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A *no a priori* knowledge estimation of the impulse response for satellite image noise reduction

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Abstract

Due to launching vibrations and space harsh environment, high resolution remote sensing satellite imaging systems require permanent assessment and control of image quality, which may vary between ground pre-launch measurements, after launch and over satellite lifetime. In order to mitigate noise, remove artifacts and enhance image interpretability, the Point Spread Function (PSF) of the imaging system is estimated. Image deconvolution can be performed across the characterization of the actual Modulation Transfer Function (MTF) of the imaging system. In this work we focus on adapting and applying a no reference method to characterize in orbit high resolution satellite images in terms of geometrical performance. Moreover, we use natural details contained in images as edges transitions to estimate the impulse response via the assessment of the MTF image. The obtained results are encouraging and promising.

Keywords: Satellite imaging; Impulse response; Noise; Blind deconvolution

1. Introduction

Deconvolution of satellite images in presence of noise when the degradation model is unknown and only the data (images) are known can be regarded as a blind deconvolution problem (Jalobeanu et al., 2007). The problem consists in calculating at the same time the approximation of the actual image, the degradation model or impulse response and noise parameters. A great number of unknowns and a multiplicity of possible solutions with the observed image and their instability make the problem particularly difficult to solve. This represents a doubly ill-posed problem with regard to the classical deconvolution (Jalobeanu et al., 2007).

The estimation of the impulse response of an imaging system constitutes an important way to quantify the image quality of earth observation satellites (Luxen and Förstner, 2002). The impulse response is mainly used to assess the ability of the imager to distinguish details in a scene. Its knowledge is useful for qualification and refocusing of in-orbit optical payload and contributes for applying deconvolution and restoration techniques.

Taken in a more pragmatic understanding, the knowledge of the impulse response of optical payload allows the estimation of the image quality or degradation of images and then fixes them.

The development of tools for a systematic and automatic assessment of the impulse response is very useful when the number of images is very important as for optical satellite systems. On one hand the satellite launching operation may cause mechanical displacements within the optical observation system due to the strong vibrations undergone by the satellite inside the launcher, which can

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cause defocus and other modifications of its focal parameters and may alternate sharpness of the produced images. On the other hand, the harsh space environment in which the satellite will evolve can produce disturbances which would affect its optical system. The selected approach is justified by the fact that it is no longer possible to intervene (measure and modify) directly on the satellite camera once launched and placed in its orbit.

The study of the state of the art of the existing methods for estimating impulse response reveals a multitude of methods that one can classify according to time consuming and ease of implementation, performance and adequacy with the specificity of satellite images.

Some existing methods fail in the estimation of the impulse response of earth observation satellite (EOS) (Jalobeanu et al., 2007), since the original scene is not known, and we often seek to estimate it at the same time as the degradations. One can explain this by the mismatch and inadequacy which can exist between the observation model and observed scenes model. Indeed the definition of a suitable observation model is a dramatic issue. The problem may be reduced to a very delicate distinction between the image and the blur (Delvit et al., 2004). The industry in the field of aeronautics and space cannot be satisfied with too coarse results which justifies the need to formulate new approaches, taking into account the specificity of data to be handled.

Classical regularization concepts like reduced space support and positivity do not provide significant improvements in earth observation deconvolution (Jalobeanu et al., 2007). Satellite imagery handles some specific and intrinsic characteristics: the scene continues well beyond the limits of the square shape image provided by ground processing facilities, absence of a uniform background justifying use of boarding constraints. The purely spatial approach adopted in a large image model is inadequate when natural observed scenes present details at all scales (Jalobeanu et al., 2007). The spectral characteristics are not all taken into account. A bad spectrum model gives a poorly estimated MTF.

The easiest ways are to exploit an image of a known target. This is not really a blind deconvolution approach but these methods are often used in the industry, on the assumption that the estimation of the system impulse response from a given scene can then be used to deconvoluate a whole set of observations where the scene is unknown using the same imaging system.

Sometimes, it is sufficient to observe stars, as they are assumed to be punctual spots because of their long distance. Thus the stars acquired images provide a direct estimation of the system impulse response which can be used to deconvoluate and restore the images taken over any other scenes (Bowen and Dial, 2002). The impulse response evaluation making use of imaging of well-known ground target and stars is categorized as ‘reference method based’. Both solutions may represent several constraints. The ground target should be maintained. Besides, imaging stars requires for spacecrafts to be designed for (Blanc and waid, 2009) and (Faran et al. (2009)). Indeed, in order to overcome these limitations, the use of a no reference method may provide an adequate approach. Meanwhile, the impulse response of an imager is defined by the system’s Optical Transfer Function (OTF) which is the transfer function of the system. The Modulation Transfer Function (MTF) is the absolute value of the OTF. The MTF is widely used to describe the sharpness and the geometrical performance of the image.

This work presents an original contribution to assess the impulse response and consequently the geometric image quality of high resolution satellite images. This method is a no reference approach which means estimation without any *a priori* knowledge of the degradation or imaging system parameters and exploits the contained information in the recorded image since it is the only one available.

This approach has been used within a wide range of author’s studies. Indeed Thomas and Wald (2007) exploited the no reference MTF estimation in order assess the geometrical image quality metrics of pan sharpened image products. Meanwhile Viallefont-Robinet (2010a,b) used the MTF estimation to assess Spot and to evaluate Pleiades defocus.

Our interest is focused on the determination of the impulse response of optical systems of satellite images in presence of noise, when the model of the degradation or the Optical Transfer Function of the payload (PSF, OTF, MTF) is not known, where PSF and OTF stand respectively for Point Spread Function and Optical Transfer Function. A simple mathematical formalism of the phenomenon can be expressed as:

$$Y = RI * X \tag{1}$$

As only the Y data are known, the problem is to calculate an approximation of X of the actual discrete image X when the RI impulse response is unknown. The impulse response of an imaging system can be represented accurately by the system’s OTF. MTF is the magnitude of OTF and is considered to be a more practical tool widely used in the characterization field of imaging systems and more generally cameras and instruments. Thus MTF was chosen by the majority of earth observation satellite operators.

2. Impulse response estimation

Usually the earth observation satellites imagers contain both the panchromatic and multispectral modalities. In general, there is a (1:4) ration between the panchromatic and the multispectral ground sampling distances. The panchromatic modality Ground Sampling Distance (GSD) is usually four times higher than that of the multispectral modality. Hence, several authors have exploited the panchromatic image for the MTF estimation rather than the multispectral one. Moreover, panchromatic images offer the possibility to find and select features such as field edges, buildings and so forth.

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