectralon Labshpere reference panel was also used to allow the RF estimations.

The raw data consistency was evaluated in order to identify the existence of outliers and bias. The mean, standard deviation and standard deviation of the mean at each point (Bevington and Robinson, 2003) were also determined.

From the RF values and their statistical uncertainties the behavior of the RF at each sample point was analyzed. Considering that the measurements at each sample point have been taken in conditions of repetitivity, for a uniform surface it is expected that both the mean and the dispersion of the data are approximately the same for every point. However, before comparing the mean values, it is necessary performing the evaluation of variances homoscedasticity.

To evaluate the homoscedasticity of the variances obtained at each of the 45 points, it was applied the Cochran test (Pinto, 2011). If the variances are homoscedastic, we can estimate the standard deviations for all points (representing the entire area), using the following equation:

$$\sigma_{mean} = \sqrt{\frac{\sum_{i}^{k} s_i^2}{k}} \qquad (3)$$

The statistical uncertainty, σ_{TypeA}, is obtained dividing the σ_{mean} by the square root of the number of repetitions performed at each point (n).

To determine the uncertainty in the measurements were taken into consideration, in addition to σ_{TypeA}, sources of uncertainty Type B: (a) the reprodutibility of the arrangement's geometry; (b) the instruments; and (c) the procedure.

As mentioned before, the reference surface is considered radiometrically uniform, i.e. the measurements at each sample point should have the same average RF. Thus, it is possible fitting a constant function to the data set. When there is some certainty about the shape of the fitted function it is possible estimating the uncertainties using the value of the reduced chi-square (χ^2_{red}) (Bevington and Robinson, 2003). Therefore, for estimating the uncertainty Type B, we decided fitting a constant function (mean RF at each point), assuming χ^2_{red} value as equal to 1 (one).

With the type A and B uncertainties estimated it could be estimated the final uncertainty RF of each sample point of the surface, according to the equation:

$$\sigma_{final} = \sqrt{(\sigma_{TypeA})^2 + (\sigma_{TypeB})^2} \quad (4)$$

It is important to remember that the main goal of the reference surface characterization is to determine the mean surface RF, ie, we are interested in the mean RF and its uncertainty. Thus, with uncertainty Type A and B determined at each point, the next step is to calculate the uncertainty of the mean. In this case, the statistical uncertainty (Type A) of the mean RF is $\sqrt{k}$ less than the statistical uncertainty for each sample point of the surface, since Type A uncertainty can be reduced by increasing the number of observations. The Type B uncertainty remains the same, since it does not depend on the number of observations. So, the uncertainty of mean RF can be calculated by:

$$\sigma_{Mean\_RF} = \sqrt{\left(\frac{\sigma_{TypeA}}{\sqrt{k}}\right)^2 + (\sigma_{TypeB})^2} \quad (5)$$

4. Results and Discussion

4.1. DN Image Analysis

The DN of the band 1 saturated, ie the signal input exceeds the maximum value measurable by the sensor in this band. Thus, it is not possible to perform data processing for this band.

Concluding the location of the eight areas on the image we calculated mean, standard deviation and standard deviation of the mean. In general, the statistical uncertainty (standard deviation of the mean) were less than 0.2% estimated in the bands 2, 3 and 4 (the band region of green, red and near infrared). For bands 5 and 7 (middle infrared) the statistical uncertainties varied between 0.6 and 1.1%. The next step was to calculate the scanning uncertainty, as Equation 1.

After calculation of these two uncertainties, a graph of mean DN in function of each one of the eight areas was built and it was performed a fit of a constant (Figure 1). Then, it was determined the instrument uncertainty, such as the value of the χ^2_{red} equal to 1 (one). The instrumental uncertainty was less than 0.5% in the bands 2, 3 and 4 and less than 5% in the middle infrared bands (band 5 and 7).

Calculated the three uncertainties (statistical, scanning and instrumental) was estimated the final uncertainty of the mean DN of each areas (Equation 2).

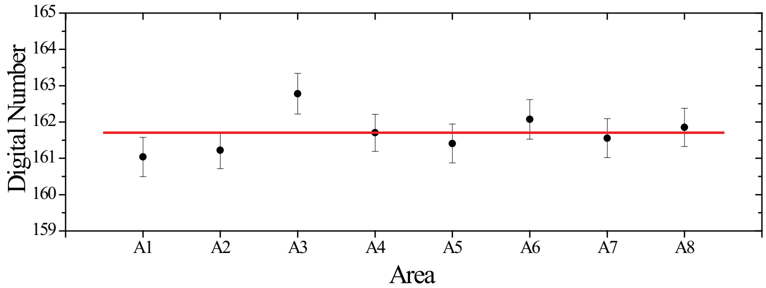

Figure 1: Graphic of mean DN of band 2 TM sensor according to each of the eight areas. The uncertainties bars plotted in this figure are the final uncertainties calculated using Equation 2. In red can be to check the fitted function (mean DN).

4.2. Atmosphere Characterization

To determine the uncertainties associated with the atmospheric characterization it was carried out a fieldwork based on sun photometer measurements. It was estimated aerosols concentration through the aerosol optical depth at 550 nm ($\tau_{Aerosol,550nm}$) and through the visible (VIS) and it was also estimated the water vapor content. Table 1 shows these three parameters with their uncertainties

Table 1: Values of visibility (VIS), the Aerosol Optical Depth at 550 nm ($\tau_{Aerosol,550nm}$) and the amount of water with their uncertainties

VIS (km)	Uncertainty (%)	$\tau_{Aerosol,550nm}$	Uncertainty (%)	Water (cm)	Uncertainty (%)
15.50 ± 0.29	1.87	0.357 ± 0.009	2,52	1.90±0,05	2.63

4.3. Surface Characterization

The first step to estimate the average FR includes assessing the raw data consistency collected from each of the forty-six points. It was found that the data did not show biased behavior. Therefore, it was possible to determine the mean, standard deviation and standard deviation of mean of the RF for each sample point.

We analyzed the behavior of the RF at each point and it was found that the estimated uncertainties were different. However, it was expected that the uncertainties were statistically the same since the measurements were carried out under the same conditions. Thus, to evaluate the homoscedasticity of variances it was performed the Cochran test. In this case, for n = 5 and k=45, the critical value was equal to 0.985 (for a significance level of 5%). The values calculated by the Cochran test were below the critical value. By this test it was concluded that the variance of the samples should be the same. From this result, we could calculate the average standard deviation, σ_{mean}, and the repeatability uncertainty of the measurements, σ_{TypeA}. So, we determined the uncertainties of type B, σ_{TypeB}. As mentioned before, the uncertainty type B has been determined so that the χ^2_{red} value equal to 1.

Once the values of σ_{TypeA} and σ_{TypeB} have been estimated, we calculated the final uncertainty, σ_{final}, according to Equation 4. The uncertainty of type B is the main component of the final uncertainty and, practically, it is responsible for the final uncertainty. The final uncertainty at each point was between 2 and 16%.

Finally, the mean RF was determined and the associated uncertainty, according to Equation 5. The uncertainty for the mean value obtained was in range 2-10%. Figure 2 shows the change in maximum and minimum average reflectance factor