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Efficient image decolorization with a multimodal contrast-preserving measure

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ABSTRACT

Decolorization is widely used in monotonic displaying, black-and-white printing, single-channel image processing, and many computer vision applications. The conversion of a color image into a grayscale one suffers from data loss. This paper presents a novel parallel decolorization method which effectively preserves not only the spatially local color contrast but also the dominant non-local color contrast. A new multimodal contrast-preserving measure with a multimodal Gaussian distribution is proposed to relax the constraint of color contrast. The dominant non-local color pair set is constructed by taking advantage of a linear bounding volume hierarchy while the local color pair set is produced by removing duplicate instances of local color pairs. The whole pipeline design is highly parallel, allowing for a real-time GPU-based implementation. Experimental results and comparisons show that the proposed method can produce plausible decolorized images. A number of single-channel image processing applications, including edge detection, image segmentation, color augmentation, and image stylization, are demonstrated to verify the feasibility of the proposed decolorization method.

1. Introduction

Decolorization, known as color-to-gray, aims to convert a three-channel color image into a single-channel grayscale one. Decolorization is a primary operation in a variety of image processing and computer vision applications. It enables efficient single-channel algorithms on color images. Many commercial displays and printers only support the black-and-white monochrome in order to reduce costs and resources. These black-and-white displaying and printing devices require effective decolorization algorithms to preserve meaningful structures of original color images as much as possible. A real-time decolorization algorithm enables an instant visual feedback and facilitates the practical use in different vision and graphics applications especially when processing a large number of images. Although color printing is becoming cheap nowadays, it is much slower than black-and-white printing because more data are required for transferring and printing. In addition, many artistic images (e.g., pencil drawings and Chinese ink paintings) convey artistic visual information in a black-and-white manner. However, decolorization is actually a kind of dimension reduction process, which inevitably suffers from data loss. The widely used decolorization method is to extract the lightness channel [1–3] from the input color image using a constant mapping. Unfortunately, using the lightness channel only fails to capture salient contrast features in some iso-luminant regions which contain different colors. In recent years, more and more researchers concentrate on contrast-preserving decolorization algorithms.

Recent decolorization methods can be roughly classified into local and global ones. Local decolorization methods [4–6] try to preserve the local color contrast between spatially neighboring pixels in the input image. Although these local methods are effective in preserving local features, they might distort appearances of constant color regions. Global decolorization methods aim to preserve both of local and global color contrasts. Many global methods [7–9] need an additional step to determine the sign of color contrast to constrain the resultant grayscale contrast. Lu et al. [10,11] alleviate the difficulty caused by determining the sign of color contrast with a bimodal Gaussian distribution. Liu et al. [12] extend the gradient magnitude similarity [13] to a novel gradient correlation similarity measure which calculates the summation of the gradient correlation between each channel of the color image and the resultant grayscale image. Our method falls into the category of global decolorization and aims to improve the performance by exploiting the advantages of the multimodal Gaussian distribution and the GPU parallelism.

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Fig. 1. An example of single-channel image processing application: (top-left) input images, (top-right) our decolorization images, and (bottom) single-channel image stylization effects.

In this paper, we present a novel parallel contrast-preserving decolorization algorithm. We relax the constraint of color contrast with a new multimodal contrast-preserving measure for each color pair by further extending Lu et al.'s bimodal Gaussian distribution [10,11,14] to a multimodal one, i.e., a mixture of three Gaussians. A parallel construction algorithm for the dominant non-local color pair set is developed by taking advantage of a GPU-based Linear Bounding Volume Hierarchy (LBVH) [15]. The local color pair set is produced by removing duplicate instances in order to avoid excessive attenuation of contrast for color pairs which have a very small number of neighboring instances. The whole pipeline design is highly parallel, enabling a real-time GPU-based implementation. In addition, we demonstrate that our new decolorization algorithm can benefit to a number of single-channel image processing applications in the context of edge detection, image segmentation, color augmentation, and image stylization. An example of single-channel application is as shown in Fig. 1.

In summary, this paper has the following contributions:

- A multimodal contrast-preserving measure is introduced for effective decolorization using the multimodal Gaussian distribution.
- A GPU-based color pair set construction algorithm is developed to capture color contrasts for both of spatially local color pairs and dominant non-local color pairs.

The rest of this paper is organized as follows. In Section 2, we briefly review some of the related work. In Section 3, we present our new parallel contrast-preserving decolorization algorithm. Experimental results and comparisons are given in Section 4 while related single-channel applications are presented in Section 5. Finally, we conclude this paper and suggest some future work in the last section.

2. Previous work

A number of image decolorization techniques have been proposed to produce perceptually plausible grayscale images for color images. The color-to-grayscale conversion maps a three-dimensional color space to a single dimension. In this section, we briefly review some of the previous work.

Some decolorization methods find an input-independent and constant mapping to perform the color-to-grayscale conversion. A common used mapping is to extract the lightness channel in the *Lab* Hunter 1948 color space [1] or the later CIE-$L^*a^*b^*$ 1976 color space [2]. Another decolorization strategy is to map the RGB color space to the YUV color space [3] and then extract the Y channel which is a linear combination of RGB channels. Nayatani [16] introduces a color appearance model with an input-independent mapping. Since these decolorization methods are independent of input visual contents, color contrast loss could happen in some isoluminant regions with different colors.

In recent years, a number of contrast-preserving decolorization methods have been proposed for more advanced color-to-grayscale conversion and can be categorized into local and global ones.

Local decolorization methods enhance grayscale contrast based on local chrominance edges. Bala and Eschbach [4] add high-frequency chromatic components to the lightness channel in order to preserve the chrominance edge information. Neumann et al. [5] regard local color and luminance contrasts as a consistent gradient field and obtain the resultant grayscale image via fast