

A Hue-Preserving Color Image Restoration Model Using Saturation-Value Total Variation

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Received 6 March 2023; Accepted 28 April 2025

Abstract. In this paper, we propose and develop a novel hue-preserving color image restoration model. In the proposed model, saturation-value total variation is used as the regularization term. In order to reduce hue loss during regularization, the hue-preserving technique is incorporated into the proposed energy functional. We then rewrite the proposed model equivalently into a three-block separable convex version and apply an alternating direction method of multipliers based algorithm to solve the proposed equivalent model numerically. We also give the convergence analysis of the proposed algorithm. Numerical examples are presented to demonstrate that the performance of the proposed restoration model is better than that of other testing methods in terms of visual quality and some criteria such as peak signal-to-noise ratio, structure similarity, and spatial-CIELAB color error.

AMS subject classifications: 65K10, 68U10, 90C25

Key words: Color image restoration, hue-preserving, saturation-value total variation, alternating direction method of multipliers.

1 Introduction

Variational techniques have been successfully applied to color image processing. Total variation (TV) [18], originally used to solve the gray image restoration problems, was generalized to handle color images by using different versions of color total variation. Blomgren and Chan [2] proposed a color TV regularization with a global channel coupling by summing the variation of each channel. Bresson and Chan [4] considered local channel coupling and proposed another color TV (CTV) regularization with channel-coupled monotonic functions. Sapiro [19] studied spectral information of the tensor $(\nabla \mathbf{u})^\top \nabla \mathbf{u}$ where $\mathbf{u}(x,y)$ is a vector-valued image defined on the bounded image domain $\Omega \subset \mathbb{R}^2$, ∇ is the gradient operator, and proposed a vectorial TV (VTV) model by intro-

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ducing a penalty function on the eigenvalues of $(\nabla \mathbf{u})^\top \nabla \mathbf{u}$. Rodriguez and Wohlberg [17] used the iteratively reweighted norm approach to propose a simple and flexible method to handle the generalized VTV (GVTV) functional by replacing the l^q norm with the weighted l^2 norm. We remark here that all the above mentioned variational models are formulated based on RGB (red, green, blue) color space. Another useful color representation model is HSV (hue, saturation, value) color space which is similar to human color perception. Jia, Ng and Wang [11] proposed and developed a new saturation-value total variation (SV-TV) in HSV color space for color image restoration, which has two parts with different components: one is to minimize the gradient of the saturation, another one aims to control the smoothness of the image regions. SV-TV regularization guarantees a great reduction of unexpected chromatic intersection. However, minimization of the saturation difference will cause the loss of hue in practice.

Hue is one of the inherent attributes of a color which decides what kind of color it is. Therefore, preserving the hue unchanged is an important issue in color image processing. Yang and Rodriguez [22] proposed two hue-preserving techniques (affine transforms: scaling and shifting) to process luminance and saturation components. Naik and Murthy [14] used similar affine transforms to propose a scheme to generalize the grayscale image enhancement method to color image enhancement with hue preserved. Based on different hue-preserving technology, many color image enhancement methods have been proposed [1, 5, 10, 13]. Fitschen *et al.* [5] took advantage of the fact that affine transformations do not change hue and proposed a variational hue-preserving technique flexibly preserving hue by solving an optimization problem. The above hue-preserving technique has been used in [15, 16, 20] for color image enhancement. Hue-preserving techniques have been widely used in color image enhancement in the literature, however, rarely applied to color image restoration problems.

The main aim of this paper is to propose and develop a novel hue-preserving color image restoration model using SV-TV. In the proposed model, we make use of SV-TV as the regularization term, and we incorporate an efficient hue-preserving technique into the proposed energy functional in order to reduce hue loss during regularization. We then formulate the proposed energy function by combining the regularization term, the data-fitting term and the hue-preserving term. In order to solve the proposed minimization problem efficiently, we rewrite the proposed model equivalently into a three-block separable convex version. Numerically, we propose a very efficient and effective algorithm with convergence guaranteed to solve the proposed optimization problem. The alternating direction method of multipliers (ADMM) [3, 6, 7] is a benchmark algorithm for solving a linearly constrained convex minimization model with a two-block separable objective function. Many ADMM-based methods for multi-block convex programming have been studied in [8, 9]. In this paper, we apply an ADMM-based algorithm with convergence guaranteed to solve the proposed model. We give the convergence analysis of the proposed algorithm by using the similar arguments in [9] for a three-block ADMM algorithm. In summary, the contribution of this paper is as follows. First, we propose and develop a novel color image restoration model by using saturation-value total variation