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Universal reconstruction method for radiometric quality improvement of remote sensing images

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ABSTRACT

The performance of remote sensing images in some applications is often affected by the existence of noise, blurring, stripes and corrupted pixels, as well as the hardware limits of the sensor with respect to spatial resolution. This paper presents a universal reconstruction method that can be used to improve the image quality by performing image denoising, deconvolution, destriping, inpainting, interpolation and super-resolution reconstruction. The proposed method consists of two parts: a universal image observation model and a universal image reconstruction model. In the observation model, most degradation processes in remote sensing imaging are considered in order to relate the desired image to the observed images. For the reconstruction model, we use the maximum *a posteriori* (MAP) framework to set up the minimization energy equation. The likelihood probability density function (PDF) is constructed based on the image observation model, and a robust Huber–Markov model is employed as the prior PDF. Experimental results are presented to illustrate the effectiveness of the proposed method.

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1. Introduction

It is well known that remote sensing imagery can be applied in many fields, including mapping land-use and cover, agriculture, soils mapping, forestry, city planning, archaeological investigations, military observation and geomorphological surveying. In many cases, however, the performance of remote sensing images in these applications is affected by some degradations of image quality, such as the effects of random noise, sensor and/or atmosphere blurring, periodic stripes and corrupted pixels caused by damage of detector elements. These make it more difficult to visually and automatically interpret the remote sensing data. Besides, the spatial resolution of a remote sensing image is often not high enough for some applications due to the hardware limits of the imaging sensor. In order to improve image quality and increase application potential, implementing some digital image processing techniques is a commonly used procedure. The related techniques include image denoising, image deconvolution, image destriping, image inpainting, image interpolation and super-resolution (SR) reconstruction.

The goal of image denoising is to recover the original image from a noisy measurement. To denoise a remote sensing image, some adaptive filters such as the Lee filter (Lee, 1980), Kuan filter (Kuan et al., 1985), Frost filter (Frost et al., 1982) and their variations have commonly been embedded in commercial remote sensing software. For high-performance denoising techniques, the MAP (maximum *a posteriori*) (Isar et al., 2006; Achim et al., 2003) and wavelet methods (Achim et al., 2003; Nasri and Nezamabadi-pour, 2009) are two of the most popular frameworks.

Image deconvolution is the process of restoring the true image from the degraded one. Here the degradation is mainly caused by optical and atmosphere PSF (Point Spread Function). To restore remote sensing images, the MTF (Modulation Transfer Function) based methods are most commonly used. Some representative references address the deconvolution problems of TM (Arbel et al., 2004), SPOT (Pinilla Ruiz and Ariza Lopez, 2002), IKONOS (Ryan et al., 2003) and CBERS-2 (Papa et al., 2008). The Wiener filter (Hillery and Chin, 1991) is a widely employed method to restore the image after the estimation of MTF.

The correction of image stripes is commonly called image destriping. The simplest destriping technique is to process the image data with a low-pass filter in the frequency domain using the discrete Fourier transform (DFT) (Chen et al., 2003). Some researchers remove the stripes using wavelet analysis, which takes advantage of the scaling and directional properties to detect and eliminate striping patterns (Torres and Infante, 2001; Chen et al.,

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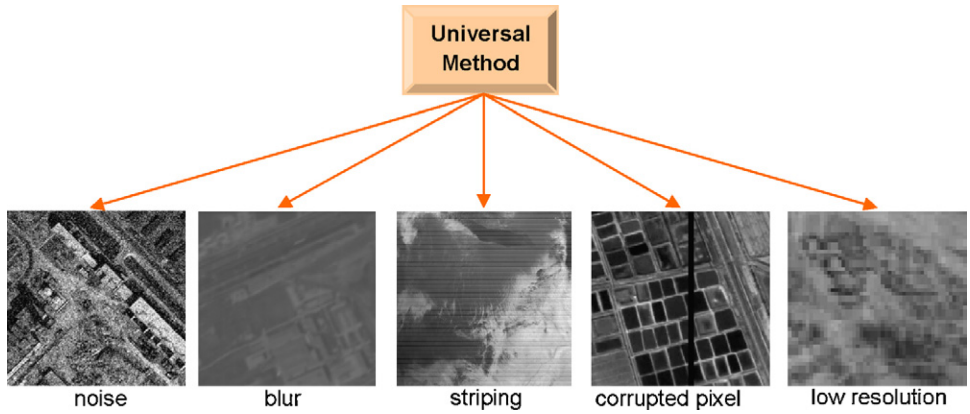

Fig. 1. The functions of the proposed method.

2006). Another destriping approach examines the distribution of digital numbers for each sensor, and adjusts this distribution to some reference distribution. There are also equalization methods (Algazi and Ford, 1981), moment matching (Gadallah et al., 2000), and histogram matching (Rakwatin et al., 2007) methods that are based on the assumption of homogeneous targets, the same mean and standard deviation and the same histogram distribution of each scanning line.

Image inpainting is the technique to recover corrupted pixels in the image. This technique is also called pixel replacement. For this problem, the nearest neighbour, average, or median value replacement methods are commonly employed (Ratliff et al., 2007). Wang et al. (2006) provide a method to retrieve Aqua MODIS band 6 using other bands based on their relationships in Terra MODIS. It is worth noting that there are a number of robust inpainting techniques (Bertalmio et al., 2003; Chan et al., 2003; Grossauer, 2004; Elad et al., 2005) which have not been applied to remote sensing image processing.

To increase the number of pixels in an image, single frame interpolation techniques have been researched extensively. These include nearest neighbour, bilinear and various cubic spline interpolation methods (Chen and de Figueiredo, 1993; Hou and Andrews, 1978; Karayiannis and Venetsanopoulos, 1991; Parker et al., 1983). The traditional interpolation methods often suffer from blurred edges or introduce artefacts around edges. To improve the subjective quality of interpolated images, Bayesian (Schultz and Stevenson, 1994), POCS (Projection-Onto-Convex-Set) (Ratakonda and Ahuja, 1998) and edge-directed interpolation schemes (Wang and Ward, 2001; Li and Orchard, 2001) have been widely researched. Using these methods, the sharp edges can be preserved either by employing an effective prior model or interpolating along the edges detected in advance.

Super-resolution image reconstruction refers to a process that produces a high spatial resolution image from several low resolution images using the non-redundant information among them. The first multi-frame SR idea in (Lee, 1980) was motivated by the requirement to improve the spatial resolution of Landsat TM images. In 2002, CNES (National Space Study Centre, France) successfully launched SPOT5, which could deliver a 2.5 m spatial resolution panchromatic image through the SR processing of two 5 m spatial resolution images (Latry and Rouge, 2003). Shen et al. (2009) proposed an image reconstruction algorithm for multi-temporal MODIS images, and Merino and Nunez (2007) proposed a variable pixel linear reconstruction based method and applied it to Landsat ETM+ images.

The image processing techniques mentioned above are highly related, but few studies so far have attempted to solve the related problems using one model. In this paper, we present a universal image reconstruction method to solve all the posed problems shown in Fig. 1. A universal image observation model is developed to relate the desired image to the degraded image by considering most of the degradations. Based on the observation model, a universal image construction model is set up using the MAP framework. The gradient descent algorithm is employed to carry out the optimization. The main objective of this paper is to validate the universal applicability of the proposed reconstruction method for different image processing problems such as denoising, deconvo-

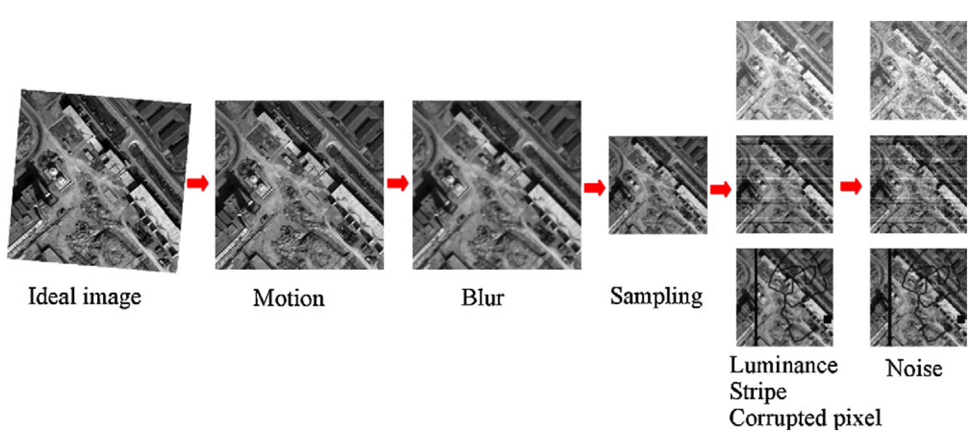

Fig. 2. Illustration of image degradation processes.

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