DETERMINING RESTORATION PARAMETERS FOR WPM/CBERS-04A IMAGE USING THE KNIFE-EDGE METHOD

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ABSTRACT

Image restoration enables better visualization of the elements contained in the scene, considering that the imaging process generates distortions in the images. The application of this technique in low spatial resolution images presents great advantages since it recovers part of the information degraded in this process. Thus, the present work seeks to obtain the sensor parameters and perform the restoration of a WPM/CBERS-04A image. The Knife-Edge method was performed to obtain the restoration parameters. Thereby, the results obtained were used to apply the Lucy-Richardson filter restoration. It was then possible to compare the result of the restoration with the application of a simple Laplacian filter on the same image. The result showed that the restoration preserved the radiometric information of the image better than this specific filter. Furthermore, the use of free software such as QGIS allows the estimation of sensor performance by using the knife-edge method.

Keywords *— CBERS-4A, Restoration, Knife-Edge, Lucy-Richardson.*

1. INTRODUCTION

Remote Sensing images have distortions during the imaging process. Factors such as the response of detectors, optical diffraction, atmospheric effects, platform movements, and relief variations, degrade the image quality and can compromise its use if not corrected [1]. This degradation causes a smoothing or blurring effect in the existing features in the image, reducing the information about its fine details (edges) [2]. Thereby, the sensor's effective spatial resolution, which takes these distortions into account, will generally be lower than its nominal or design resolution [3].

It is possible to estimate the effective instantaneous field of view (EIFOV) of a sensor from its Modulation Transfer Function (MTF) or Point Spread Function (PSF). The MTF can be used to evaluate the performance of sensors in orbital platforms. It measures the ability of the system to recreate the spatial frequency content (details) of a scene. On the other hand, PSF is the function that describes the way a sensor captures the signal from a point light. If the sensor were perfect, the point light source would be represented as identical to the original [4]. Therefore, since there are no perfect sensors, all systems have a scattering rate that varies depending on its type [3, 4].

Thus, image restoration is a radiometric correction technique that aims to recover part of the degraded information during the imaging process [5]. From the modeling of the degradation, the restoration proposes the application of an inverse process (inverse function), making it possible to obtain an approximation of the original image [6, 7]. In practice, as no restoration method is perfect, the result is the enhancement of details that appear smoothed in the image [8] behaving as a high-pass filter and the approximation of the restored image to the scene will depend on the accuracy of the model and the projected filter [9].

In the literature, it is possible to observe different image restoration techniques, which are classified as iterative and non-iterative filters [2], these can also be classified as blind and non-blind. Non-blind filters are those that require a priori knowledge of the degradation process [10, 11]. Among the classical restoration, methods are the inverse filter, the modified inverse filter, Wiener filter, modified Wiener filter, and the Lucy-Richardson filter [2, 9, 11].

Therefore, this work seeks to propose restoration parameters for images from the WPM sensor on board the CBERS-04A by using the Knife-Edge method. In addition, an application of the restoration technique using the Lucy-Richardson filter was performed. The scientific contributions of this work are: to verify the performance of the sensor in question, expose the applicability and efficiency of the methodology used and compare the application of a restoration with a simple high-pass filtering.

2. MATERIAL AND METHODS

For the edge method, the application only needs the image that is desired to estimate the MTF, in this case, a WPM image. In this process, only the near-infrared (NIR) band of WPM/CBERS-04A (band-4) with 8m of nominal

spatial resolution was used. The methodology applied can be seen in figure 1.

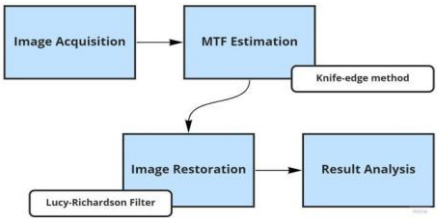


Figure 1. Workflow chart.
Source: The authors.

2.1. MTF Estimation

2.1.1. Knife-Edge method

Among the various existing methods, a way to estimate the sensor's MTF is by applying the knife-edge method. Despite a rigorous theoretical foundation, this method is easy to implement and has a high signal-to-noise ratio, producing reasonable estimates [12]. Taking into consideration that the PSF depicts the system response to a point of light (or a pulse), the Line Spread Function (LSF) represents the sensor's behavior in the representation of a perfect line. The relationship between these two functions can be seen in Equation 1. According to [12], based on optical theory, the modulus of the LSF Fourier Transform is the MTF in one dimension (eq. 2).

$$LSF(x) = \int_{-\infty}^{\infty} PSF(x,y)dy \qquad \text{eq. 1}$$

$$MTF(f_x) = |\,F[LSF(x)]\,| \qquad \text{eq. 2}$$

The Knife-Edge method uses these concepts to estimate the 1-D MTF of the sensor system. Simplifying, it calculates the LSF by sampling the gray values of pixels near a well-defined linear edge between two high-contrast (black and white) targets. Through this sampling it is possible to calculate a function that describes the linear edge between the objects, called ESF (Edge Spread Function) and its differentiation generates the LSF [12, 13]. Equation 3 shows the relationship between these two functions and figure 2 depicts a simplified scheme of the method.

$$LSF = \frac{d}{dx}\,ESF(x) \qquad \text{eq. 3}$$

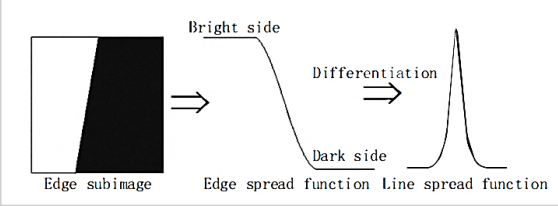


Figure 2. Schematic of the knife-edge method.
Source: [14]

The entire mathematical description of this method and the conditions necessary for its application can be found in [12]. The practical application of this method was performed using the "MTF estimator" plugin in QGIS, whose implementation can be found in [15]

In this work, a long, thin, and well-defined edge between two high-contrast homogeneous agricultural areas was used as knife-edge, as shown in Figure 3.

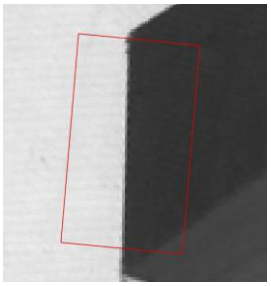


Figure 3. Edge chosen for processing by the knife-edge method.
Source: The authors.

2.2. WPM Image Restoration

Among the non-blind restoration methods, the Lucy-Richardson filter was used for the restoration of the WPM image. It is a non-linear and iterative filter that assumes the noise present in the image has Poisson or Gaussian distribution and restores the image based on the knowledge of the PSF [10, 11]. This technique is widely used in astronomical image restoration processes, such as those captured by the Hubble telescope, removing the noise present in the image without degradation of the original resolution [16]. Information about its mathematical implementation can be found in [2, 10].

The filter was implemented in MATLAB, which has some functions dedicated to minimizing distortions in the image. It is possible to perform the restoration of an input image from simple parameters such as mask size and standard deviation of the PSF.

2.3. Results Evaluation

The restoration result using the Lucy-Richardson method was evaluated through comparisons with the result of filtering the same image with a 3x3 Laplacian high-pass filter. The comparisons were made visually, by the perception of edge enhancement; by subtracting the original and the processed image to verify where their differences are; and by statistical metrics.

Some metrics were used to evaluate the restoration quality statistically, such as mean, standard deviation, correlation coefficient, and the Universal Image Quality Index (UIQI). The UIQI is a metric proposed by [17] that models any image distortion as the combination of three factors, namely: correlation loss, illumination distortion, and contrast distortion. Then being A and B the original image

and the restored image, respectively, we can calculate the UIQI of the restoration through the expression:

$$UIQI = \frac{\sigma_{AB}}{\sigma_A \sigma_B} \cdot \frac{2\mu_A \mu_B}{(\mu_B)^2 + (\mu_B)^2} \cdot \frac{2\sigma_A \sigma_B}{\sigma_A^2 \sigma_B^2} \quad \text{eq. 4}$$

The range of this metric is [-1,1], and the optimal value of 1 is achieved only if the two images are equal.

3. RESULTS AND DISCUSSION

As a result of applying the Knife-Edge method, its output information serves as parameter for restoring and checking the performance of the system. This information can be seen in Table 1 below.

Parameters	
FWHM(LSF):	1,56 px
MTF30:	0,480594
MTF50:	0,322979
MTF at Nyquist:	0,283595

Table 1. Parameters obtained through the *knife-edge* method.

Using the FWHM (Full Width at Half Maximum) of Gaussian that best-fits the LSF and assuming that PSF of the sensor is symmetrical, it was possible to calculate the standard deviation and this value was applied in a restoration filter. Another important parameter is MTF50. Based on this information, the image EIFOV could be estimated (Table 2).

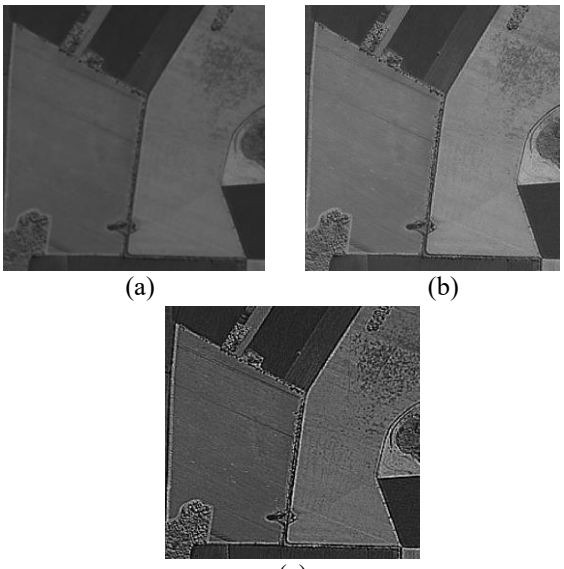
Results	
σ:	0,66 px
EIFOV:	12,38m

Table 2. Estimated EIFOV and PSF standard deviation.

Table 2 shows the EIFOV calculated for band-4 (NIR) of the WPM sensor using the knife-edge method with 12.38m. This value may be related to the method used, as the estimates are being made directly on the image without considering the sensor components, for example.

3.1. Image Restoration

By applying the Lucy-Richardson restoration filter to a region of interest of the WPM image, reasonable visual improvement in the restored image was noticed (Figure 4b).

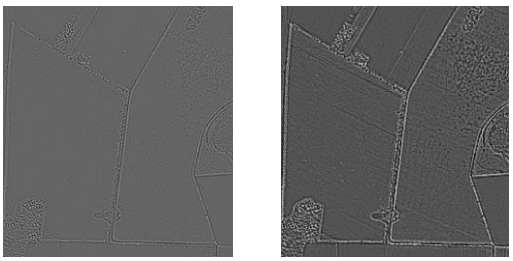


(a) (b)

(c)

Figure 4. Restoration process of a CBERS-4A WPM image using Lucy-Richardson Filtering. (a) Original image, (b) restored image and (c) filtered image. Source: The authors.

Comparing the restored image with a filtered image using a common Laplacian filter, it can be seen that although the Laplacian filter enhances the edges, it modifies the original image more intensely than the restoration process. This can be seen from the difference in the images (Figure 5).



(a) (b)

Figure 5. (a)Difference between the restored product and the original image; (b) difference between a Laplacian filtering and the original image. Source: The authors.

The figure 5 shows the highest differences at the edges of the objects and in the regions with the most textures. It is noticeable that the differences in (b), are stronger than in (a), showing that the restoration has improved the edges and details much more smoothly than the filtering. The metrics calculated for the original (A), restored (B) and filtered (C) images is shown in table 3.

Image	μ_i	σ_i	*r*	UIQI
A	55,66	19,96	-	-
B	53,53	19,73	0,95	0,94
C	58,37	40,65	0,71	0,56

Table 3. Resulting metrics.

From the values of correlation and UIQI shown in table 3, it is possible to observe that the restored image (B), given the parameters used, preserved better the radiometric information of the original image (A) than the filtered image (C). The brightness value of image C, given by the mean, is close to the original value, however, the contrast (given by the variance) was totally modified, which corroborates the values found for r and UIQI. This may indicate that the restoration in fact better preserves the information of the original image.

4. CONCLUSIONS

Based on the experiments, a simple solution to find parameters to perform image restoration is by using the knife-edge method, which is easy to implement and has algorithms available for free as in the case of QGIS. Metrics were calculated from the MTF estimation, such as EIFOV, which evaluates the performance of the imaging sensors. In the case of this work, PSF was assumed to be uniform in the along and across-track directions. It is suggested to continue the study with other bands and calculate, if possible, PSF in both directions.

Although restoration was performed using the Lucy-Richardson filter, the performance of other non-blinded restoration filters should be considered. Based on the PSF estimation, it showed good preservation of the original image radiometry, subtly enhancing fast image transitions such as edges and details. In addition, it should be noted that the comparison was presented against only one specific high-pass filter. Future work can evaluate how much the various high-pass filters (added to the original image) degrade its radiometric quality.

ACKNOWLEDGEMENTS

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5. REFERENCES

[1] G. A. Boggione et al. Avaliação de imagens simuladas da câmera mux do satélite cbers-4 aplicadas à análise ambiental. *Boletim de Ciências Geodésicas* [online], v. 20, n. 3, pp. 590-609, 2014. Disponível em: <https://doi.org/10.1590/S1982-21702014000300034>.

[2] L. A. S. Carvalho, G. A. Boggione, L. M. G. Fonseca, E. M. L. M. Novo. Simulação e Restauração de Imagens HRC CBERS 2B. In: *Anais* XV Simpósio Brasileiro de Sensoriamento Remoto - SBSR, Curitiba, PR, Brasil, 30 de abril a 05 de maio de 2011, INPE, pp. 2652-2660, 2011.

[3] L. M. G. Fonseca, G. S. S. D. Prasad and N. D. A. Mascarenhas. Combined interpolation - restoration of Landsat images through FIR filter design techniques, *International Journal of Remote Sensing*, v. 14, n. 13, pp. 2547-2561, 1993.

[4] G. A. Boggione. *Avaliação da Resolução Espacial de Sensores Ópticos Orbitais.* Tese (Doutorado em Sensoriamento Remoto) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos, pp. 159, 2017.

[5] J. P. Papa. *Restauração das imagens do satélite CBERS-1 utilizando POCS*. Dissertação (Mestrado em Ciência da Computação) – Universidade Federal de São Carlos, São Carlos, pp. 94, 2005.

[6] R. C. Gonzalez and R. E. Woods. *Digital Image Processing*. ed. 3. Pearson Prentice Hall, pp. 954, 2007.

[7] A. K. Katsaggelos. *Digital image restoration.* Chicago: Springer-Verlag, 1989. 243 pp.

[8] G. A. Boggione. *Restauração de imagens do satélite Landsat-7*. Dissertação (Mestrado em Sensoriamento Remoto) - Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, pp. 160, 2003. Disponível em: <http://urlib.net/ibi/6qtX3pFwXQZ3P8SECKy/zcpzr>.

[9] R. Dash. *Parameters estimation for image restoration*. Doctor of Philosophy (PHD in Computer Science and Engineering), National Institute of Technology Rourkela, Rourkela, 2012.

[10] S. Sharma and R. Mehra. Image restoration using modified Lucy Richardson algorithm in the presence of Gaussian and motion blur. *Advance in Electronic and Electric Engineering*, v. 3, n. 8, pp. 1063-1070, 2013.

[11] N. Gulati and A. Kaushik. Remote sensing image restoration using various techniques: A review. *International Journal of Scientific & Engineering Research*, v. 3, n. 1, pp. 6, 2012.

[12] X. Li, X. Jiang, C. Zhou, C. Gao, X. Xi. An analysis of the knife-edge method for on-orbit MTF estimation of optical sensors. *International Journal of Remote Sensing*, v. 31, n. 17-18, pp. 4995-5010, 2010.

[13] C. Fan, G. Li, C. Tao. Slant edge method for point spread function estimation, *Applied Optics*, v. 54, n. 13, pp. 4097-4103, 2015.

[14] L. Yang and J. Ren, Remote sensing image restoration using estimated point spread function, *International Conference on Information, Networking and Automation (ICINA)*, pp. V1-48-V1-52, 2010.

[15] J. Gil. FidMTF: An MTF Estimator, 2021. GitHub repository. Disponível em: https://github.com/JorgeGIlG/MTF_Estimator

[16] P. E. U. Souza. Restauração de imagens CCD/CBERS-2 pelo método de Richardson-Lucy modificado. In: *Anais* XII Simpósio Brasileiro de Sensoriamento Remoto, Goiânia, Brasil, 16-21 abril, INPE, pp. 1107-1114, 2005.

[17] Z. Wang, A. C. Bovik. A universal image quality index. *IEEE Signal Processing Letters*, v. 9, n. 3, pp. 81-84, 2002.