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A REFERENCE SURFACE UNIFORMITY EVALUATION FOR SENSORS ABSOLUTE CALIBRATION

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Abstract: The aim of this work is to present the methodology used to evaluate the radiometric uniformity of a reference surface with the potential to be used in absolute calibration missions of imaging systems for remote sensing. Besides this work also estimates the main sources of uncertainties associated with radiometric measurement process.

Keywords: Imaging sensors; absolute calibration; reference surface; uniformity.

1. INTRODUCTION

There are two approaches used nowadays as regards the use of remote sensing data in the study of natural resources: one is a qualitative, it's identify the type of resources; and the other quantitative, when determining physical or chemical properties of objects or surfaces, through the data. To know the second approach (quantitative) it's necessary to have a high degree of reliability on the sensor which can be obtained through their absolute calibration [1].

Several methods have been proposed to perform an absolute calibration. Methods that are based on the use of reference surfaces have been widely used for orbital sensors, as the *Enhanced Thematic Mapper Plus* (ETM+) [2].

In these methods the reference surface should have, among other characteristics, radiometric uniformity along its length. So the first step to carry out a radiometric calibration mission of imaging sensors, using this method, is to realize a characterization of the reference surface.

Then within that context, the aim of this work is to present the methodology used to evaluate the uniformity of a radiometric reference surface. In addition, the study also estimates the main sources of uncertainties associated with radiometric measurement process.

2. REFLECTANCE FACTOR

The reflectance, ρ, is the property that a target has of reflecting the electromagnetic radiation (EMR) incident on it, i.e. the ratio of the reflected flow of EMR and the incident flow on a surface. However, the reflectance can't be measured directly because the infinitesimal elements of solid angle do not contain measurable amounts of radiant flux [3]. Thus, due to technical difficulties in obtaining the reflectance in experiments, one obtains in practice a quantity called equivalent Reflectance Factor (RF) [4]. This quantity is estimated by the ratio of the spectral radiance of a sample (target) with the spectral radiance of an ideal Lambertian surface under the same conditions of illumination and observation, thus:

$$FR = \frac{L_{target}}{L_{panel}} \tag{1}$$

where: L_{target} is the radiance of the target and L_{panel} is the radiance of a reference panel (supposedly with lambertian reflectance). To simplify the notation, the spectral and angular dependence of the RF was omitted.

Therefore, checking the behavior of the reflectance factor over the surface, can determined if it is radiometrically uniform.

3. RADIOMETRIC MEASUREMENTS

Brazil does not have an "ideal" reference surface for absolute calibration purpose [5]. However, to test the methods for evaluating reference surfaces we chose to carry out studies in an area and time most suitable for the realization of radiometric measurements.

In the extreme west of the Bahia state, it is possible to identify some areas for agricultural plantations, which have partially some positive features for testing. In this way, on the premises from the Santa Luzia (13^{o} 40' 23''S and 45^{o} 54' 04'' W) in the municipality of Correntina, a reference surface (approximately 300 by 300 m), composed of quartz sand was used to perform radiometric measurements. The fieldwork was developed on April 13, 2010, the period of the 9h00 to10:00 a.m.

The radiometric uniformity of the surface is characterized by the RFs and, in general, is evaluated by comparing the measured values in some sample points on the reference surface. Therefore, the objective is to verify the existence of differences/similarities between the RF values. Thus, within the selected surface, twenty points were marked to perform the radiometric measurements.

The measurements were done using an ASD FieldSpec Pro spectroradiometer, which is a portable instrument that operates in a spectral range from 350 to 2500 nm [6]. As reference panel was used a Spectralon panel of the LabSphere.

All the procedures were performed by two operators: one was the operator of the spectroradiometer and the other was the operator of the reference panel. The spectroradiometer was operated manually, and the collection unit (with field of view of 8°) was kept vertically pointed to the ground, with the operator stood facing the sun, avoiding the projection of his shadow on the surface to be measured. The reference panel was kept on a tripod near the point to be characterized, keeping the operator as far as possible the panel and the collection unit. The time necessary to go through all twenty points on the surface was approximately 1 hour.

The measurements were made in reflectance mode in the FieldSpec Pro, and in each of the twenty sampling points were made: (1) four measurements of the reference panel, (2) four measurements of the target, and (3) again, four measurements of the reference panel. Although the measurements of the reference panel (before and after the reference surface) seem to be redundant, they were repeated to establish a criterion of control, for both: procedure and equipment, and also for uncertainty evaluation.

4. METHODOLOGY FOR UNIFORMITY EVALUATION

The first step of the evaluation methodology was to examine the consistency of the raw data collected at each point of the surface. The data was checked for outliers, and the bias. After that was determined the mean, standard deviation and standard deviation of the mean for each point [7].

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 points was analyzed. As the measurement points were taken in conditions of repetitivity, it was expected for a uniform surface that, both the mean and dispersion of the data were approximately the same for all points. However, before comparing the mean values, were necessary to perform the evaluation of variances homoscedasticity.

To evaluate the homoscedasticity of the variances obtained in each of the twenty points was performed the Cochran test. For each sample (ie, for the twenty sampling points) was calculated the variance (s_i^2 , where i = 1, 2, 3,... k), as all samples have the same size, of n measurements (in this case, four measurements). Thus, the value of the Cochran test, C, is given by [8]:

$$C = \frac{s_{\max}^2}{\sum_i^k s_i^2} \tag{2}$$

where: s_i^2 is the variance of the sample i; $s_{\max}^2$ is the highest value found in the variances; and k is the number of sample points.

The critical values for the Cochran Test are tabulated as a function of sample size, n, and the amount of samples, k. If the calculated value given by Eq. 2 is less than the critical value, this implies that the variances are homoscedastic. Otherwise, the variances are heteroscedastic.

If the variances of the twenty points are different, is not be possible determine a "common" uncertainty, meaning that their distributions (characterized by mean and standard deviation) are also different. This implies that the surface is not uniform. However, if the variances are homoscedastic, we can estimate a mean and 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:

$$\sigma_{Global} = \sqrt{\frac{1}{k \times (n-1)} \times \left[\sum_1^n \left(x_n - \overline{x_1}\right)^2 + \sum_1^n \left(x_n - \overline{x_2}\right)^2 + \cdots + \sum_1^n \left(x_n - \overline{x_k}\right)^2 \right]} \tag{3}$$

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 repeatability. For the repeatability uncertainty, $\sigma_{repetitivity}$, we used the equation:

$$\sigma_{repetitivity} = \frac{\sigma_{Global}}{\sqrt{n}} \tag{4}$$

To determine the uncertainty in the measurements were taken into consideration, 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, were made measurements of the target (reference surface) and the reference panel. With these measurements it was possible to "estimate" the RF of the reference panel, RF_{Panel}, in each of 20 points. These measurements include the uncertainties related to items (a), (b) and (c) listed above. This is because: the reference panel was always the same and their physical characteristics have remained unchanged during the measurements; the weather remained constant throughout the measurement; and the influence of the illumination angle, solar zenith angle, in the determination of the RF of the panel is not very important [9].

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

$$\sigma_{several} = \sqrt{\left(\frac{1}{k-1}\right) \times \sum_1^k (x_k - \overline{x})^2} \tag{5}$$

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:

$$\sigma_{final} = \sqrt{\left(\sigma_{repetitivity}\right)^2 + \left(\sigma_{several}\right)^2} \tag{6}$$

Now with the FR_{target} for each point of the surface and its (final) uncertainty was made to correct them in relation to the reference panel used, according to the equation:

$$FR_{Corrected} = FR_{target} \times FR_{panel} \tag{7}$$

where: FR_{panel} is the reflectance factor of the reference panel, which is a calibration coefficient determined for the reference panel used.

The uncertainty of $FR_{Corrected}$ is given by:

$$\sigma_{FR\,Corrected} = FR_{Corrected} \times \sqrt{\left(\frac{\sigma_{FR_{target}}}{FR_{target}}\right)^2 + \left(\frac{\sigma_{FR_{panel}}}{FR_{panel}}\right)^2} \qquad (8)$$

Finally, after the *FR* correction the behavior surface RF over the points was re-analyzed, and performed the fit of the data obtained. After this procedure, the quality of the fit was evaluated by the value of the reduced chi-square χ^2_{red}. This value is useful and appropriate to assess the quality of a fit, and in general, is expected to have a value close to 1 in a good fit [7].

5. RESULTS

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. Therefore, it was possible to determine the mean, standard deviation and standard deviation of mean of the reflectance measurements for each sample point.

After that, the RF and their uncertainties, related to the repetitivity (standard deviation of the mean) of each sample point were calculated. Then we analyzed the behavior of the RF over the points (Fig. 1).

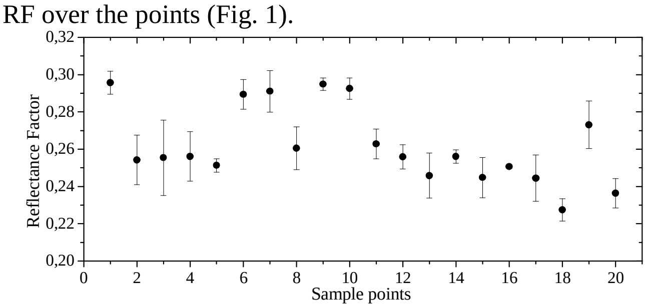

Fig.1. Behavior of the reflectance factor of twenty points over the surface to the wavelength of 835 nm. The uncertainty bars represent the 68% confidence level.

As can be seen in Fig.1, the uncertainties at each point 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 was performed the Cochran Test (Eq. 2). In this case, for $n = 4$ and $k = 20$, the critical value is equal to 0.2205 (for a significance level of 5%). In Tab. 1 are presented the results of this test for four wavelengths.

In Tab. 1 all *C* calculated are below the critical value. By this criterion, we can conclude that the variances of the samples may be the same (ie, are equal) for a 5% level of significance. Therefore, we chose to consider that the variances, obtained in each point of the reference surface, are homoscedastic. Hence, we can calculate the overall standard deviation, σ_{Global}, and the uncertainty due the repetitivity, $\sigma_{repetitivity}$, with Eq. 3 e 4**,** respectively. Then the $\sigma_{several}$ was calculated using Eq. 5.

Finally, we calculated the final uncertainty, σ_{final}, using Eq. 6. These three uncertainties: repetitivity, $\sigma_{repetitivity}$; several, $\sigma_{several}$; and final, σ_{final}, are shown in Fig.2.

Tab. 1. Results of Cochran Test for four wavelengths.

Wavelength **[nm]**	***C***
560	0,2135
835	0,2071
1650	0,2039
2210	0,1620

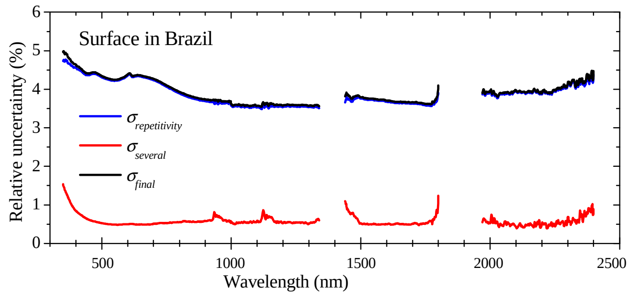

Fig. 2. Graph of the estimated uncertainties for each point on the reference surface as a function of wavelength. The spectral regions of water absorption were not presented.

As seen in Fig. 2, the uncertainty curve due the repetitivity is close of the final uncertainty curve. For this reason, the uncertainty due to repetitivity of the measurements is the main component of the final uncertainty. In general, the relative uncertainty for each point was approximately 4%, Fig. 2 (except in the spectral regions of water absorption).

In the next step, the estimated RF of the surface, RF_{target}, and its uncertainty, σ_{final}, were corrected with Eq. 7 and 8, respectively. This new uncertainty (to the corrected FR) remained the same as the final uncertainty. This is because the uncertainties of calibration plates were very small [10], then it was irrelevant to the front σ_{final}.

Finally, we reassess the behavior of the RF over the 20 points of the surface. In Fig. 3 can be seen the values of the RF (corrected by the reflectance of the reference panel), in each of the points, with their respective final uncertainty.

Due to an evaluation of the isotropy [10] of the surface reflectance, was expected that the RF would increase with decreasing solar zenith angle. It could also be expected a possible correlation between the RF and its location in the reference area. However none of these effects were observed.

Wherefore, we chose to perform a fit to the experimental data with a constant function, $y = constant$, which correspond to the simple mean of the 20 points. In Fig. 3 one can be seen the fitting for the 835 nm wavelength and Tab. 2 are presented the results for four wavelengths adjustments.

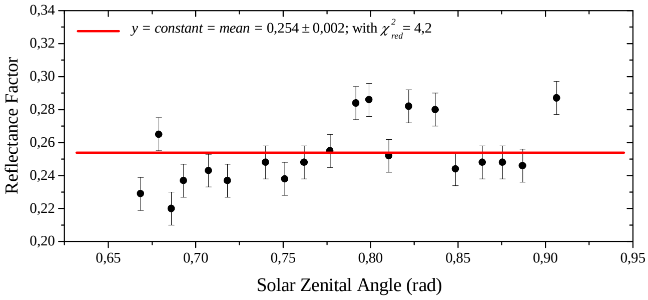

Fig. 3. Behavior of the surface RF as a function of solar zenith angle, for the wavelength of 835 nm. The surface RF was corrected by reference panel used.

Tab. 2. RF Adjustments for four wavelengths.

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

The expected reduced chi-square, for 19 degrees of freedom, may range between 0.4 and 1.9, for the 98% confidence level. However, looking at Tab. 2, the values are outside of the acceptable range. The values are much larger than one, indicating that: (a) the uncertainties may have been underestimated, or (b) the used function is 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 to represent the data, this would indicate that the surface is not radiometricaly 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, and this difference is not explained by isotropy the reference surface or other effect.

The surface non-uniformity 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.

6. CONCLUSION

In this work was presented a methodology to evaluate the radiometric uniformity of a surface as well the uncertainty of the procedure. In this methodology is necessary to make measurements of the reflectance factor not only of the surface but also of a reference panel.

To exemplify the application of the methodology a surface was chosen. We made radiometric measurements from 20 sampling points in the surface. The final uncertainty in the reflectance factor, obtained for each sample point, was approximately 4% in the spectral region from 350 to 2500 nm (except in the spectral regions of water absorption). However, there were significant differences between the mean values of surface reflectance in the sampling points, differences which can't be explained by the statistical fluctuation of the data nor by anisotropy of the surface and nor by other effect. Therefore the area used in the test has no radiometric uniformity.

The surface uniformity evaluation was conducted from measurements carried out on the ground (fieldwork). However, the data collection can be performed at the airborne or orbital level. Therefore, it would be interesting check and evaluate other levels of uniformity.

7. REFERENCES

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