AN ADAPTIVE ALGORITHM FOR L1-FIDELITY COLOR IMAGE RESTORATION*

Wei Wang [1], Chengyun Yang and Qifan Song

School of Mathematical Sciences, Key Laboratory of Intelligent Computing and Applications
(Ministry of Education), Tongji University, Shanghai 200092, China
Emails: wangw@tongji.edu.cn, 2211185@tongji.edu.cn, 2030928@tongji.edu.cn

Abstract

In this paper, we propose an adaptive algorithm for L1-fidelity color image restoration by using saturation-value total variation. The main contribution of this paper is to employ the generalized cross validation method efficiently and automatically to estimate the regularization parameter in a saturation-value total variation plus L1-fidelity color image restoration model. We consider Poisson noise and mixed noise in this paper, and the experimental results show that the visual quality and the SSIM/PSNR/SAM values of the restored images by using the proposed algorithm are competitive with other tested existing methods, which makes the proposed algorithm to be comparable both quantitatively and qualitatively.

Mathematics subject classification: 65J22, 65K10, 68U10.
Key words: Adaptive algorithm, Saturation-value total variation, L1-fidelity, Cross validation, Poisson noise.

1. Introduction

Image restoration is a crucial task in image processing because real images are often corrupted by factors such as noise, dust, and scratches that reduce the effectiveness of other image processing activities like segmentation and pattern recognition. One of the critical issues associated with image restoration is image denoising, which entails reducing noise in digital images obtained from diverse imaging systems such as cameras, scanners, microscopes, and telescopes. The four main types of noise that occur in digital images are Gaussian, Poisson, impulse, and mixed Gaussian-Poisson noise. Poisson noise is especially prevalent in low-light conditions, resulting in grainy or speckled images, which can be represented as a Poisson distribution that describes the probability of detecting a certain number of photons over a given time or area. Various techniques such as smoothing filters [30,31] or denoising algorithms [17,32] that utilize the statistical properties of noise can be employed to reduce Poisson noise.

In this paper, we focus on variational methods. As we know that L2-fidelity does not give satisfactory results when dealing with non-Gaussian noise. Several non-smooth data-fitting terms such as L1-norm have been extensively studied for dealing with non-Gaussian noise including impulse noise, Poisson noise, etc. Chan and Esedoglu [6] further studied non-smooth fidelity for image restoration with respect to non-Gaussian noise. The total variation regularization plus L1-fidelity (TV-L1) model has been studied in the literature, e.g. the connection with

mathematical morphology [7], applications in impulse noise removal [23,25], cartoon-texture decomposition [1, 5, 13, 29], etc. In 1998, Blomgren and Chan [2] proposed a color total variation (CTV_1) regularization model by using a global channel coupling which is specifically considering the L2-norm of each channel's total variation. Bresson and Chan [3] proposed CTV_2 model which is a local channel coupling by considering the L2-norm of all channels' derivations locally. Duran *et al.* [9] pointed out that CTV_1 is good at color image restoration under similar noise in each channel, and CTV_2 can determine edge locations in different channels due to its stronger channel coupling. Liu *et al.* [20] presented a hybrid model that combines the TV regularizer and the high-order TV regularizer with L1 data-fitting term (HTV-L1) for salt-and-pepper impulse noise removal. High-order TV regularizer can effectively suppress the occurrence of staircase effects. The Framelet transform is regarded as a regularization term that uses wavelets for image processing [4, 8, 24]. Dong *et al.* [8] presented two framelet-based regularization approaches employing L1-fidelity for blind image inpainting and other applications, such as random-valued impulse noise removal. Saturation-value total variation (SVTV) is designed for color image processing, which considers the channel coupling based on quaternion framework. SVTV has been proved to be very effective for color image recovery [16]. Wang and Song [27] developed SVTV-L1 model for Poisson noise removal by introducing saturation-value total variation as a regularizer and the L1-norm as a data-fitting term in the energy functional.

In the variational model, the regularization parameters must be determined properly so that the numerical algorithms can be used to provide good recovered images. The above-mentioned models [27] do not give an efficient method for searching suitable regularization parameters. Generalized cross-validation (GCV) [12] is a rotation-invariant version of the ordinary cross-validation, and is usually used to find a good ridge parameter, e.g. automatic deblurring [22,26], image denoising [18], learning based systems [11], etc. The main contribution of this paper is to employ the generalized cross validation (GCV) method efficiently and automatically to estimate the regularization parameter associated with the priors in SVTV-L1 model for color image restoration. We develop a novel adaptive alternating-iteration algorithm to handle the L1 data-fitting term and to search the optimal parameters at the same time. Numerical examples are presented to demonstrate that the performance of the proposed algorithm is efficient, effective, and competitive in terms of visual quality and some criteria such as peak signal-to-noise ratio (PSNR), structure similarity (SSIM) [28], and spectral angle mapper (SAM) [19].

The outline of this paper is given as follows. In Section 2, we will give a detailed discussion of the proposed alternating-iteration algorithm for solving SVTV-L1 model automatically. The numerical experiments are given in Section 3 to demonstrate the effectiveness of the proposed algorithm. Finally, some concluding remarks are given in Section 4.

2. The Proposed Adaptive Algorithm

2.1. The formulation

We consider the following SVTV-L1 model for color image restoration in this paper:

$$\min_{\mathbf{u}} \lambda \, \text{SVTV}(\mathbf{u}) + \|\mathbf{Ku} - \mathbf{f}\|_1, \tag{2.1}$$

where

$$\text{SVTV}(\mathbf{u}) = \sum_{i=1}^{m} \sum_{j=1}^{n} \sqrt{|(\mathbf{D}_x \mathbf{u})_{ij}|_s^2 + |(\mathbf{D}_y \mathbf{u})_{ij}|_s^2} + \alpha \sqrt{|(\mathbf{D}_x \mathbf{u})_{ij}|_v^2 + |(\mathbf{D}_y \mathbf{u})_{ij}|_v^2}.$$