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COLOR-TO-GRAY CONVERSION WITH PERCEPTUAL PRESERVATION AND DARK CHANNEL PRIOR

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Abstract. This paper aims to present a decolorization strategy based on perceptual consistency and dark channel prior. The proposed model consists of effective fidelity terms and a prior term. We use the ℓ_0-norm to control the sparsity of the dark channel prior. To solve the non-convex minimization problem, we employ the split and penalty technique to simplify the minimization problem and then solve it by the carefully designed iteration scheme. Besides, we show the convergence of the algorithm using Kurdyka-Łojasiewicz property. The numerical evaluation in comparison with other state-of-the-art methods demonstrates the effectiveness of the proposed method.

Key words. Color-to-gray, perceptual consistency, dark channel, Kurdyka-Łojasiewicz property, non-convex.

1. Introduction

Color-to-gray, which is also named as decolorization, is a technique that transforms a color image (3-D) to a grayscale one (1-D). It is of great importance in black-and-white printing, E-ink monotone display, image preprocessing (then for segmentation, edge detection) and object recognition. A natural problem in decolorization is that information loss happens due to dimension reduction. How to produce a perceptually plausible grayscale image, which hopes to preserve enough structures and contrast from the original color image, is the main concern in the literature. The application-driven tasks and unavoidable difficulties in decolorization make the problem important and attract a lot of research attention [6, 16, 15, 8].

Extracting the luminance channel in a transformed color space such as CIE Lab is an intuitive way of generating a grayscale image. Although this method is very simple and cost-less, it fails to preserve salient structures and features of the iso-luminant regions in the color images. Another simple decolorization method is to implement a linear combination of different channels if the color image is represented in RGB color space. The same disadvantage happens since the linear combination of different sets of R, G and B values may generate the same luminance response in the grayscale result [22]. To overcome this problem, many outstanding decolorization methods have been proposed to perceptually preserve salient features in the color-to-gray conversion.

As reported in [17, 11, 15, 14], decolorization methods can be roughly classified into two categories: one is the local mapping method which treats the pixels differently in different local regions in one image [2, 20, 11]; However, these algorithms would bring artifacts since they tried to visualize all details. The other type of

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method is the global mapping method which processes the pixel mapping independent of the pixel location [8, 9, 12, 21, 16]. Recently, deep learning based methods are used for decolorization. Zhang and Liu [27] proposed to combine global features and local semantic features learned by the convolution neural network for decolorization. They reported that their method can better preserve the contrast in both local color blocks and adjacent pixels of the color image. Cai et al. [7] proposed a system which used deep representations to extract content information based on human visual perception, and automatically selected suitable grayscale for decolorization.

Different from other methods, You et al. [25] emphasized that many existing methods mainly focus on best-preserving contrast while paying less attention to the consistency with human perception. The authors designed two optimization framework using ℓ_1-norm and ℓ_2-norm respectively. Their experiments showed that ℓ_1-norm works better than ℓ_2-norm. As we know, the computation related to ℓ_1 is more difficult compared with ℓ_2-norm. In this paper, we propose a new color to gray conversion model in light of the perceptual consistency and the dark channel prior. Our idea is to consider ℓ_1-norm and ℓ_2-norm in one model which can balance the quality and computation. Furthermore, to better improve the quality of decolorization, we enforce the sparsity prior to the dark channel. This prior has been successfully applied in blind deconvolution [19] and image dehazing [10]. Our experiments show that the proposed method works very well compared with other popular decolorization methods.

The main contribution of this paper is that we propose a new sparsity-driven and perceptually consistent model for decolorization. The perceptual fidelity on brightness and contrast are controlled by the ℓ_1 norm and the ℓ_2 norm, respectively. The prior information of the gray is that the dark channel property preservation. To control the sparsity the dark channel, we use ℓ_0 norm as a regularization term. We propose an alternating minimization algorithm with the technique of split and penalty to solve our model. Although the ℓ_0-norm which makes the problem highly nonconvex, we use Kurdyka-Łojasiewicz (KL) property [4] to prove the convergence of the related algorithm.

2. Proposed method

2.1. Related work. In [25], You et al. elaborately proposed a graphical model based method which balances brightness and contrast perceptual consistency. They aim to preserve the perceptual properties of the color image as much as possible. The model is composed of the brightness perceptual energy E_b and the contrast consistency term E_c:

$$E_b(g) = \|\Lambda(p_1 - g)\|_\ell,\ E_c(g) = \sum\nolimits_{i=1}^{3} \alpha_i \|C(p_i - g)\|_\ell, \tag{1}$$

where $g \in \mathbb{R}^{mn\times 1}, p_i \in \mathbb{R}^{mn\times 1}, i = 1, 2, 3$, m and n are the height and width of the input image. g is the decolorized gray-scale image, p_1 is the brightness, p_2 and p_3 are the color values in the CIE Lab space of the input color image, respectively. The parameters $\alpha_i, i = 1, 2, 3$ balance the importance between different channels.