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Color recovery of black-and-white halftoned images via categorized color-embedding look-up tables

Chang-Hwan Son *, Hyunseung Choo

College of Information and Communication Engineering, Sungkyunkwan University, 300 Chunchundong, Jangangu, Suwon 440-746, South Korea

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ABSTRACT

A new method of recovering the original colors of black-and-white (B&W) halftoned images with homogeneous dot patterns is proposed. The conventional inverse halftoning method, which uses a look-up table (LUT), can establish the relation between the halftoned patterns and the corresponding gray levels, while the conventional reversible color to gray conversion method can recover the original colors from a given color-embedded gray image. To accomplish our goal of original color recovery from B&W halftoned patterns, an approach of combining the conventional inverse halftoning and reversible color to gray conversion is presented in this paper. Differently from the conventional method of inverse halftoning via LUT, four LUTs categorized according to the red, green, blue, and gray reference colors are designed to more accurately map a specific B&W halftone pattern into the corresponding color-embedded gray level based on the observation that the shapes of the halftone patterns depend on input colors, thereby increasing the color recovery accuracy. Also, a color mapping method based on a linear regression which models the relation between the recovered colors and the original colors is introduced to adjust the initially recovered colors more closely to the original colors. Experimental results show that unknown original colors can be recovered from B&W halftoned images via the proposed method.

1. Introduction

Color has been expressed as a three-dimensional (3D) vector whose elements have 255 discrete levels, especially in the RGB color space [1]. It is often required to be converted into the gray, that is, scalar quantity for many purposes: black-and-white printing, data transmission via a mono fax, design of the algorithm in image processing and computer vision, and artistic rendering [2]. Since this color to gray conversion reduces the dimensionality, some different colors can be mapped into the same gray; hence the reverse color to gray conversion of restoring the original colors from the grays in an image is an ill-posed problem. Even though a new color transferring method [3] or colorization method [4] of assigning realistic pseudo colors to the grays based on the reference color image with similar objects and structures can be an effective solution, it has a limitation to recover the unknown original colors, due to unstable spatial and luminance matching between the reference color image and input gray image. In addition, the same objects or species can have different unique colors, and thus it is impossible to search for a reference color image perfectly matched to a unique gray image. However, recently introduced reversible color to gray conversion methods [5,6] were successful in recovering the original colors from the gray image based on the color extraction of the embedded chrominance images into the high frequency wavelet subbands. A relatively considerable color information, i.e., two chrominance images resized can be encoded as pleasant and less visible texture patterns highly correlated with image contents. This reversible color to gray conversion method [5,6] provided a breakthrough in the original color estimation from the gray image.

Nevertheless, there still remains a more challenging problem, i.e., the estimation of original colors from a B&W halftoned image with homogeneous dot patterns, which is the binary image [7] widely used in digital printers, copiers, and faxes. In some applications, it is more necessary to restore the original colors from the B&W halftoned image rather than the gray image with 255 discrete levels. In B&W printing, digital halftoning [7] is conducted after the color to gray conversion [8] to generate the B&W halftoned image from an input color image. The B&W halftoned image is used to determine whether or not black toners will touch the surface of the photoconductor drum in laser printers, whereas, in the inkjet printers, it is used to determine the spatial position of the black ink that drops on a paper. Ultimately, the printed images such as printouts, books, or newspapers, belong to the binary image with

* Corresponding author. Fax: +82 31 299 4134.
E-mail addresses: jjdhompy@hotmail.com (C.-H. Son), changhwan76.son@gmail.com (H. Choo).

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homogeneous dot patterns where the printed areas with black toner or ink indicate the logic of 1 and the other unprinted areas indicate the logic of 0. In other words, the printed image can be regarded as the B&W halftoned image digitally represented. After the B&W printing, the only available information is the B&W halftoned image, from which it is often required to produce its original color version. In addition, the B&W halftoned image transmitted via a mono fax can be saved in the memory of the client's fax or multifunctional printer (MFP). At this time, it is very useful to directly show the original colors from the saved B&W halftoned image. Nowadays, for the artistic rendering, digital color photos can be turned into the B&W halftoned images on the smart phones with image-editing tools. In such a case, the original color restoration can be required. Furthermore, the reversible color to halftone conversion can be effectively used for the binary image compression.

This paper attempts to solve the challenging problem abovementioned, i.e., original color restoration from a B&W halftoned image. This is generalized to finding the 3D vector with 255 discrete levels from a scalar quantity with two levels per pixel, and thus this is a highly ill-posed problem. To simplify this, the original color restoration of the B&W halftoned image will be decomposed into two steps: the one is the gray image reconstruction from the B&W halftoned image and the other is the color image restoration from the reconstructed gray image. However, to make this approach possible, original color information should be embedded into the B&W halftoned image. At this time, it is important that the embedded color information should not break the homogeneous halftoned patterns. Authors found that recently introduced reversible color to gray conversion [9] can help achieve this goal. This is because the reversible color to gray conversion enables to encode the original colors as less visible gray textures highly correlated with image contents. This means that the homogeneity of halftoned patterns can be guaranteed during halftoning and the color information encoded as less visible gray textures can be embedded into the halftoned patterns. Given an input B&W halftoned image, this paper will first reconstruct the color-embedded gray image, and then restore the original color image from the reconstructed color-embedded gray image.

This approach of decomposing the original color restoration into two steps focuses on the first step, that is, the reconstruction of the color-embedded gray image from a B&W halftoned image. In other words, the second step of restoring the color version of the color-embedded gray image can be done by applying just the inverse order of the reversible color to gray conversion. Moreover, the first step can be regarded as the inverse halftoning of reconstructing a gray image from its halftoned version [10]. However, most inverse halftoning methods tend to remove the fine textures and noisy dots on flat regions. As a result, invisible color-embedded gray textures can be removed, and thus the color restoration can fail. Therefore, it is important in the first step to restore less visible gray textures indicating the color-embedded information. To realize this, the LUT-based approach is proposed. The basic idea is from the conventional LUT-based inverse halftoning method [11], which makes it possible to establish the relation between a specific binary pattern and a gray level via a LUT. However, direct application of this inverse halftoning method to the original color restoration problem cannot provide satisfactory results. Most recovered colors are very desaturated and inaccurately estimated. Some colors cannot be recovered. Therefore, the LUT-based inverse halftoning method needs to be modified to be more appropriate for the original color restoration, which is our purpose. The key idea of enhancing the LUT-based approach for better color restoration is that the color-embedded gray textures are shaped depending on the colors, due to the embedding process of the chrominance images, e.g., Cb and Cr images into the high frequency wavelet subbands, e.g., HL and LH subbands. Thus, the categorization of the color-embedded gray textures and the corresponding B&W halftoned patterns can improve the color restoration accuracy. In this paper, a method of constructing four LUTs categorized according to the red, green, blue, and gray reference colors will be introduced. In addition, from only the given B&W halftoned image, a way of combining the return values of the four LUTs will be presented. The median filtering and non-local means image denoising will be adapted for color noise removal of the recovered color images. Following the proposed scheme decomposed into two steps, the possibility of estimating the original colors from an input B&W halftone image will be verified.

2. Motivation

As briefly mentioned in the introduction, conventional reversible color to gray conversion generates less visible textures on the color-embedded gray image, due to the embedding process of the two chrominance images into the high frequency wavelet subbands. This means that these textures' shapes depend on the embedded colors into the subbands. For example, in the case of the Queiroz' method [5,6], an input RGB image is converted into the YCbCr image, and then the discrete wavelet transform (DWT) is applied to the *Y* image. For color embedding, the resized Cb and Cr images are inserted into the HL and LH subbands, respectively. These embedded Cb and Cr images into the HL and LH subbands are encoded as less visible textures on the color-embedded gray image through the inverse discrete wavelet transform (IDWT). If the input RGB image has many reddish colors, the values of the Cr image are larger than those of the Cb image. Thus, the LH subband that contains the Cr image will influence the edge direction, in other words, the color-embedded gray textures will be shown as vertical lines. In contrast, if the colors of the input RGB image are blue, the textures will be shaped as horizontal lines.

Fig. 1 shows the color-embedded gray images with the reversible color to gray conversion methods [6,9]. To understand how the less visible textures can be affected by the embedded-colors, the same 'rose' images but with different red and blue colors are given in the first column of Fig. 1. These 'rose' images are converted into the color-embedded gray images with the Queiroz's method [6], and then the blue and red rectangles marked in the images are extracted and zoomed. The zoomed color-embedded gray patches are shown in the third column. In these patches, the textures indicate the encoded color information. For comparison, the corresponding *Y* patches extracted from the *Y* image are given in the second column. It is noticed that the textures are shaped according to the colors. In other words, the textures in the red 'rose' patch are encoded as vertical lines, whereas the textures in the blue 'rose' patch have horizontal lines. These textures will be quantized into binary patterns during the halftoning, however the textures' patterns can be remained on the halftone patches, as shown in the fourth column. The drawback of the Queiroz's method [6] is that the textures are regular and visible, and thus other reversible color to gray conversions [9,12,13] have been developed. Ko's et al. adopted the discrete wavelet packet transform (DWPT) providing more decomposed subbands, and then inserted the Cb and Cr images into the horizontal subband of a vertical subband and the vertical subband of a horizontal subband [9]. Since these two subbands statistically have the minimum amount of information, textures' visibility can be reduced, as shown in the fifth column. Moreover, the halftoned patterns can be homogeneously distributed, as shown in the sixth column. Similar to the Queiroz's method, the textures with Ko's method depend on the embedded colors into the predefined subbands, however the textures are more invisible and irregular. Based on these observations, it is expected that the categorization of the color-embedded textures and