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A destriping algorithm based on TV-Stokes and unidirectional total variation model

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ABSTRACT

Imaging from a degenerated push broom scanner usually leads to an undesired stripe noise which seriously affected the image quality. The original unidirectional total variation (*UTV*) model produces a poor performance on stripe images which has a strong contrast between cleaning image area and striped area or different image area. In this research, a new destriping method which combines *TV-Stokes* and *UTV* model (*UTV-Stokes* for short) has been developed to overcome the disadvantages of *UTV*. By distinguishing stripe region and no-stripe region in calculation, this method can avoid excessive smoothing or residual's appearing through less filtering. Comparative results on simulated and real striped images taken with MODIS and hyperspectral imaging systems demonstrated that the proposed method not only can handle various stripe images with different noise intensity but also can preserve the edge and detailed information.

1. Introduction

The stripe noises commonly exist in imaging systems with multi-detectors, such as Moderate Resolution Imaging Spectroradiometer (MODIS) images [1,2] and hyperspectral images [3]. The presence of stripes cannot only be attributed to the imperfect relative calibration of the sensor detectors because other factors such as source spectral distribution and polarization or random noise in the internal calibration system can intervene [4,5]. This type of noise usually brings difficulties in data classification and restoration of useful information. Consequently, it is critical to remove the stripe noise and to improve the quality before the subsequent image interpretation processes.

In the past two decades, many useful methods have been developed to deal with this kind of noise—for example, the histogram modification [3] and moment matching methods [6], transformed domain filtering algorithms such as Fourier transform [7] and wavelet decomposition [2,8,9]. Recently, along with the coming forth of a lot of fast numerical algorithms for the PDE method, and the favorable ability, the PDE-based methods gained more and more attention and turned out to be a promising approach. Under the variational/PDE-based frames, the process that estimates the latent image u from the observation f is a typical ill-posed inverse problem, and the regularization is necessary to be added to enforce the stability on the solution. Using prior information, an estimate of the true image can be computed by minimizing an energy functional that includes both a term that translates the fidelity of the estimated solution to the original image and a regularization term weighted by a positive parameter that regulates the smoothness of the solution. The variation-based regularization has been widely used in variety of image restoration problems, including denoising [10] and deconvolution [11–14]. Because the total variation (TV) item can remove noise while remaining the edge effectively, it became the most popular fidelity item used in variational/PDE method, and is first invited in ROF model [15]. In [1], the authors proposed a unidirectional total variation model to remove the stripe noise, which assumes that the gradients cross the stripe lines are seriously affected by the stripe noise corresponding to the ones along it and shows a surprising performance. It can be seen from the experiment that the *UTV* model is superior to other methods which are not based on variational/PDE frame, but because of the simplicity of the model, when the source image includes "weak" and "heavy" stripes at the same time, it will result in too many residuals in the output. To improve the efficiency of this method, a stripe reweighted version of this algorithm [16] was developed and then the framelet regularization [17] was also taken into account to maintain more details. In [16], the authors use a spatial striping indicator which called difference eigenvalue [18] to distinguish striping noise from other nonstripe regions and has obtained a better de-striping result. When the stripe noise becomes more and

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more heavy, most of the methods turned out to be invalid gradually. In [19], the authors introduce a weighted matrix to combine two different unidirectional total variation models, and the experimental results showed that the algorithm does improve the denoising results.

The main disadvantage of *UTV* model is that it doesn't distinguish stripe region and no-stripe region when performing the process, so we must add more regular items to this model to control its smoothing action carefully. In this paper, we proposed a unidirectional total variation-Stokes (*UTV-Stokes*) model, which combines *TV-Stokes* model [20] and *UTV* model. There are two steps in its processing. In the first step, we use *UTV* regularization to restore the tangential vector (or normal vectors) of a stripe image. In the second step, we use the same *UTV* model, but add two new items: a new regularization item which makes the normal vectors of stripe image consistent with normal vectors obtained from the first step and a new fidelity item, instead of the original fidelity item, when the pixel value reaches the limitation of sensor. The key idea is adding two new items to this model, which shows very helpful to control the smooth action of this model in different areas. The experimental results show that the model is superior to other models either from technical indicators or visual effect.

Comparative results on simulated and real striped images taken with MODIS and hyperspectral imaging systems show that the proposed method is superior to *UTV* model [1], *HUTV* model [19], and all the other methods which are not based on variational/PDE frame such as *wavelet-FFT* filter [9] and Statistical Linear Destriping (*SLD*) [21]. It cannot only handle various stripe images with different noise intensity but also preserve the edge and detailed information.

Although there are many fast algorithms to obtain a minimizer of energy functional with TV regularization and L^p fidelity ($p = 1$ or 2) such as the dual methods [22], split Bregman iteration [23] and alternating minimization algorithm [24], we use the basic gradient descent optimization method to solve *UTV-Stokes* model; and both the parameter configuration and the experimental results in Section 3 are based on this method. But in Appendix A, we will give the solve method on the basis of split Bregman iteration for *UTV-Stokes* model.

The paper is organized as follows. In Section 2, we propose the *UTV-Stokes* models, give the formula to solve it and explain some basic properties of the proposed model. In Section 3, we present numerical examples. In Section 4, we conclude the paper.

2. The proposed *UTV-Stokes* model

2.1. Problem modeling

The stripe is often modeled as an additive process [25–27], the degradation process can be formulated as

$$f(x, y) = u(x, y) + n(x, y) \quad (1)$$

where $f(x,y)$ is the degraded image by the instrument at pixel (x,y), $u(x,y)$ is the potential clean image to be recovered, and $n(x,y)$ is the stripe noise. The stripe noise $n(x,y)$ includes detector to detector stripes, mirror banding, and random stripes.

2.2. *UTV model and its three disadvantage*

UTV model was first proposed in [1] to remove the stripe noise, and was successfully used for estimating the detector biases in MODIS Thermal Emissive Band [28]. Stripes can be viewed as a structured noise, of which variations are mainly concentrated along the y-axis, so in their framework, destriping is viewed as an

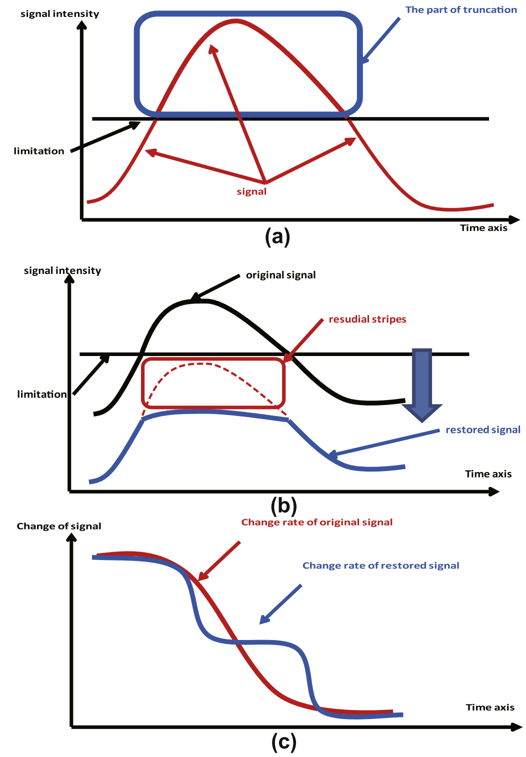

Fig. 1. Disadvantages of *UTV*: (a) signal reaches the imaging ceil/floor, (b) residual stripes, (c) information of variations lost.

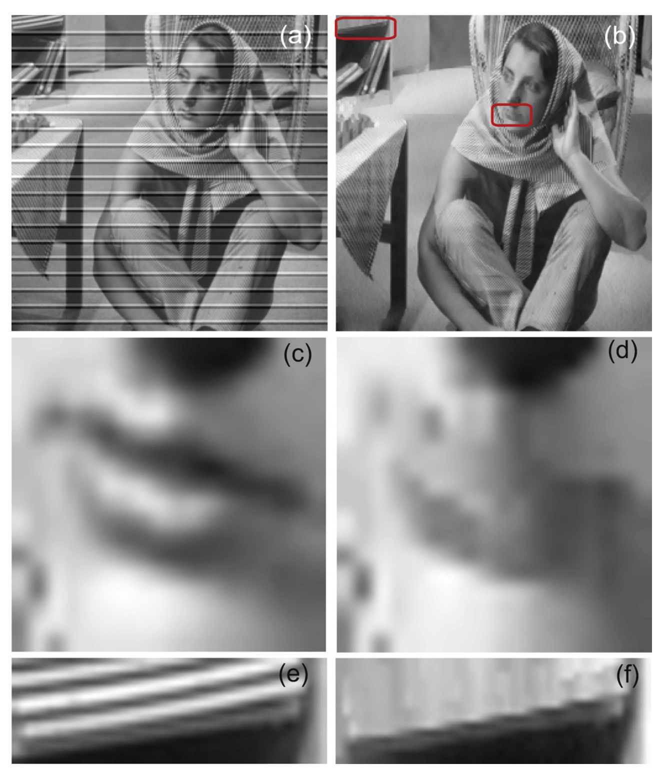

Fig. 2. The disadvantages of *UTV*: (a) striped 'babara', (b) restored by *UTV*, (c) the mouth of original 'babara', (d) the mouth of restored image, (e) stripes of bookcase in original 'babara', (f) smoothened bookcase in restored image.