A reference surface uniformity and isotropy evaluation for orbital or airborne sensors absolute calibration

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Abstract

The aim of this work is to present the methodology used to evaluate two features of a surface potentially considered as a reference in imaging sensors absolute calibration missions: uniformity radiometric and isotropy. Addition this work also estimates the main sources of uncertainties associated with radiometric measurement process.

Keywords: calibration, reference surfaces, uniformity, isotropy, uncertainties

1. Introduction

There are two possible approaches in natural resources studies carried out by remote sensing technology: qualitative (basically mapping procedures in which the identification of specific targets on the Earth surface is the main focus) and quantitative (a connection between biophysical or geophysical parameters and radiometric data from remote sensing products is established). Several absolute calibration methods have been proposed. Considering those based on in-flight methods that include the definition of reference surfaces located on the Earth surface, it is desirable that the surfaces being as isotropic and uniform as possible. So, the first step to perform an absolute calibration campaign based on reference surfaces includes their spectral characterization.

Absolute calibration campaigns have already been conducted in Brazil due to the needs of the China-Brazil Earth Resources Satellite (CBERS) program in spite of the Brazilian territory does not have ideal reference surface. Recently these campaigns have included the uncertainties estimation in order to inform properly users about data quality.

This work describes the methodology that has been applied to evaluate two characteristics of a potential reference surface: (a) the radiometric uniformity; and (b) the isotropy. The main sources of uncertainties associated with the reference surface spectral characterization have also been estimated.

2. Radiometric Measurements

As mentioned before, Brazil does not have an ideal reference surfaces for absolute calibration purposes, but at the western region of Bahia state there are some agricultural areas that present positive characteristics (Ponzoni *et al*., 2006). This region has been used as a basis of absolute calibration campaigns since 2004 and the results have been compared with those achieved internationally.

On April 13, 2010, on the premises from the Santa Luzia's farm (13°40' 23''S and 45°54' 04'' W) in the municipality of Correntina, a reference surface (approximately 300 by 300 m), composed by sandy soil was used to perform radiometric measurements.

The radiometric uniformity of the surface is characterized by Reflectance Factors (RFs). During the experiment twenty points inside the surface were defined to perform the radiometric measurements. The time spent to perform the radiometric measurements on these twenty sample points was approximately 1 hour long.

The radiometric measurements were performed by a FieldSpec (ASD, 2002) spectroradiometer, which operates from 350 to 2500 nm and a Spectralon reference panel from Labshpere was used permitting the FRs calculation.

The measurements were taken at the reflectance mode of the FieldSpec and at each of the twenty sample point four measurements from the reference panel, four measurements from the target and again four measurements from the reference panel were taken. Although the measurements of the reference panel seem to be redundant, they were repeated to establish a control criterion, for both procedure and equipment, and also for uncertainty evaluation.

The isotropy refers to the influence of changes in the geometric conditions of illumination and sighting on the RFs. To evaluate the isotropy it was used a radiometer CE313/CIMEL (Pinto *et al*, 2011) positioned at a single point on the reference surface all day long. This radiometer runs in five spectral bands and four measurements from the reference panel, four measurements from the reference surface and four measurements from the reference panel again were taken. As reference panel was used Spectralon of Labshpere. The steps followed in the range of approximately 10 minutes.

2.1. Methodology for Uniformity Evaluation

The first step of the methodology was examining the consistency of the raw data collected at each sample point. The data was checked for outliers and bias. It was determined the mean, the standard deviation and the standard deviation of the mean for each sample point (Bevington and Robinson, 2003).

With the RF values of the surface (RF_{target}) and their statistical uncertainties related to repetitivity (standard deviation of the mean), the behavior of the RF over the sample points was analyzed. As the measurements at each point were taken in repetitivity conditions, for a uniform surface it was expected that both the mean and the data dispersion were approximately the same for all points. However, before comparing the mean values, it was necessary performing the evaluation of the variances homoscedasticity.

To evaluate the homoscedasticity of the variances obtained at each of the twenty points it was applied the Cochran test (Costa Neto, 1977). If the variances were homoscedastic, we can estimate the mean and the standard deviations. So, in this case, we can calculate an overall standard deviation, which takes into account the scattering of all data points using the following equation:

$$\sigma_{Global} = \sqrt{\frac{1}{k \times (n-1)} \times \left[\sum_{1}^{n} \left(x_n - \overline{x_1}\right)^2 + \sum_{1}^{n} \left(x_n - \overline{x_2}\right)^2 + \cdots + \sum_{1}^{n} \left(x_n - \overline{x_k}\right)^2 \right]} \quad (1)$$

where: k is the number of points; n is the number of repetitions performed at each point; x_n is the value obtained in the n repetition; and $\overline{x_k}$ is the mean value obtained at point k.

The σ_{Global} is related to the measurements repetitivity. The repetitivity uncertainty, $\sigma_{repetitivity}$, is obtained dividing the σ_{Global} by the square root of the number of repetitions performed at each point (n).

To determine the measurement uncertainties it was taken into account, in addition to statistical uncertainties (repetitivity), three sources of uncertainty: (a) the reprodutibility of the arrangement's geometry; (b) the instruments; and (c) the procedure.

As previously described, it was taken measurements from the reference surface and from the reference panel. From these measurements it was possible to "estimate" the RF of the reference panel, RF_{Panel}, at each of the 20 points. These measurements included the uncertainties related to items (a), (b) and (c) listed above since the reference panel always was the same and their physical characteristics have remained unchanged during the measurements; the weather remained stable during the measurement procedure and the influence of the illumination geometry in the panel's RF determination is not so important (Höpe and Hauer, 2010).

Thus, based on data from RF_{Panel} determined at each point, the uncertainty, which we call "several", $\sigma_{several}$, was estimated by:

$$\sigma_{several} = \sqrt{\left(\frac{1}{k-1}\right) \times \sum_{1}^{k} (x_k - \overline{x})^2} \quad (2)$$

where: k is the number of sample points; x_k is the RF of the panel in point k; and $\overline{x}$ is the mean of the RF of the panel.

So, the final uncertainty, σ_{final}, can be calculated by:

$$\sigma_{final} = \sqrt{\left(\sigma_{repetitivity}\right)^2 + \left(\sigma_{several}\right)^2} \quad (3)$$

Finally, with the surface RF and its final uncertainty was re-analyzed the behavior of the surface RF over the points, and performed the fit of the data obtained. After that the quality of the fit was evaluated by the value of the reduced chi-square (χ^2_{red}). In general is expected having a value close to 1 in a good fit (Bevington and Robinson, 2003).

2.2. Methodology for Isotropy Evaluation

The methodology explored to verify the surface isotropy was similar to the evaluation of the uniformity. The first step was to analyze the consistency of the raw data. After this verification, it was calculated the mean, the standard deviation and the standard deviation of four measurements taken at each time. With the values of RF_{target} and their uncertainties, we investigated the RF behaviour as a function of time measurement.

We performed at each time measurements of the target and the reference panel. It was possible to use these data to obtain the RF_{Panel}. Taking into account that the reference panel was the same and their physical characteristics have remained unchanged during the measurements procedure, that the weather remained stable and that the influence of the solar zenith angle in an experimental setup was not significant, then measurements RF_{Panel} included the uncertainties of reproducibility, the instrumental uncertainties and the uncertainties of the procedure.

Thus, from the RF_{Panel} determined at each time we estimated the “Uncertainties several”, $\sigma_{several}$ (Equation 2). We also calculated the final uncertainty (Equation 3) and again the behavior of the target *RF* was analyzed on the basis of the time measurement. Finally, we performed an adjustment of the data and for evaluating the quality of fit we calculated the value of the reduced chi-square, χ^2_{red} and the coefficient of determination, r^2.

3. Results and Discussion

3.1. Evaluation of Isotropy

The isotropy of the surface refers to the influence of geometry changes in RF measurements. The uncertainty due to repetitivity was around 0.2% of the mean value for the five bands of the radiometer CE313/CIMEL (Pinto *et al*, 2011). However, in addition to uncertainty due to repetitivity, we considered other sources of uncertainty: the "Uncertainty Several" (Equation 2), which were lower than 2%.

From these two sources of uncertainty it was determined the final measurement uncertainty, σ_{final}, applying Equation 3. These σ_{final} values were around 2%. Figure 1 shows the graph of the surface RF values as a function of solar zenith angle with to their uncertainty.

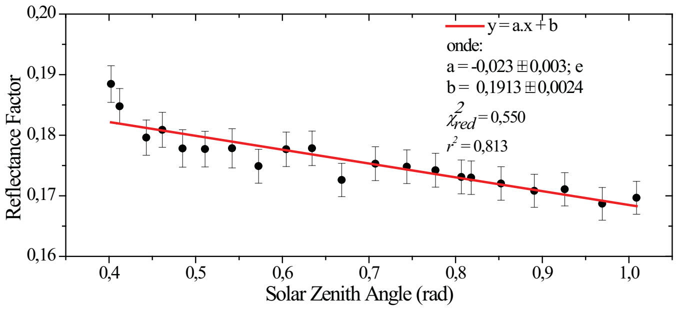

Figure 1: Graph of surface RF as a function of the solar zenith angle to the second band of the radiometer CE313/CIMEL, which ranges 595-701 nm. In red can be seen the function fitted to experimental data.

Looking at Figure 1 and the other sets of results for the other bands, it seems that the dependence of the surface RF with the solar zenith angle presented a behavior similar to a straight line. This result suggests that the reference surface was not isotropic in the wavelength range considered. Thus, we fitted a line to the experimental data. The linear and angular coefficients values were obtained for each spectral band. The results can be observed on Table 1.

It was expected that the value of χ^2_{red} ranging from 0.4 to 1.9 (with 98% confidence level), since we have 19 the freedom degree in the adjustment. All the values of χ^2_{red} (Table 1) were within the acceptable range, indicating that the uncertainties were correctly estimated and that the function used represent the data set. Thus, the surface RF behavior as a function of the solar zenith angle can be described by a straight line, as observed visually (Figure 1). So, we concluded that the reference surface (at least for the spectral range explored here) had not an isotropic behavior.

Table 1: Angular and linear coefficients values for each spectral band, with their uncertainties and with r^2 and χ^2_{red} values.

Band	Linear Coefficient [rad^{-1}]	$\sigma_{Relative}$ (%)	Angular Coefficient	$\sigma_{Relative}$ (%)	χ^2_{red}	r^2
B1	0.244 ± 0.003	1.2	-0.025 ± 0.004	16	0.50	0.78
B2	0.1913 ± 0.0024	1.3	-0.023 ± 0.003	13	0.55	0.81
B3	0.1466 ± 0.0017	1.2	-0.0194 ± 0.0024	12	0.66	0.83
B4	0.1078 ± 0.0011	1.0	-0.0152 ± 0.0016	11	0.98	0.83
B5	0.394 ± 0.004	1.0	-0.036 ± 0.006	17	0.68	0.74

3.2. Evaluation of Uniformity

As described earlier, the first stage of the evaluation was to assess the uniformity of the raw data consistency. In this analysis it was found that the data did not show biased behavior or outliers. Therefore, it was possible to determine the mean, the standard deviation and the standard deviation of mean of the reflectance measurements for each sample point.

The RF and their uncertainties, related to the repetitivity (standard deviation of the mean) of each sample point were calculated. To evaluate the homoscedasticity of variances it was applied the Cochran Test. In this case, for $n = 4$ and $k = 20$, the critical value is equal to 0.2205 (for a significance level of 5%).

The values calculated of the Cochran test were below the critical value. Through this criterion, we can conclude that the variances of the samples may be the same (homoscedastic) at level of significance of 5%. Hence, we can calculate the overall standard deviation, σ_{Global}, (Equation 1) and the uncertainty due the repetitivity, $\sigma_{repetitivity}$. Then the $\sigma_{several}$ was calculated using Equation 2. Finally, we calculated the final uncertainty, σ_{final}, using Equation 3. The uncertainty due to repetitivity of the measurements is the main component of the final uncertainty. In general, the relative final uncertainty for each point was approximately 4%.

Finally, we reassess the behavior of the RF over the 20 points of the surface. Due to an evaluation of the isotropy of the surface reflectance, it was expected that the RF would decrease with the solar zenith angle increases. It could also be expected a possible correlation between the RF and its location in the reference surface. However none of these effects were observed.

Wherefore, we carried out a fitting procedure to the experimental data with a constant function, $y = constant$, which corresponds to the simple mean of the 20 points. In Table 2 are presented the results for four wavelengths adjustments.

Table 2: RF adjustments for four wavelengths.

wavelength (nm)	Mean	χ^2_{red}
560	0,1496 ± 0,0014	3,9
835	0,254 ± 0,002	4,2
1650	0,429 ± 0,004	2,3
2210	0,343 ± 0,003	2,5

The expected reduced chi-square, for 19 degrees of freedom, ranged between 0.4 and 1.9, for the 98% confidence level. However, looking at Table 2, the values were outside of the acceptable range. The values were much larger than one, indicating that: (a) the uncertainties could be underestimated, or (b) the used function was not the most suitable to represent the data set.

If the case (a) were correct, the uncertainties would be larger than estimated, making the constant acceptable in the adjustments and, therefore, implying that the surface would be uniform. However we have a good confidence in the estimate of uncertainty, since $\sigma_{several}$ "carries" all the uncertainty type B and $\sigma_{repetitivity}$ carries the statistical uncertainty. Thus, the σ_{final} contains all the "information" available about the dispersion of the mean RF of the target.

If the case (b) is true, the constant is inadequate representing the data set, indicating that the surface was not radiometrically uniform.

Therefore, assuming that the uncertainties have been adequately assessed, it is possible to conclude that the reference surface in question is not uniform, since there are significant differences between the mean values of the RF on the surface of sample points.

The non-radiometric uniformity of the surface implies that we cannot determine an average RF, for the whole area. But, this fact does not preclude its use for sensor calibration. Eventually, can be possible to perform a sensor calibration for each point (for each sub-surface area) or use an average RF with an external uncertainty.

4. Conclusion

To evaluate the surface uniformity we have taken into account the radiometric data collected from sampling points of the surface. The final uncertainty obtained for the reflectance at each sampling point was around 4% in the 350-2500 nm spectral range. The surface here studied is not homogenous. There were significant differences between the mean values of surface reflectance in the sampling points that cannot be explained by the surface anisotropy and neither by the statistical fluctuation.

The isotropy refers to the influence of geometry changes on the RFs. The final uncertainties in the measurements were on the order of 2% for the five spectral bands of radiometer. The results showed that the surface used was not isotropic. The dependence of the surface RF with the solar zenith angle presented a line behavior, decreasing with solar zenith angle increase.

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