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Regular article

Structure-guided unidirectional variation de-striping in the infrared bands of MODIS and hyperspectral images

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HIGHLIGHTS

- A novel de-striping method for MODIS and hyperspectral infrared bands is proposed.
- A novel stripe detecting method that can distinguish between texture and stripes is proposed.
- Spatial information extracted using the stripe detecting method is utilized to construct spatially weighted parameters.
- All parameters have the default setting, which greatly improves the practicability of our method.

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ABSTRACT

Images taken using moderate resolution imaging spectroradiometer (MODIS) and hyperspectral imaging systems, especially in their infrared bands, usually lead to undesired stripe noises, which seriously affect the image quality. A variational de-striping model has been proven to have good performance, but knowing how to detect stripes effectively, especially to distinguish them from edges/textures, is still challenging. In this paper, a structure-guided unidirectional variational (SGUV) model that considers the structure of stripes is proposed. Because of the use of structure information, which textures and edges do not have, the proposed algorithm can effectively distinguish stripes from image textures and almost does not blur details while removing stripes. Comparative experiments based on real stripe images demonstrated that the proposed method provides optimal qualitative and quantitative results.

1. Introduction

Stripe noises commonly exist in imaging systems with multi-detectors, such as moderate resolution imaging spectroradiometer (MODIS) images [1] and hyperspectral images [2]. There are 36 spectral bands, ranging from the visible (0.4 μm) to the long-wave infrared (14.4 μm), in MODIS data, while bands 20–25 (3.660–4.549 μm) and 27–36 (6.535–14.385 μm) belong to emissive bands. The striping effect is clearly visible in MODIS emissive bands [3] and is particularly serious in bands 27 (6.535–6.895 μm), 30 (9.580–9.880 μm), 33 (13.185–13.485 μm), and 36 (14.085–14.385 μm) [1], as shown in Fig. 1(a) and (b). There are 196 spectral bands, ranging from the visible (356 nm) to the short-wave infrared (2577 nm), in Hyperion satellite images, and the striping effect exists in almost every band, as shown in Fig. 1(c) and (d). Its presence 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 seriously affects image quality and creates difficulties in data classification and the restoration of useful information [6].

In the past two decades, many useful methods have been developed to address this type of noise, e.g., histogram modification [7], moment matching methods [8], and transformed domain filtering algorithms such as the Fourier transform and wavelet decomposition (Wavelet-FFT) [9–11]. In recent years, image de-striping methods based on the variational/PDE framework have attracted more and more attention. Bouali and Ladjal [1] introduced a unidirectional variational (UV) model to remove stripes in MODIS images. UV is superior to traditional methods and has successfully been used to detect the detector biases in the MODIS Thermal Emissive Band [12]. Later, more and more methods improved the efficiency of UV by using different regularization or adaptive technology [13–16]. For example, Zhou et al. [17] developed a stripe

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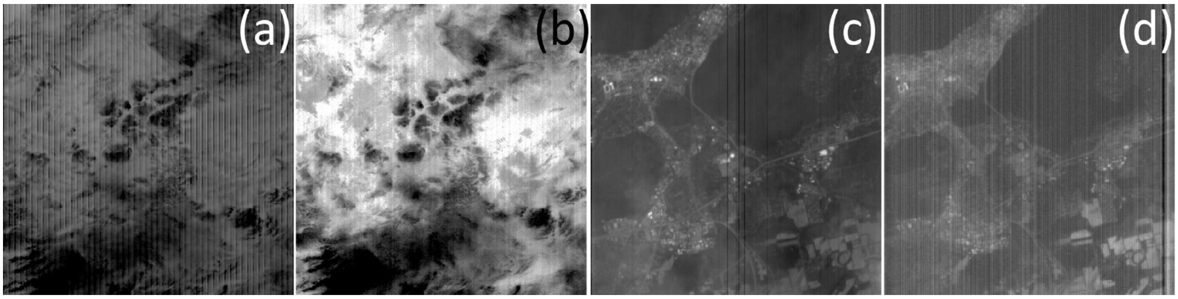

Fig. 1. Stripe noise in MODIS and hyperspectral data: (a) MODIS image (band 27), (b) MODIS image (band 36), (c) Hyperion image (band 26), and (d) Hyperion image (band 189).

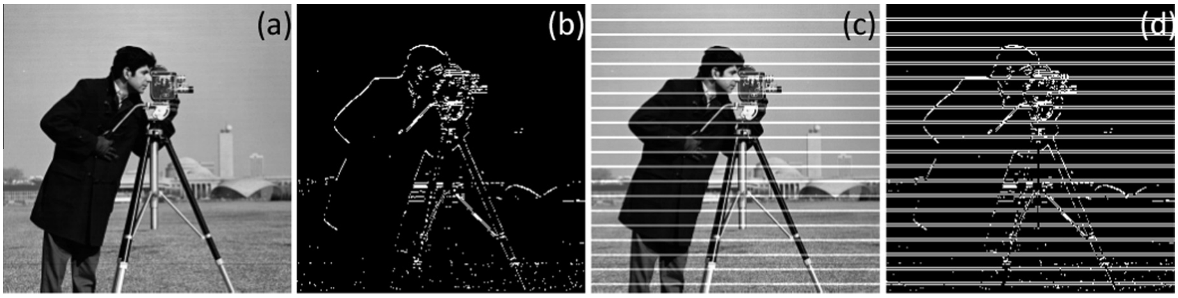

Fig. 2. (a) Stripe-free image, (b) $|\nabla_y u|$ of (a), (c) simulated stripe image, and (d) $|\nabla_y u|$ of (c). Values that are too small in (b) and (c) have been removed, using the same threshold.

reweighted version of UV(SAUTV), and then Chang et al. [18] considered the framelet regularization to attain more details. Zhou et al. [19] introduced a weighted matrix to combine two different unidirectional total variation models (HUTV), which can deal with "weak" and "heavy" stripes. Wang et al. [3] adjusted the de-striping strength adaptively by introducing difference curvature for spatially weighted parameters. Zhang et al. [20] combined the TV-Stokes model and UV model (UTV-S) and obtained a better result due to the introduction of "divergence free" prior [21,22]. Chang et al. [23] combined the UV model and sparse representation over a learned dictionary to de-stripe and denoise at the same time.

All of the methods above have to strike a balance between removing stripes and preserving details, which leads to residual stripes or/and excessive blurring. However, the more information (prior) the algorithms use, the better the results reached. In this letter, we propose a structure-guided unidirectional variational (SGUV) de-striping algorithm, which makes full use of the information regarding stripes and can effectively distinguish between the image texture and stripes. The key idea is to construct a weighted matrix that considers the structure of stripes and guides the behavior of regularization with different weighted parameters in three types of areas: "weak" stripe areas, "heavy" stripe areas, and truncation areas. A specialized experiment is carried out to obtain the suitable parameter configuration, and the comparison of experimental results shows that because more information is introduced, the algorithm results in almost no residual stripes or excessive blurring and is slightly better than SAUTV and HUTV.

The remainder of this paper is organized as follows. Section 2 describes the proposed model in detail. Experiments regarding parameters selection and the comparison of different algorithms are described in Section 3. Finally, the conclusions are drawn in Section 4.

2. The proposed method

2.1. Degradation model

The striping effect is often modeled as an additive process [24–26]; the degradation process can be formulated as

$$\mathbf{f}(x,y) = \mathbf{u}(x,y) + \mathbf{n}(x,y) \tag{1}$$

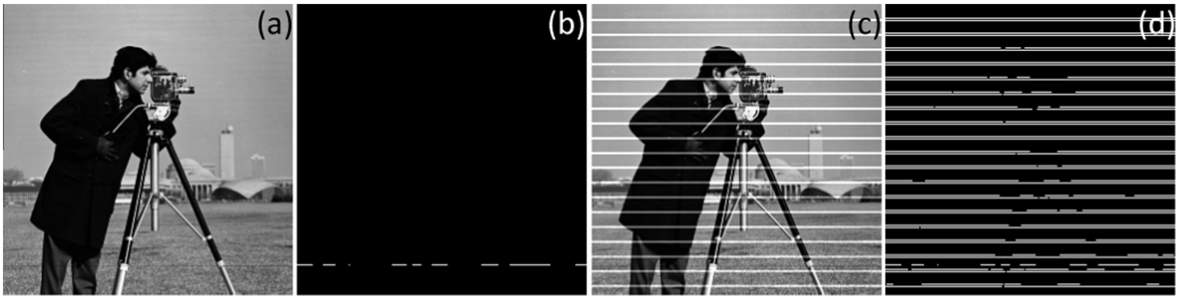

Fig. 3. (a) Stripe-free image, (b) detecting result of (a) using SGSD, (c) simulated stripe image, and (d) detecting result of (c) using SGSD.